Automotive Emotions: A Human-Centred Approach Towards the Measurement and Understanding of Drivers' Emotions and Their Triggers

A thesis submitted for the degree of Doctor of Philosophy

by
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Abstract

The automotive industry is facing significant technological and sociological shifts, calling for an improved understanding of driver and passenger behaviours, emotions and needs, and a transformation of the traditional automotive design process. This research takes a human-centred approach to automotive research, investigating the users' emotional states during automobile driving, with the goal to develop a framework for automotive emotion research, thus enabling the integration of technological advances into the driving environment. A literature review of human emotion and emotion in an automotive context was conducted, followed by three driving studies investigating emotion through Facial-Expression Analysis (FEA):

An exploratory study investigated whether emotion elicitation can be applied in driving simulators, and if FEA can detect the emotions triggered. The results allowed confidence in the applicability of emotion elicitation to a lab-based environment to trigger emotional responses, and FEA to detect those.

An on-road driving study was conducted in a natural setting to investigate whether natures and frequencies of emotion events could be automatically measured. The possibility of assigning triggers to those was investigated. Overall, 730 emotion events were detected during a total driving time of 440 minutes, and event triggers were assigned to 92% of the emotion events.

A similar second on-road study was conducted in a partially controlled setting on a planned road circuit. In 840 minutes, 1947 emotion events were measured, and triggers were successfully assigned to 94% of those. The differences in natures, frequencies and causes of emotions on different road types were investigated. Comparison of emotion events for different roads demonstrated substantial variances of natures, frequencies and triggers of emotions on different road types. The results showed that emotions play a significant role during automobile driving. The possibility of assigning triggers can be used to create a better understanding of causes of emotions in the automotive habitat.

Both on-road studies were compared through statistical analysis to investigate influences of the different study settings. Certain conditions (e.g. driving setting, social interaction) showed significant influence on emotions during driving.

This research establishes and validates a methodology for the study of emotions and their causes in the driving environment through which systems and factors causing positive and negative emotional effects can be identified. The methodology and results can be applied to design and research processes, allowing the identification of issues and opportunities in current automotive design to address challenges of future automotive design. Suggested future research includes the investigation of a wider variety of road types and situations, testing with different automobiles and the combination of multiple measurement techniques.

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Glossary

FEA	Facial-Expression Analysis
AU	Action Unit
SAM	Self-Assessment Manikin
EE	Emotion Events
GSR	Galvanic Skin Response
EEG	Electroencephalography
EMG	Electromyogram
PET	Positron-Emission Tomography
fMRI	Functional Magnetic Resonance Imaging
PrEmo	Product Emotion Measuring Instrument
FACS	Facial Action Coding System
IOR	Inter-Observer Reliability
NTA	No trigger assigned
FACS	Facial Action Coding System
IoT	Internet of Things
V2V	Vehicle to Vehicle
n	Number of Instances/Participants

1 Motivation

Exponential technological growth

> *"We are energized by the great power of technological impact on us. We are intimidated by the magnitude of problems it creates or alerts us to."*
>
> *Herbert Simon, Nobel Prize Winner 1978, Economics (Boutellier and Heinzen, 2014, p.1)*

In 1965 Gordon Moore, the co-founder of Intel, predicted that in the future processing power would double every 18 months. 'Moore's Law' is still referred to today to predict the growth of technology (Loveridge, 1990). Revolutionary technological developments have a large impact on every aspect of human life. Technologies such as 3G and 4G, smartphones and the World Wide Web provide numerous benefits and have simplified our lives. We now have easy access to information and education, financial transactions can be completed online, and world trade business is conducted faster. But the exponential growth of technology is also causing difficulties (Loveridge, 1990). The McKinsey Global Institute's report 'Disruptive technologies' of 2013 explores how technological changes transform the way we live and work, stating:

> *"Business leaders and policy makers need to identify potentially disruptive technologies, and carefully consider their potential, before these technologies begin to exert their disruptive powers in the economy and society."* (Manyika et al., 2013, preface)

The report analyses technological developments in automation, the internet of things, cloud technology, advanced robotics, energy storage, 3D printing and more. Predicted changes in established norms and technological developments will force society to adapt (Manyika et al., 2013). One discipline highly influenced by these technological developments is the automotive industry. A selection of the most popular current and future technological developments in the automotive industry is presented in Table 1 below.

Development	Current/Future	Source
• Connected cars, • Vehicle to vehicle (V2V) communication • Real-time internet of things (IoT) connectivity	Current and future	Intland, 2016; Kalogianni, 2016; Karlsson, Ahn and Choi, 2017
• Increasing number of sensors implemented	Current	Manyika et al., 2013
• Gesture control systems • Voice recognition	Current	Ropert, 2014
• Sophistication of in-car technologies • Disruptive Technologies	Current	Manyika et al., 2013
• Electric cars	Current and future	Manyika et al., 2013; The Guardian view of the car industry: an electric future, 2017
• Car sharing • Shared mobility	Current and future	Harris, 2017; Manyika et al., 2013
In-car connectivity: • Internet connection • Integration of social media • Integration of mobile devices	Current	Brauer, 2015; Kalogianni, 2016; Karlsson, Ahn and Choi, 2017
• Augmented reality included into the interface	Current	Ropert 2014
• Partially autonomous driving • Driver assistance features	Current	Kalogianni, 2016
• Fully autonomous driving	Future	Karlsson, Ahn and Choi, 2017

Table 1 Most popular current and future technological developments in the automotive industry

1.1 Developments in the Automotive Industry

The main focus of automotive research on basic functional requirements from 1886-1919, changed from 1920-1930 with the dawn of human factors. Increasing speed, growing numbers of vehicles on roads and increasing travel times called for a shift in focus towards safety from 1940-1949. Further developments in the 1960s included 3-point-seatbelts and research on mental workload and driver fatigue. In the 1970s and 80s emphasis on driver comfort grew. With an increasing number of functions in the automobile and concentration on the user experience the focus of research shifted towards the driving experience. The development of multimedia interfaces and navigation systems was followed by lane-keeping, breaking and blind-spot-warning systems in the 2000s, a significant step towards further automation of automobiles (Akamatsu, Green and Bengler, 2013; Miller, 2001; Normark and Gkouskos, 2012). Today, the connected car has improved communication, connection and networking (Manyika et al., 2013), major steps towards autonomous driving (Figure 1).

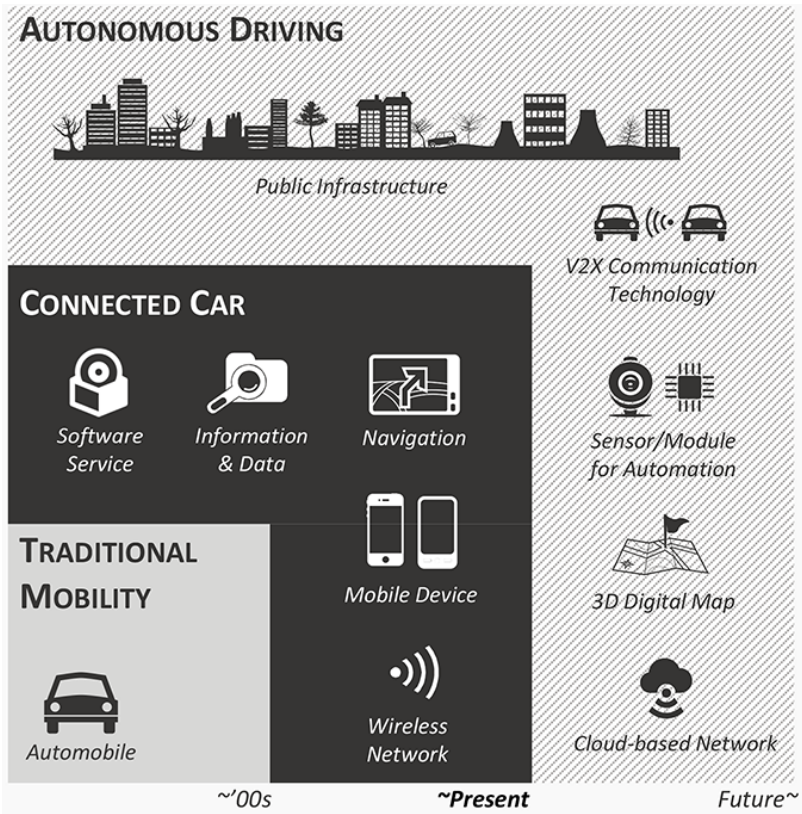


Figure 1 Technological developments in the present and future (Karlsson, Ahn and Choi, 2017)

In the future self-driving technologies are forecasted to enhance driver safety, reduce traffic congestion etc. (Thrun, 2010). The number of sensors implemented in the automobile is constantly increasing (Manyika et al., 2013). Infotainment systems are offering more entertainment options (Regan, 2004) and connected automobiles do not only offer wireless internet access, but also connection to a broad network of automobiles and enable V2V communication. Gesture control systems are developing; augmented reality is included into the automobile interface (Ropert, 2014). The amount of software and technology built into automobile interfaces and applications for navigation, music, internet, communication and connection to social networks challenge the driver by providing a large volume of information. Drivers are preoccupied with electronic devices, potentially degrading performance, impacting road safety. Attention sharing in a hazardous environment, such as the driving environment, presents a significant safety issue (Regan, 2004).

Self-driving automobiles could transform the driving environment from a potentially stressful environment requiring high concentration and responsibly, to an environment for relaxation and social interaction (Rand Report, 2014). While increasing automation is predicted to enhance safety and decrease the environmental impact of automobiles, concerns regarding self-driving vehicles arise, such as fears of privacy issues and hacking of on-board computer systems (Ropert, 2014). The greatest obstacle in the way of developing technologies for the automotive environment is human acceptance (Thrun, 2010). With increasing automation and growing sophistication of in-car technologies customer behaviour and needs will change (Gao et al., 2016) and a more emotional relationship between drivers and their automobiles will be created (Michael, 2001; Hagel et al., 2017).

When comparing the developments in the automotive industry to Maslow's Pyramid of Human Needs multiple comparisons are obvious. In his book 'A Theory of Human Motivation', Maslow explains human motivation through his pyramid visualising the hierarchy human needs. Even though the model was created in 1943, it is prescient in its content and often referred to in modern research. In Maslow's Pyramid of Human Needs the appearance of one need rests on the satisfaction of the prior need (Maslow, 1943). This approach has been used as an analogy in multiple disciplines, such as marketing or design (Heppard, 2015; Baches, 2016) and has some strong similarities to the developments in the automotive industry and research (Figure 2).

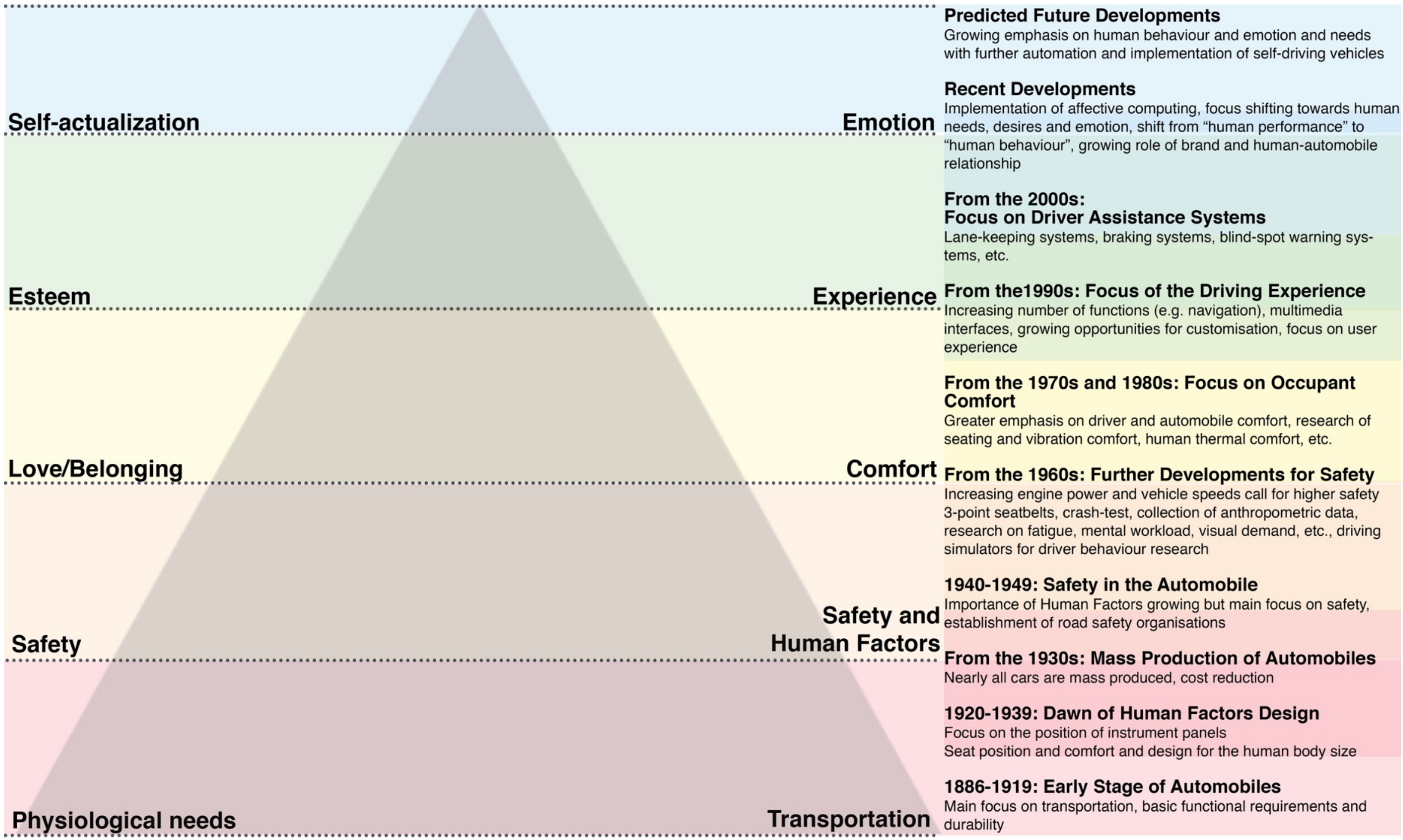


Figure 2 Analogy between Maslow's Pyramid of Human Needs and historical developments in the automotive industry (based on Akamatsu, Green and Bengler, 2013; Hagel et al., 2017; Miller, 2001; Normark and Gkouskos, 2012)

While the first four stages of physiological needs, safety, love/belonging and esteem can be seen in parallel to the past developments in the automotive industry of transportation, safety and human factors, comfort and experience, the peak of the pyramid is based on predictions and recent and future developments. In order for future automotive design to adapt to the mentioned challenges the traditional automotive design process needs to adapt (Giuliano, Germak and Giacomin, 2017). A shift towards human emotion and a more human-centred approach to automotive design is required. To accomplish this the significance of the role of emotion in the driving environment must be gauged.

1.2 The Importance and Role of Emotion

The automotive environment is highly emotional (Sheller, 2004), encompassing the driving experience, corresponding feelings and emotional states (Carrabine and Longhurst, 2002), the social relationship between the automobile and driver (Hagman, 2010), the emotional values an automobile objectifies (Urry, 2004) and the identification of drivers with their vehicles (Edensor, 2004). The emotional components of the driving experience become apparent through expressions like “thrill of driving”, “passion of the collector” (Sheller, 2004, p.5) and often directly involve expressions with a high emotional value (Miller, 2001; Sheller, 2004). Semantics addressing emotions, feelings or desires are used in marketing strategies of major automobile companies such as BMW with the headline “Joy is BMW” (Blanckenberg, 2009) or Peugeot using “Motion and Emotion” (Peugeot Motion & Emotion, 2010). The emotional significance of the pleasure of driving for instance can be explained by the “kinaesthetic experience” (Katz, 2001, p.144), which defines driving as an embodied and sensuous experience and emphasises the feelings created through the experience of “movement and being moved together” (Sheller, 2004, p.68).

The relationship between drivers and automobiles might be the most emotional human-machine-interaction (Michael, 2001; Miller 2001). The automobile is personified as a companion or even as wife or lover (Sheller, 2004). This relationship is reinforced by major automobile companies, offering applications emphasising the connection between driver and automobile such as watches or mobile applications, which create a 24-hour bond between human and machine (e.g. BMW smart watch). Moreover, the automobile is strongly connected to significant human values, such as freedom and independence (Sheller, 2004). The ownership of an automobile creates the feeling of power and freedom; the automobile is often referred to as a status symbol eliciting feelings such as pride and power (Urry, 2004). Moreover, ownership is strongly connected to the identification of a driver with his/her vehicle (Hagman, 2010). The purchase choice is strongly influenced by the values and characteristics the buyer can identify with (Hagman, 2010). The decision to purchase an automobile is an emotional one, as the identification with the vehicle includes self-reflection and self-realisation (Carrabine and Longhurst, 2002). A strong identification again leads to a stronger connection between human and automobile (Sheller, 2004).

> *"Car design influences the lives of millions of people throughout the world. Whether the car serves as merely a practical means of transport or as an extension of one's personality, its design and brand will always attract comment." (Newbury, 2002, p.11)*

Research (Hsu, Lu and Ho, 2013; Warell, 2008) into the visual appeal of automobiles, such as the study by Cornet and Krieger (2005), identified the four most important influences on the purchase of an automobile as "exterior styling", "interior styling", "trendy" and "makes me feel attractive" (Cornet and Krieger, 2005, p.1). Factors such as expression, emotional response and brand impression are significant to the automotive industry (Cornet and Krieger, 2005). Further studies covered the influence of the exterior styling (Desmet, 2002), the social roles (Pelly, 1996) and other emotional aspects in the automotive industry.

Negative emotions can have a major impact on driving performance, and cause accidents or road deaths (Dement, 1997; Wells-Parker et al., 2002). These emotional states include aggressiveness and anger (Wells-Parker et al., 2002), fatigue and drowsiness (Lyznicki et al., 1998), stress (Matthews et al., 1998), confusion (Ball and Rebok, 1994), nervousness (Li and Ji, 2005) and sadness (Dula and Geller, 2003). Aggressiveness and anger can cause aggressive driving behaviour (Wells-Parker et al., 2002). Fatigue and drowsiness can influence concentration, judgement, perception and reaction time, potentially causing accidents (Dement, 1997). Another common problem is driver stress, often leading to a significant decrease in driving performance (Hoch et al., 2005; Uchiyama et al., 2002). Driver confusion can cause increased reaction time, or decreased decision-making ability (Jonsson et al., 2005). Confusion is prevalent amongst elderly drivers, but with the increasing sophistication of digital technologies it is expected to become a greater issue in the future. Nervousness and sadness can negatively influence the driving performance and lead to human error and accidents (Li and Ji, 2005). Human error is still the largest cause for accidents and road deaths (National Highway Traffic Safety Administration, 2008). While the influence of negative emotions on driving has been studied in the past, in-depth investigations of multiple emotional states during driving are limited. This research takes the view that a systematic investigation of multiple emotional states is necessary to respond to the aforementioned challenges in automotive design.

1.3 The Importance of Emotion for Autonomous Vehicles

Autonomous vehicles offer many potential benefits for the future, including reduced CO2 emission and fuel consumption (Bullis, 2011), increased safety and reduced fatalities (Manyika et al., 2013) and decreased congestion (Dumaine, 2012). Autonomous driving could lead to social benefits; occupants could decide freely how to use their time in the vehicle. Predictions present the idea of the future automobile as a living room, workplace or the new ‘third place’ (e.g. Mercedes concept self-driving automobile introduced at CES 2015 Las Vegas).

Automotive technology is progressing strongly towards higher automation (Manyika et al., 2013), with self-parking systems, steering assistance and automatic breaking systems. Toyota, General Motors, Mercedes, BMW, Audi and Volvo are testing autonomous systems (Manyika et al., 2013). Several predictions see autonomous automobiles on the streets by 2025-2030 (Gott, 2014; Jacques, 2014; Stanley and Gyimesi, 2015).

> *“That would translate into approximately 10 to 20 percent of the 1.2 billion private automobiles projected to be on the road in 2025 having the ability to self-drive in at least half of all traffic situations.” (Manyika et al., 2013, p.81)*

The largest issue facing autonomous vehicles is therefore not the technology, but regulatory frameworks and most importantly public support and human acceptance (Manyika et al., 2013; Thrun 2010). Without human acceptance, there is no foundation for connected, self-driving automobiles. Thrun states that:

> *“We need to overcome the old belief that only people can drive cars, and embrace new modes of transportation that utilize the twenty-first century technology.” (Thrun, 2010 p 106)*

Schoettle and Sivak conducted research into the acceptance of self-driving vehicles and 43.5% of the participants stated that they always want to be in full control of their vehicle, only 15.6% had a positive point of view towards autonomous automobiles and more than 60% of participants expressed concerns about riding an autonomous automobile (Schoettle and Sivak, 2014). With the automobile taking over tasks that the driver once used to perform, issues of acceptance, trust and pride can arise (Koo et al., 2015, p.2). To prevent this from happening Koo et al. emphasise the “need for designers to observe this phenomenon from the perspective of the human driver” (Koo et al., 2015, p.2). Recent surveys investigating the public opinion of partially autonomous and self-driving vehicles reinforce the need for further research and adaptations (Business Wire, 2014; Cisco, 2013; Schoettle and Sivak 2014; Silberg et al., 2013). The role of emotion research becomes highly significant when taking into account upcoming changes in the automotive environment due to automation. Koo et al. state the concern that “cars are starting to make decisions on our behalf” (Koo et al., 2015, p.1).

When looking at the stages of vehicle automation (Figure 3) it becomes apparent that we are currently in the progress of entering a stage of highly automated vehicles, facing full automation in 2025.

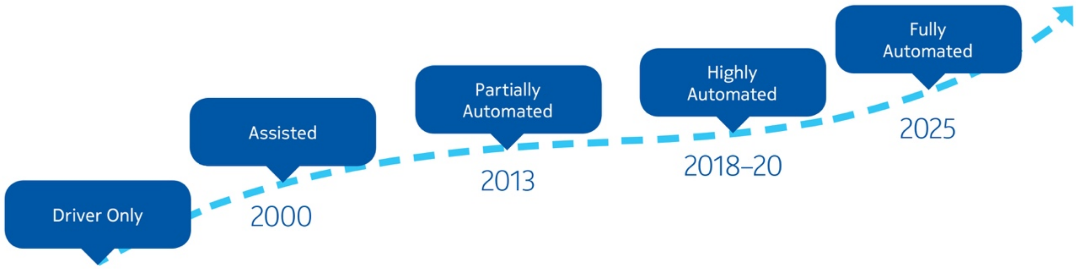


Figure 3 Arch of vehicle automation (Horrell, 2014)

For highly automated vehicles where the driver still has an active role and control is shared between the automobile and the driver, the role of human-automobile interaction is highly significant. While the role of the driver in a fully manual automobile, as well as in a fully self-driving automobile is obvious, the biggest challenges arise with partially autonomous cars (Norman, 1990). With automobile and driver cooperating, interaction needs to happen on an affective level to create a successful control loop. To keep the human informed, the automobile must understand and respond to human behaviour and emotions (Shaikh and Krishnan, 2013). Therefore, a high level of understanding of drivers is required.

In the fully automated stage, the role of the driver will change into a passenger role, with the automobile taking over all tasks which used to be human-controlled. For the passengers to trust their self-driving automobile an affective passenger-car communication is required. The automobile must understand human needs and respond to behaviour and emotion; emotional factors and affective states are therefore crucial for acceptance, safety and comfort of future automotive design (Eyben et al., 2010). Furthermore, new communication models between automobiles and pedestrians have to be created in order to ensure the pedestrian's safety and comfort. The automobile will need to be able to predict the pedestrian's behaviour (Meeder, Bosina and Weidmann, 2017).

While multiple researchers are investigating the requirements stemming from current and future stages of automation and the necessity to respond to needs of drivers, passengers and pedestrians (Eyben et al., 2010; Meeder, Bosina and Weidmann, 2017; Shaikh and Krishnan, 2013) further research on methods of emotion investigation during driving is required.

1.4 Current Technology for Estimating Human Emotion and Current Uses of the Collected Information

To meet human requirements for coping with current and future automobile technology, it is important to understand the multi-layered emotional role of the automobile (Sheller, 2004). To achieve this, studies of human behaviour and emotional states in the driving context are required. We need to be able to predict the channels of user behaviour and emotion while driving. As Norman states "we must design our technologies for the way people actually behave, not the way we would like them to behave" (Norman, 2007, p.12). Furthermore, a shift of the main focus of the automobile industry from human performance to human behaviour is required for future design to address issues such as the greater sophistication of technologies and the increasing complexity of the automotive habitat. To respond to these challenges a better understanding of human behaviour, needs, desires and emotions is necessary (Giuliano, Germak and Giacomin, 2017).

While most research approaches focus on negative emotions and their consequences (Deffenbacher et al., 2002; Parkinson, 2001), the focus is gradually shifting towards the investigation of multiple emotional states in the automotive environment. One approach to a better understanding of human emotion which has recently been applied in automotive research is affective computing, the study of systems or devices which can recognise, interpret or process human emotion (Picard, 2003). Different physiological measurement tools (e.g. Galvanic Skin Response, Respiration Rate), behavioural sensors (e.g. Facial-Expression Analysis, Speech Analysis) or self-report tools (e.g. Car Logs, Self-Assessment Manikin) have been applied to driving research (Healey, 2000; Hoch et al., 2005; Jones and Jonsson, 2005). Moreover, numerous modern human–centred design approaches combining various methods have been applied to automotive research and design, to investigate the drivers' and passengers' behaviour, emotion and needs and improve the driving experience (Gkatzidou, Giacomin and Skrypchuk, 2016; Giuliano, Germak and Giacomin, 2017).

Current research and appropriate methods for the investigation of emotions during driving are not only limited but also not comparable due to major differences in applied methodologies, investigations of emotion and measurement tools. Furthermore, research methodologies and results are often highly influenced by their limitations (Chapter 3.2 Emotion Measurement in Automobile Research). Therefore, further research systematically investigating emotional responses within the automotive habitat is required. This research uses identification of the limitations and shortcomings of previous efforts to direct the line of investigation. Through the development of specific queries that must be answered, an improved framework for the study of human emotion in the automotive environment may be developed.

1.5 Research Questions

This research takes the view that there is a need for the automotive industry to shift the focus towards the driver's behaviour, emotions and needs. A better understanding of the driver's emotional response to changes in the driving environment is required, especially considering current and future technological developments. The aim of this research is to investigate the measurability, natures and causes of emotional responses during simulated and on-road driving. Furthermore, the ability to causally assign individual emotional responses to specific sources of the emotion will be explored. Additionally, this thesis will investigate the assigned causes for emotional events in the driving environment and the influence of different road types and situations on those. Finally, a dataset of emotional responses and their causes in different driving settings will be created. A comparison featuring a statistical analysis of the collected results will be conducted to investigate how different driving settings influence drivers' emotions. Therefore, the main research questions of this thesis and are:

- How can human emotional responses be measured in an automotive environment?

- Can emotional responses be triggered and measured in a simulated driving environment? What are the major challenges?

- What are the typical natures, frequencies and causes of emotional events in a natural real driving environment?

- What are the typical natures, frequencies and causes of emotional events in a partially controlled real driving environment?

- How can the typical natures, frequencies and causes of emotional events between two on-road studies in different settings be compared?

1.6 Research Outcome and Future Application

Results of this research will reinforce the notion that emotions play a significant role during automobile driving and provide knowledge on causes for the emotional influences. This research will provide a methodology for the in-depth investigation of emotional responses during driving, enabling the construction of methods and systems that will allow future research to address the previously highlighted issues. For example, the results of this research may be applied in the design of standardised road tests intended to investigate emotional responses during driving.

Considering the challenges the automotive industry is facing, the introduced methodology could be used to determine the emotional influence of specific factors (e.g. the navigation system, functionality of control systems), or circumstances and scenarios (e.g. weather conditions, road conditions), aiding the understanding of the root causes of emotions and how the action of driving and the emotional driving experience are affected. To achieve this, data and knowledge collected through this research can be applied to test different automotive system components and their application during driving in order to investigate potential emotional influences. Outcomes could be used for the formulation of automotive design criteria. Furthermore, knowledge acquired in this research could see further application in tailoring the driving experience, allowing causes of positive emotions to be emphasised, and those of negative emotions to be prevented. This could lead to prediction of emotional responses to a given situation, and personalisation of the driving experience based on the knowledge collected about the user's emotions during driving.

The net result may be an enhanced human-machine interaction, serving to aid in the human adoption of technologies, for instance through dynamic information flow to the driver, leading to a greater trust in autonomous automobiles by occupants. Machine learning will be a vital tool in the implementation of upcoming automotive technologies. For effective machine learning large data sets are required. One of the aims of this research is the development of a framework within which these large datasets may be produced, ready for application to machine learning processes (Frank, 2017).

1.7 Thesis Outline

The body of work of this thesis falls into three phases. The first phase includes a literature review of human emotion, human emotion in the automobile and an overview of the applied research methodologies. The second phase of the thesis contains a driving study in a simulated environment and two driving studies in an on-road environment in different settings, as well as a comparison of the two on-road studies. The third phase includes a review of the conducted research, discusses the potential of the human-centred design approach to aid future automotive design and considers future research directions. This thesis is divided in 9 chapters:

Chapter 1: Motivation of the thesis including an overview of the current state of the industry, the importance and role of emotion, the importance of emotion towards the future of automotive design and current technologies for the investigation of human emotion. Research questions, as well as the research outcome and potential future applications are presented.

Chapter 2: Literature review of the development of emotion research through philosophy, biology, psychology and neuroscience as well as a definition of emotion. Furthermore, emotion measurement techniques including self-report tools, behavioural measurements, physiological measurements and neural measurements are introduced.

Chapter 3: A more focused literature review of the role of emotional states in automobile driving and the measurement of human emotion in the automotive environment, providing the rationale for the conducted studies. Review of 24 publications covering applied measurement methods, affective states measured, the research focus, the study environment and limitations.

Chapter 4: Introduction to research methodologies applied in the thesis. Discussion of research paradigm, approach, strategy and research design, data collection and analysis methods as well as sampling, ethics, reliability, validity and limitations.

Chapter 5: Report on a driving study carried out in a driving simulator investigating Facial-Expression Analysis (FEA) and emotion elicitation. Explanation of the study, carried out with 11 drivers and 10 passengers, including different emotion elicitation scenarios to measure emotional states in the simulated automotive habitat.

Chapter 6: Report on an on-road driving study with 22 participants in their own automobiles on a familiar route to collect data on natures, frequencies and causes of emotional responses in a natural driving environment.

Chapter 7: Report on an on-road driving study involving 21 participants in a research vehicle on a previously planned road circuit, involving different driving and road situations. Investigation of natures, frequencies and causes of human emotional responses in a partially controlled driving environment and comparison between different road types. Use of thematic coding and an inter-observer reliability test to ensure validity of the results.

Chapter 8: Comparison of the on-road driving studies and a comprehensive statistical analysis.

Chapter 9: Revision of the research questions and hypotheses and examination of the extent to which those have been answered. Discussion of the contributions to the field, further findings of the research, research limitations, suggested applications and future work.

In Figure 4 below, the outcome of each chapter and the logical progression of the research conducted is visualised.

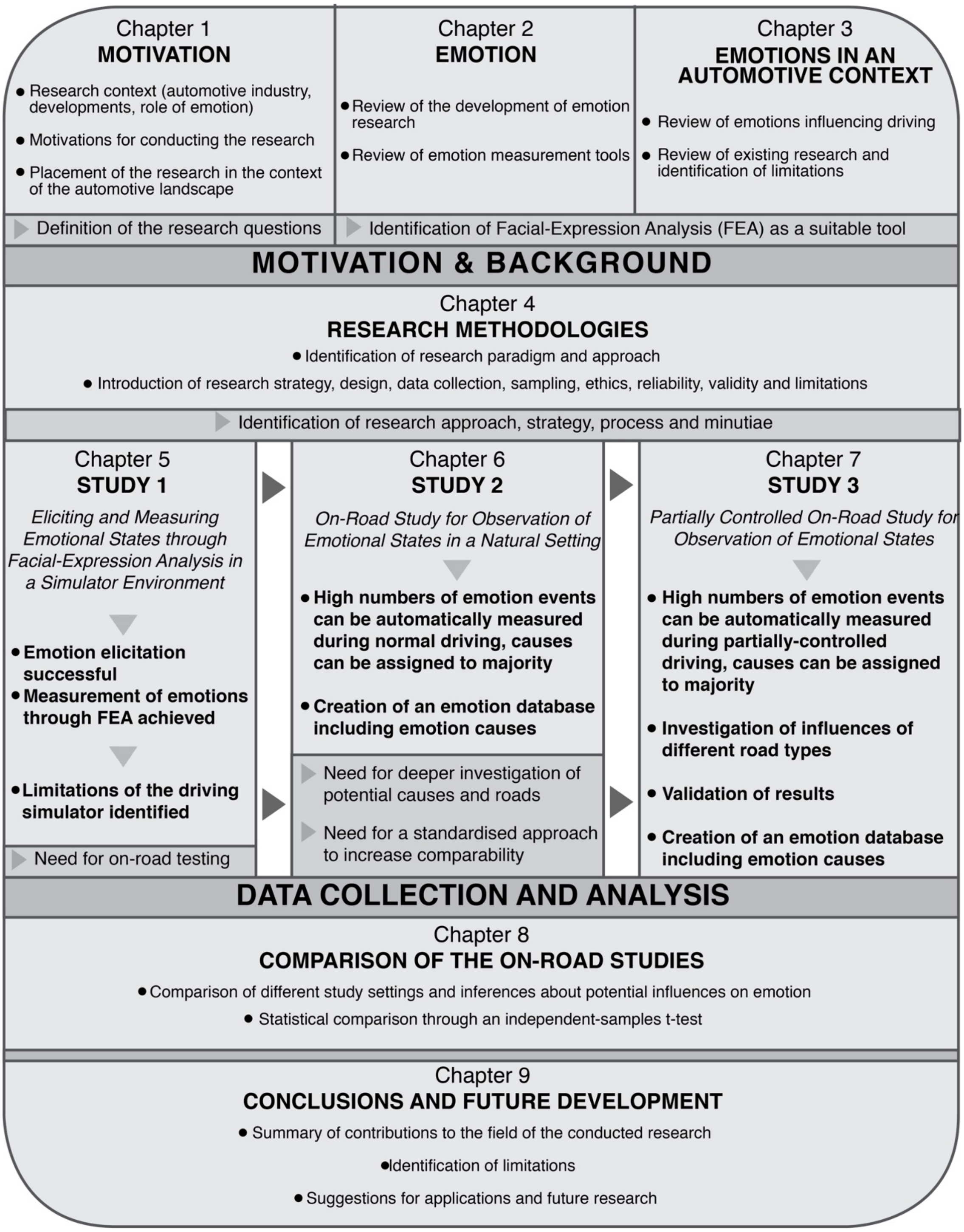


Figure 4 Narrative and architecture of the thesis

2 Human Emotion

2.1 The Development of Emotion Research

2.1.1 Introduction

A systematic literature review of emotion research and emotional theories in different disciplines was conducted. Articles, publications and papers from IEEE Explore, Brunel Library, PubMed and Google Scholar were reviewed. For all sources, a set of simple search strings was used, the chosen keywords are as follows: emotion/feeling/emotional states AND history/theories/research/review/selection AND human/historical/history. The primary selection criterion for the choice of material to be reviewed was an evaluation of the abstract towards the relevance of the material for this research. In a second review of all sources (61 sources), more specific secondary inclusion and exclusion criteria were applied.

Criteria for inclusion of the identified source were:

- Provides important information about the origin, role, communication or expression of emotion
- Conducted in a research field relevant for this thesis
- Can be historically classified
- Shows theories/approaches/research areas in perspective

Criteria for exclusion of the identified source were:

- Provides no new or additional information
- Cannot be related to any identified sources

The remaining information (18 sources) was structured, covering human emotion in philosophy, biology, psychology and neuroscience.

Human emotion is a widely researched interdisciplinary field (Strongman, 1996), owing to the importance of emotions in our everyday lives, and the influence of emotions in many human processes, such as our perception, cognition and decision-making. A review of the academic debate and research in the area was conducted to gain a multi-layered perspective of the numerous theories and developments that have contributed to this field. The following chapter presents a review of emotion research and theories from different disciplines, which are most relevant for this thesis.

2.1.2 Human Emotion in Philosophy

Philosophy was the first discipline in which emotion was considered an important area of research (Strongman, 1996). It was not until the late 19th century that other disciplines, such as psychology, started to show interest in the research area (Solomon, 1976). Plato and Aristotle presented the first two contradictory theories of human emotion. This represented the genesis of emotional theories, and both are frequently referred to in more recent theories. Plato's view on emotion had a relatively negative connotation. He defined human emotions as lacking a central position, distracting us from human reasoning (Strongman, 1996). In contrast Aristotle viewed emotions as facets of existence and a part of higher cognitive experiences. He was the first to define emotions such as pity, fear and pain and his early theory is reflected in modern psychological theories. Furthermore, Aristotle's theory of emotion is now often used as an ethical framework for further research (Solomon, 1976). Despite the continued relevance of Aristotle's theory in modern times, in the past his ideas fell into disfavour, and there was instead a clear preference for Plato's theory. Stoic and Epicurean philosophers saw emotion as fundamentally socio-moral constructs like Aristotle, which is often seen as the first approach to a cognitive model of emotions (Vaida and Ormenisan, 2013). Descartes later reviewed Aristotle's theory; he clearly separated humans from animals and saw emotion as experiences which only humans could undergo (Lyons, 1999). In his theory, he defined the 'mind-body dualism' in a mechanistic explanation of body functions and their production of emotions (Vaida and Ormenisan, 2013). Spinoza's theory about affects (love, hate, pride, envy) defines emotions as determined in their occurrence. He divides human affect into actions and passions and defines the human “power to persevere in being” (Kennington, 1980, p. 42). Spinoza calls an affect any positive or negative change of this power and distinguishes affects, which are actions and sourced in our nature alone, from passions sourced outside of us (Kennington, 1980).

Hume discusses emotions from a sentimentalist’s perspective, defining emotions as motivations for action and reasoning. He categorises emotions in general as among the perceptions of the mind, divided into calm affective states (sentiments), and violent affective states (passions). While passions are seen as low-order perceptions, sentiments have a reflective character. Our emotions can develop historically and socially and are standards for judgement. Furthermore, we all share normative standards for moral judgements, which are created through sympathy (Schmitter, 2006). Hume influenced later theories with his approach to emotions and moral sense and his explanation of the standard in our judgements of taste. Smith refers to Hume’s theory in his ‘Theory of the Moral Sentiments’ (1759), with similar views on sympathy and emotion. In contrast to Hume, in his view sympathy does not solely have the purpose of communicating passions to others. He agrees on Hume’s view that our sentiments create the general point of view and standards for judgment (Schmitter, 2006).

2.1.3 Human Emotion in Biology

Contrastingly, Darwin’s research is based on another dimension of emotion: the expression of emotion. Darwin attempted a human-animal comparison of emotion in 1872. He published one of the most influential and ground-breaking theories of emotions and behaviour in his work ‘Expression of the Emotions in Man and Animals’. In this he expressed his support of his theory of evolution, showing similarities between the expression of emotion in animals and humans (Figure 5). He was one of the first researchers to directly link emotions to the nervous system, suggesting that the expression of emotion is not a learned behaviour. This contradicted the cultural theory of emotion, which had been highly respected prior to Darwin’s assertions, seeing emotions as cultural characteristics, comparable to language and learned behaviours. The theory is based on the idea that people from different cultures experience different emotions in response to the same stimuli. Darwin's work, on the contrary, states that emotion is universal and includes one of the first studies on facial expressions and behaviour. His research was a landmark in the history of emotion research (Strongman, 1996).

Figure 5 Darwin’s theory of emotion expression in animals (Darwin and Prodger, 1998)

2.1.4 Human Emotion in Psychology

Building on Darwin’s theory of emotion expression, James and Lange published possibly the most famous theory of emotion in 1884-1885, sparking long-lasting controversy. It was the first psychological theory of emotion, limited to emotions directly linked to bodily expressions, including the viscera and the skeletal muscles. James and Lange directly link perception and feeling, calling the product of both emotion. They claim that emotions which are not directly connected to bodily expressions do not exist. According to the theory emotion ceases to exist once we have overcome the physiological impact of the emotion. Therefore, the cortical activity is not caused by the emotion, but is itself the emotion occurring in the brain. The theory was the foundation of research into bodily expressions of emotions, including facial expression (Solomon, 1976; Strongman, 1996). The Cannon-Bard theory (1915-1932) criticises the James-Lange theory, proposing an alternative approach. Their criticism was based on the viscera, its reaction to emotional states and its insecurity. The criticism was contradicted by Mandler (1962) and Schlachter (1964), who argued for the James-Lange theory and the described role of the viscera (Strongman, 1996).

Ekman and Izard based their research on Darwin's findings in an effort to put an end to the debate over the universality of facial expressions. In the late 1960s they conducted experiments to prove that certain facial expressions are universally consistent across different countries and cultures (Strongman, 1996). Ekman and Izard showed images of facial expressions to people of different cultures, who were then asked to identify which emotion was being expressed. They found strong cross-cultural similarities, which led to Ekman's definition of the six basic emotions. They are: anger, fear, surprise, disgust and joy (Ekman and Friesen, 1971). According to Ekman's theory these six basic emotions are universal and innate (Figure 6).

Figure 6 Ekman's basic emotions (Ekman and Friesen, 1971)

Ekman and Friesen conducted studies on the basic emotions and their corresponding facial expressions, developing a Facial Action Coding System (FACS) allowing the development of software which can identify human emotion from facial expressions. In 1990, Ekman added further emotions (e.g. shame, amusement, contempt, guilt) stating that not all emotions can be encoded through facial expression. Izard focused on the evolution and relationship of emotions and language, questioning the negative and positive impacts on human ability to show emotions. Izard's research claims that the development of language negatively influenced our ability to show, interpret and understand emotions (Strongman, 1996).

Following Ekman's initial attempts to define a universal set of emotions came a second wave of theories that proposed frameworks for research into the universality of emotion. Two such theories are the 'Dimensional Theory of Emotion', and 'Plutchik's Wheel of Emotion' (Larsen and Diener, 1992). The dimensional theory of emotion is often referred to in modern research, especially when intending to measure emotion. Human emotions are defined by valence and arousal and can therefore be mapped in a two-dimensional space (Lang et al., 1993; Larsen and Diener, 1992). While valence reflects how negative or positive the experience is, arousal measures the level of activation from calm to very excited (Figure 7).

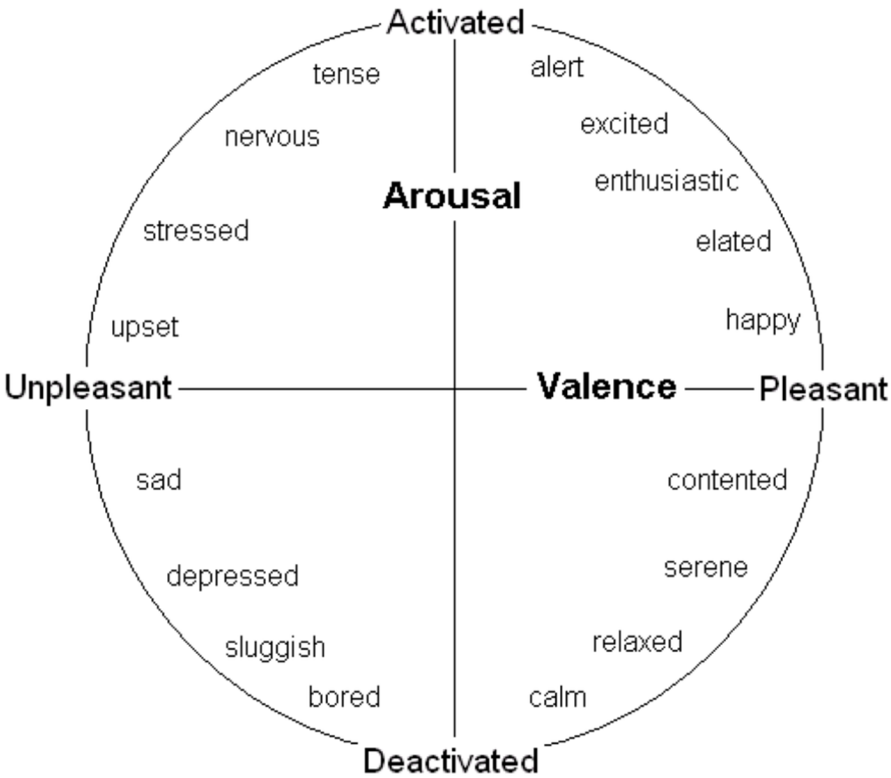


Figure 7 Dimensional theory of emotion (Posner, Russell and Peterson, 2005)

Plutchik’s 1980 ‘Wheel of Emotions’ divides emotions into levels, starting from primary emotions and forming bipolar pairs. Figure 8 shows how primary emotions are the base for secondary, higher emotions.

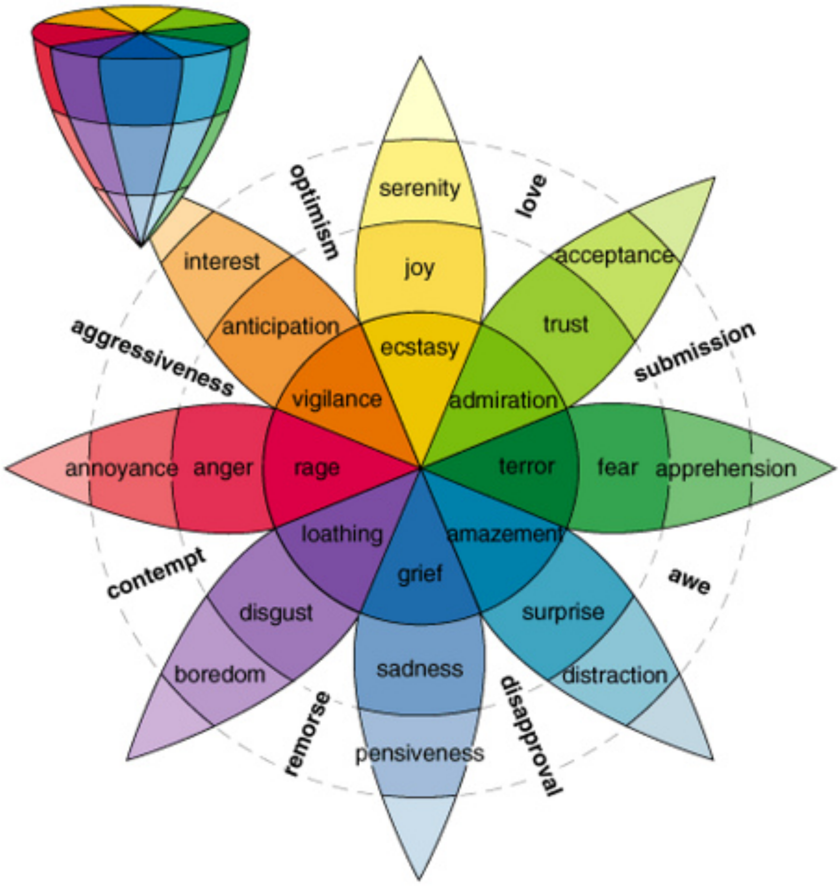


Figure 8 Plutchik’s Wheel of Emotion (Strongman, 1996)

More recent research has drawn a close connection between emotions and higher forms of human experience like implicit and explicit memory (Bradley and Lang, 2000), interpersonal relationships (Reis and Patrick, 1996), perception and attention, decision-making and judgement (Forgas, 1992). One theory of higher emotions stems from Paul Griffiths (1997) who defined the higher cognitive emotions as love, guilt, shame, embarrassment, pride, envy and jealousy. As with Ekman's theory of the six basic emotions, the higher cognitive emotions are universal, but in contrast require greater amounts of cognitive processing and are therefore slower to build up and subside. Griffiths' theory is based on an evolutionary perspective; he criticised other emotion theories for their lack of attention to biological fact and conceptual precision (Strongman, 1996). Contrasting both Ekman's theory and Griffiths' theory is Parrott's 2001 theory of primary, secondary and tertiary emotions, encompassing over 100 different emotions. The primary emotions are comparable to Ekman's six basic emotions, with numerous secondary and tertiary emotions.

Primary emotion	Secondary emotion	Tertiary emotions
Love	Affection	Adoration, affection, love, fondness, liking, attraction, caring, tenderness, compassion, sentimentality
	Lust	Arousal, desire, lust, passion, infatuation
	Longing	Longing
Joy	Cheerfulness	Amusement, bliss, cheerfulness, gaiety, glee, jolliness, joviality, joy, delight, enjoyment, gladness, happiness, jubilation, elation, satisfaction, ecstasy, euphoria
	Zest	Enthusiasm, zeal, zest, excitement, thrill, exhilaration
	Contentment	Contentment, pleasure
	Pride	Pride, triumph
	Optimism	Eagerness, hope, optimism
	Enthrallment	Enthrallment, rapture
	Relief	Relief
Surprise	Surprise	Amazement, surprise, astonishment

Figure 9 Excerpt of Parrott's theory of primary, secondary and tertiary emotion (Parrott, 2001)

Inherent in the above theories of emotion is the assumption that every emotional state can be described through language, and that such definitions are objective and universal. In reality, individuals face difficulties in verbally expressing their exact emotional state, and the meaning of such expressions is subject to disagreement (Caicedo and Van Beuzekom, 2006). Difficulties arise when intending to translate the linguistic aspects of emotional theories into other languages (Desmet, 2003). If a verbal theory is used as a basis for emotion measurement tools, this can cause major limitations.

2.1.5 Human Emotion in Neuroscience

Emotions are more recently known to play an important role in the complex field of human experience (Damasio, Tranel and Damasio, 1990). Damasio, Tranel and Damasio's theory stems from neuroscience and links emotions to consciousness and decision-making. They reviewed and verified past ideas of emotions but included studies on decision-making connected to emotional abilities (1990). In his book 'Descartes' Error', Damasio presents the 'somatic marker hypothesis', a theory which implies the guidance of emotions, through decision-making and behaviour. He explains this through the case study of Elliot (Damasio, 1994), a patient who suffered a tumour in the prefrontal cortex of the brain. The tumour caused significant damage and strongly impacted his ability to feel emotions. Consequently, Elliot lost his emotional intelligence and his ability to master human interaction and make reasonable decisions, leading to serious life-changing problems. In more recent studies, Damasio included tools like functional neuroimaging to prove the close connection between activity in certain parts of the brain and mental processes.

2.2 Definition of Human Emotion

In the last 50 years the topic of human emotion has become increasingly investigated across a range of disciplines (Figure 10) and recent research has produced many useful publications, dedicated solely to the study of human emotions, affect, mood and human behaviour (Ekkekakis, 2013; Lewis, Haviland-Jones and Barrett, 2010).

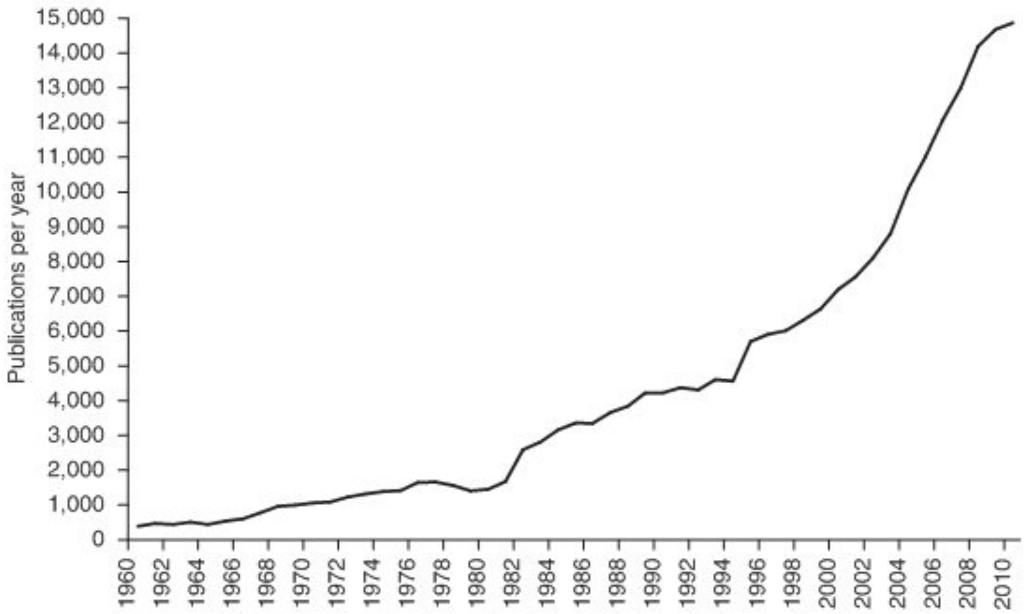


Figure 10 Number of publications per year in the PsycINFO database from 1960-2010 including the keywords ‘affective’, ‘mood’, ‘emotion’ (Ekkeakis, 2013)

A wide variety of definitions of the term ‘emotion’ exist (Kleinginna and Kleinginna, 1981). As a basis for this thesis a single definition was chosen. Kleinginna and Kleinginna attempted to find a conclusive definition by collecting, structuring and categorising 92 definitions of emotion. From their analysis they concluded:

> *“Emotion is a complex set of interactions among subjective and objective factors, mediated by neural-hormonal systems, which can (a) give rise to affective experiences such as feelings of arousal, pleasure/displeasure; (b) generate cognitive processes such as emotionally relevant perceptual effects, appraisals, labelling processes; (c) activate widespread physiological adjustments to the arousing conditions; and (d) lead to behavior that is often, but not always, expressive, goal-directed, and adaptive.”* (Kleinginna and Kleinginna, 1981, p. 355)

The definition was chosen as the basis of the research for this thesis, as it encompasses the different dimensions of emotion and is synthesised from a large set of definitions from experts in different disciplines.

One facet of modern emotion research is the measurement of emotion. The ability to understand and measure emotions is important to many disciplines (Ekkeakis, 2013). In the following, the measurement of emotion is discussed.

2.3 The Measurement of Emotional States

2.3.1 Introduction

When referring to the measurement of emotional states, the various dimensions of emotions must be differentiated. Based on the definition of Kleinginna and Kleinginna (1981), human emotion can be labelled in four dimensions: affective experiences, cognitive processes, physiological adjustments and the behavioural response the emotional experience triggers. The measurement of emotion can be achieved through the application of a range of tools which can be categorised into self-report, behavioural measurements, physiological measurements and neural measurements. Emotion measurement tools are commonly combined, for instance physiological measurements or behavioural measurements with self-reported measures (e.g. Galvanic Skin Response and the Self-Assessment Manikin), thus achieving correlations of up to 91% between measured and self-assessed emotion data (Collet et al, 1997; Ekman, Levenson and Friesen, 1983; Picard, Vyzas and Healey, 2001).

To investigate techniques for the measurement of emotional states, a systematic literature review was conducted. Articles, publications and papers from the main sources IEEE Explore, Brunel Library, PubMed and Google Scholar were reviewed. A set of simple search strings was used: *emotion/feelings/emotional* states *AND measurement/monitoring AND techniques/methods/tools.* The primary selection criterion for the choice of material to be reviewed was an evaluation of the abstract towards the relevance of the material for this research. In a second review of all sources (125 sources), more specific secondary inclusion and exclusion criteria were applied.

Criteria for inclusion of the identified source were:

- Introduced technique has been applied and validated in previous research
- Application or method is of importance for this thesis or has been widely used for a similar purpose
- Application or method has substantial evidence of its effectiveness in a research context

Criteria for exclusion of the identified source were:

- Provides no new or additional information
- Technique highly specific and therefore not relevant

The remaining information (66 sources) was structured, into self-reports, behavioural measures, physiological measures and neural measures which are introduced below.

2.3.2 Self-Reports

The subjective experience of emotion can be measured using self-reports. In the following, a set of the most frequently adopted self-reporting tools is introduced. These include pictorial self-reports, verbal self-reports and recall self-reports.

Pictorial Self-Reports

Self-Assessment Manikin (SAM)

The SAM (Bradley and Lang, 1994) is a non-verbal, self-assessment technique, investigating three dimensions of affect. The SAM uses images of a cartoon character to measure pleasure, arousal and dominance. On a 1-to-5 scale, the participant can choose a visual, representing his/her emotional experience. The SAM is a widely-applied tool for measuring participants' reaction to stimuli (Ekkekakis et al., 2000; Smith et al., 2002), due to its universal, quick, cheap and intuitive application. The tool is ideal for use with children or in cross-cultural environments. A disadvantage is that no specific emotion can be investigated (Morris, 1995).

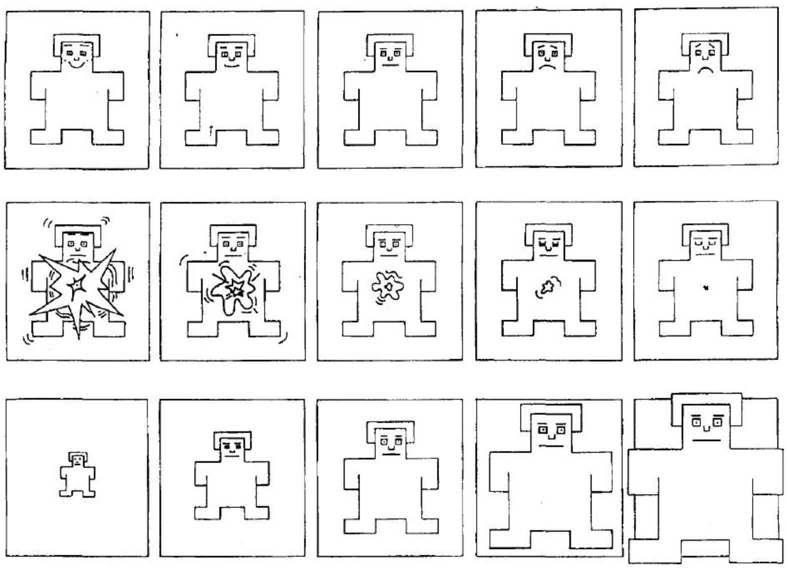


Figure 11 Self-Assessment-Manikin (Lang, 1980)

Product Emotion Measuring Instrument (PrEmo)

Desmet developed the PrEmo in 2003. Comparable to SAM, a cartoon character is used to represent 14 different emotions. In contrast to SAM, this cartoon character is animated. Participants are asked to rate their emotional state for each of the 14 emotions presented, using a three-degree scale reaching from 'not felt at all' to 'intensely felt'. Since several emotions are rated, more complex emotional responses can be investigated. Although the software tool is more complex than SAM, PrEmo is intuitive and important insights can be gained through its application. Emotions not relevant for a specific study can be excluded, making PrEmo adaptable and increasing its usability (Desmet, 2003; Caicedo and Van Beuzekom, 2006).

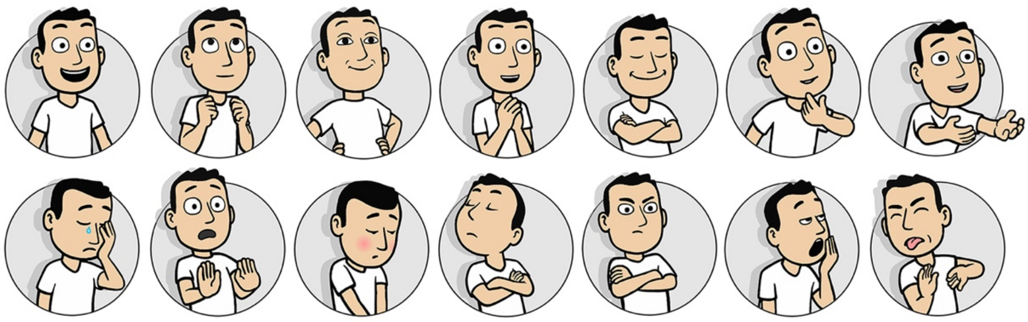


Figure 12 PrEmo (Desmet, 2003)

Summary

In comparison to other methods, the advantage of pictorial self-reports is the intuitive application i.e. the lack of dependence on language. This prevents misunderstandings of definitions of emotional states or feelings and allows for cross-cultural use. It can be argued that the visuals might be subjective and interpreted differently (Isomursu et al., 2007).

Verbal Self-report

Geneva Emotions Wheel

Bänziger, Tran and Scherer developed the Geneva Emotions Wheel in 2005. It shows a set of emotions represented on a circular graphic (Figure 13). The participant is asked to note any emotion experienced and its intensity, indicated by the different sizes of circles (Bänziger, Tran and Scherer, 2005;

Caicedo and Van Beuzekom, 2006). The Geneva Emotions Wheel is based on Wundt's three-dimensional emotion theory (1905).

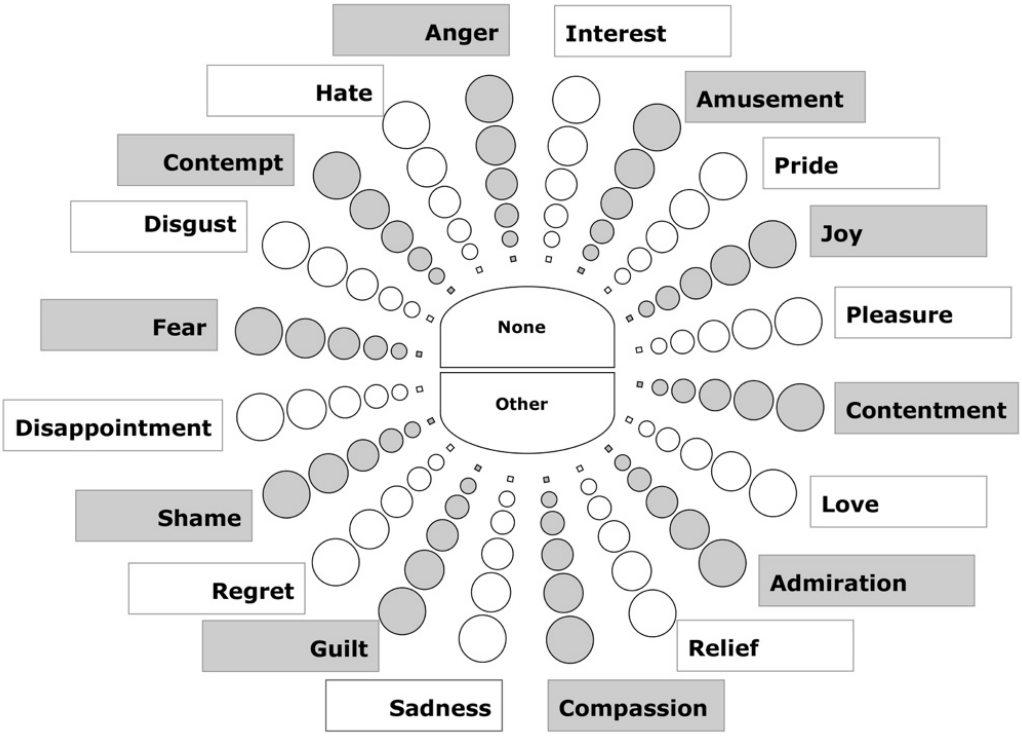


Figure 13 Geneva-Emotions-Wheel (Bänziger, Tran and Scherer, 2005)

Summary

Verbal self-report techniques are strongly influenced by the participant's subjectivity and the researcher performing the study (Fox, 2008). Other factors include the inherent inability of language to convey a precise emotion (Caicedo and Van Beuzekom, 2006) and ambiguity introduced through translation between languages and cultures (Desmet, 2003). Since results are communicated verbally, they may be affected by the lack of anonymity (Nancarrow and Brace, 2000). Contrasting pictorial methods, verbal methods are often more time-consuming, which can influence results (Fox, 2008).

Recall Self-Report

Recall self-reports include recording a video of the participant, which is to be presented to the participant after the study. He/she is asked to recall emotions and feelings experienced during the study (Bentley, Johnston and von Baggo, 2005). The method is often combined with physiological measures. While advantageous in that it does not require interruption of the participant during the study, the accuracy of recollections is questionable (Bentley, Johnston and von Baggo, 2005).

Summary

Self-assessment-tools have the advantage of measuring the participant's subjective experience and therefore, when applied correctly, provide the opportunity to gain important insights about the experienced emotion. In contrast to physiological, behavioural and neural measures, the result will not be affected by applied technology. A key disadvantage of the tools is that the assessment cannot take place during the study without interruption. The methods require a relatively lengthy period of time to perform, potentially resulting in unreliable data (Isomursu et al., 2007). Finally, some people face difficulty expressing their emotions (Fox, 2008) and results can be influenced by the general emotional state (Desmet, 2003).

2.3.3 Behavioural Measures

There are numerous ways to express emotions, several of which have been monitored in past research. In the following section the most popular behavioural measurement techniques are reviewed.

Emotions in Speech

Emotion recognition in speech has recently been much investigated (Kim et al., 2007). As communication is an important part of human-computer interaction, the investigation of emotion in speech for the improvement of software has gained popularity in research (Shah, 2010; Wöllmer et al., 2010). Several methods for the investigation of emotion in speech have been explored (Murray and Arnott, 1993; Pittam and Scherer, 1993). Vocal expression analysis extracts information such as pitch and volume from speech. Other approaches are investigating word information, but no single method or algorithm has been widely accepted so far (Kim et al., 2007). While the method has been applied in call centres for years, more recently other fields (e.g. heath care, automotive industry) have explored the application and benefit of using speech to investigate emotion (Tischler et al., 2007).

Facial Expression

Ekman and Darwin (Chapter 2.1) investigated the representation of emotional states through facial expressions (Bartlett et al., 2003). In further research Ekman developed the Facial Action Coding System (FACS), the most comprehensive and widely used taxonomy for the coding of facial behaviour (McDuff et al., 2016). The FACS codes (action units) each encode a specific facial movement, and certain combinations represent a given emotional expression. While in the past facial expressions were coded by hand through human coders, algorithms are now used in Facial-Expression Analysis software tools to provide a fully automated, real-time result (Calvo and D'Mello, 2010). Facial-Expression Analysis is a completely non-contact method for the investigation of emotional states (Kapoor, Qi and Picard, 2003) and has achieved up to 90% correlation with self-assessed emotions in previous research (Zeng et al., 2009). An in-depth introduction to Facial-Expression Analysis can be found in Chapter 2.4 Facial-Expression Analysis – State of the Art.

Head Movement Analysis

In the past head movement analysis has been used primarily for fatigue detection in the transportation and automotive sector. One symptom of drowsiness and fatigue is a tilted head orientation, often lowering of the head, which is measured through a three-dimensional model. In the future, this method could be used to prevent accidents caused by human error (Brandt, Stemmer and Rakotonirainy, 2004; Ji and Yang, 2002; Rau, 2005). Head movement analysis as a tool for emotion detection has recently gained popularity due to the significant role of head movement in emotional communication (Davidson, 1994; Dahl and Friberg, 2007). Head movement analysis is often combined with Facial-Expression Analysis through vision based computational models (El Kaliouby and Robinson, 2005).

Posture and Movement Analysis

Contrasting Facial-Expression Analysis, posture and movement analysis is a more recent development. Nevertheless, a number of posture and body action coding systems have been created in nonverbal behaviour research. Although these methods have been applied in emotion research, a framework to support the understanding of body movements has not been developed so far (Harrigan, 2005). Various methods have been developed in an attempt to create a functional and reliable method for the detection of emotions in posture and body movement, such as the application of an accelerometer in combination with analysis methods (Coombes, Cauraugh and Janelle, 2007), trained human observers (James, 1932; Wolff, 2015), motion tracking systems (Pollick et al., 2001) or video based automatic tracking techniques.

Summary

Compared to physiological tools, behavioural measurement techniques have some significant advantages for the research of human emotion. They often provide insights into multiple channels of emotions, while physiological measurements are often limited to arousal and valence. Expressive behaviour is measured through non-contact sensors, which allow measurement with low intrusiveness. Cameras and microphones can be hidden or placed out of the participant's visual field to minimise intrusiveness. A major disadvantage of behavioural measurement techniques is the fact that the researcher often requires special training for the usage of such tools (Busso et al., 2004).

2.3.4 Physiological Measurement

Physiological signals can be neural, electrical and vascular and can be measured using biosensors. Measured signals can determine the intensities of valence and arousal (Calvo and D'Mello, 2010). In the following section a selection of physiological measurement techniques is introduced.

Heart Rate

A participant's heart rate can be measured using an Electrocardiogram (ECG). Changes in beats per minute can be correlated to arousal level triggered by stress, for example. Therefore, heart rate is a suitable physiological sign to indicate the intensity of an emotional change (Graham, 1992; Lang et al., 1993).

Respiration Rate

A variety of sensors (e.g. Respiratory Monitor) can be applied to measure a participant's respiration rate. The physiological measurement is defined as the frequency of inhale and exhale cycles per minute. Respiratory activity occurs through contraction and relaxation of respiratory muscles. A participant's respiration rate is increased through sympathetic nervous system activity and decreased through parasympathetic nervous system activity. Respiration rate is therefore a reliable indicator for emotional states (Healey and Picard, 2005; Kim, Bang and Kim, 2004; Kreibig et al., 2007).

Galvanic Skin Response (GSR)

Galvanic skin response is the measurement of changes in the electrical conductivity of the skin. Sweat level is a physiological signal that indicates sympathetic nervous system activity. With an increasing stress level, sympathetic nervous system activity increases, resulting in increased sweat gland activity. The presence of saline sweat causes the conductivity of a person's skin to increase. GSR is usually measured on the wrist or fingertip. It has been correlated to arousal and activation and is often used as a supplementary tool to investigate the intensity of emotional states (Revelle and Loftus, 1992; Yaremko, Blair and Leckart, 1970).

Body/Skin temperature

Body and skin temperatures are influenced by changes in blood flow. Blood flow is directly related to the sympathetic nervous system activity and can therefore be an indicator of emotional states. Body or skin temperatures can be measured in different ways, e.g. a thermometer placed on the participant's skin or infrared thermography. Body and skin temperatures are often correlated with emotional changes, it has for instance been documented that an increased forehead temperature can imply frustration (Puri et al., 2005).

Summary

In research, a set of physiological measurements is often combined to gain more reliable, multidimensional results. A number of existing measurement tools and commercially available sensors combine different physiological measurement techniques (e.g. Empatica E4). Frequently combined measurements include heart rate and GSR. High correlations have been achieved through combination with self-report tools (Meehan et al., 2000; Meehan et al., 2001; Riva, Wiederhold and Molinari, 1998). Compared to self-report, physiological measurements are known to be more objective, as the participant cannot consciously control them. As continuous measurements they can record emotional states over time. A limitation of several physiological measurement tools is their highly intrusive application. This can not only decrease the participant's comfort, but also have significant impact on the measurement result. When contact is required for measurement, e.g. GSR, there is a risk of losing contact and jeopardising the measurement results. Additionally, as physiological measures differ between individuals, baseline corrections are often required to allow for comparison between participants. Noise and data-transfer problems can occur (Ji, Zhu and Lan, 2004; Matthews et al., 2006; Riva, Davide and Ijsselsteijn, 2003).

2.3.5 Neural Measurements

Multiple researchers (Bard, 1928; Cannon, 1931) suggest neural technologies for the measurement of emotional states, a modern approach compared to self-reports and physiological measurement techniques (Mauss and Robinson, 2009). Physiological correlates of emotions are, according to research (Panksepp, 2007), more likely to be found in the human brain than in physiological responses. In the following, a selection of neural measures is introduced.

Electroencephalography (EEG)

EEG is used to measure changes in the brain activity and widely applied to customer research for instance to investigate the customer's motivation. EEG can be applied to measure increased activation of the right/left frontal lobe indicating positive/negative valence respectively (Amodio, Zinner and Harmon-Jones, 2007; Davidson, 1992).

Positron-Emission Tomography (PET) and fMRI (functional magnetic resonance imaging)

PET scans and fMRI can be used as an indication of the blood flow to a particular region of the brain (Aguirre et al., 2002; Detre and Wang, 2002). For both measurement techniques the underlying assumption is that greater blood flow to a certain region (e.g. the cingulate cortex, the hypothalamus) reflects a greater engagement (Damasio, 2003). Neuroimaging studies, such as fMRI and PET have the advantage of being able to locate activation in more specific brain regions than EEG and have therefore been suggested as more suitable measurement techniques for human emotion (Panksepp, 1998). Nevertheless, it has been claimed that complex emotional states are likely to affect brain circuits instead of isolated brain regions (Storbeck, Robinson and McCourt, 2006).

Summary

While the neural correlates of emotions have been less robust than correlates achieved through other measurement techniques (Murphy, Nimmo-Smith and Lawrence, 2003) some progress was made in understanding how neural correlates relate to certain emotions (e.g. sadness, fear, disgust). Nevertheless, strong replicable results have yet to be achieved (Mauss and Robinson, 2009). Moreover, neural measurements are highly intrusive and can only be applied in laboratory settings.

Conclusion

For the investigation of human emotion and behaviour in a natural environment, a measurement technique which offers a non-intrusive and ideally non-contact application is of high importance. High intrusiveness can have a major impact both on the participant's expressiveness of emotion and the actual emotional experience and should therefore be avoided (Busso et al., 2004). While different measurement tools are often combined in research in order to achieve a more reliable result (Caicedo and Van Beuzekom, 2006; Höök, Isbister and Laaksolahti, 2006; Nass et al., 2005) the amount of real-time data collected should not be underestimated and must be controlled by the researcher to ensure a continuous data stream (Lima et al., 2012).

2.4 Facial-Expression Analysis – State of the Art

This research focuses on the application of Facial-Expression Analysis (FEA) for the investigation of emotional states. In the following, an explanation of FEA is given.

The field of automatic detection of facial expressions involves behavioural science, machine learning and computer vision. In the past decade, significant advances have been made (Goeleven et al., 2008; Ming-Zher, McDuff and Picard, 2011; Calvo and D'Mello, 2010). Based on these developments, commercial systems (e.g. Affectiva Affdex, Emotient Facet) were created and validated (Malmir et al., 2013; Mota and Picard, 2003; Chen et al., 2014), many of which can now be purchased on the commercial market.

FEA or Facial Emotion Recognition can be conducted using physical sensors (e.g. EEG) or facial images. This research focuses on FEA through facial images, as visual expressions are one of the main information channels in interpersonal communication (Ko, 2018). A major advantage of FEA through facial images is a non-contact measurement with low intrusiveness, minimising the impact of the detection equipment on the results. For the collection of facial images a standard video camera can be used.

Conventional FEA approaches follow three steps for the recognition of facial expressions (Figure 15):

1. Face and facial component detection:
   A facial image and its landmarks (e.g. corners of the eyebrows or tip of the nose) are detected and mapped from an input image through computer vision algorithms.
2. Feature extraction:
   Spatial and temporal features are extracted from the facial components.
3. Expression classification:
   Machine learning algorithms, which are trained facial expression classifiers (e.g. support vector machines), produce a recognition result based on pixels analysed in the extracted features.

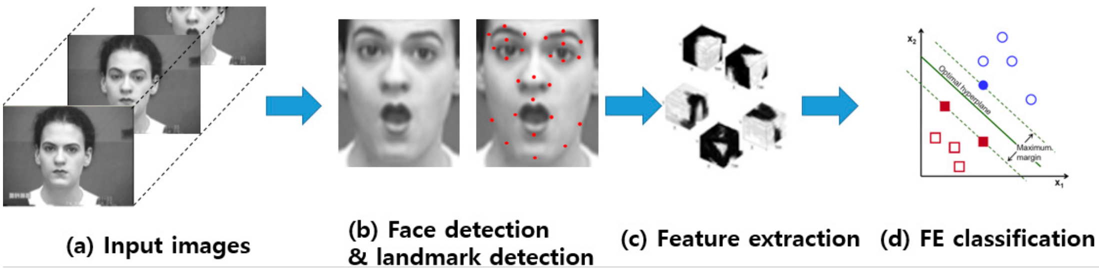


Figure 14 Procedure used in conventional FEA approaches: From input images (a), face region and facial landmarks are detected (b), spatial and temporal features are extracted from the face components and landmarks (c), and the facial expression is determined base

The feature detection and landmark detection maps facial landmarks (e.g. eye brow corners) and feature groups (e.g. the entire mouth) on the participants face and creates a simplified face model (iMotions, 2013). Information on features, landmarks and their movements (via changing distance between features) is then fed into the classification algorithm which is based on the Facial Action Coding System (FACS) (Ko, 2018; Lucey, et al., 2010). The FACS is used to classify facial expressions and/or action units (AU). Each AU corresponds to a face muscle (group) and has a number

(AU12=lip corner pull, AU6=cheek raise). Each facial expression can be broken down into its AUs (Figure 15).

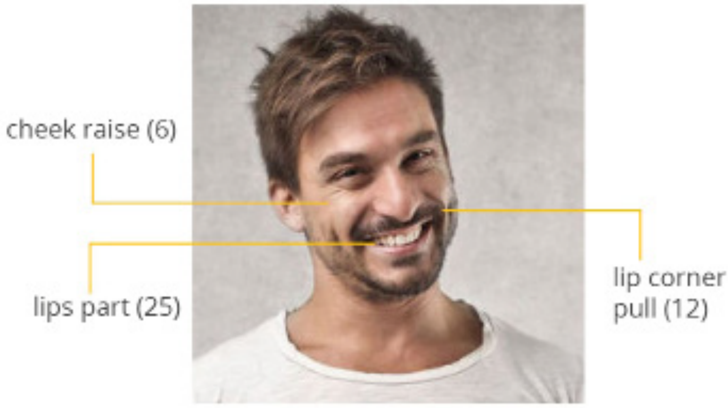


Figure 15 Facial Expression Joy with corresponding action units (iMotions, 2013)

The combinations of these facial expressions and/or action units are then mapped to emotions. For mapping emotions, the algorithms are trained on different data sets (for instance The Extended Cohn-Kanade Dataset) which are ideally created from thousands of photographs and videos taken in real settings, with variations in age, gender, race, and facial hair as well as head pose, and lighting (iMotions, 2013).

For each video frame the FEA software then provides “evidence scores” (Figure 17) (e.g. for Emotionet Facet ranging from -4 to 4, for Affectiva Affdex ranging from 0 to 100). These are numerical values which correspond to the probability of the presence of each emotion in the facial image. A threshold value is then manually determined and set by the user to distinguish between the presence or absence of an emotion, displayed in Figure 16 (iMotions, 2013).

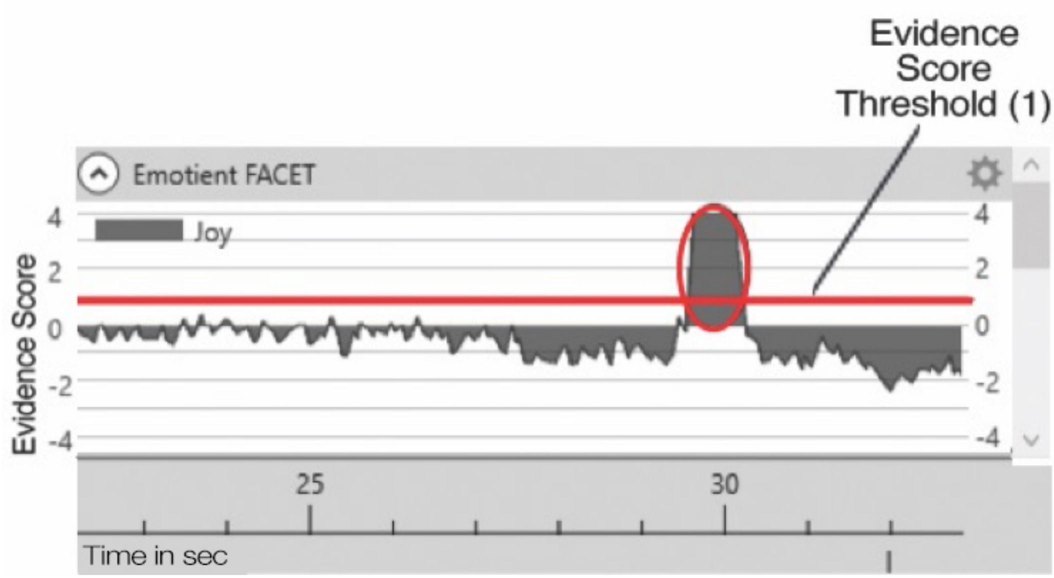


Figure 16 FACET interface with indication of joy evidence score above threshold

3 Emotions in an Automotive Context

Human emotion has played an important role in automotive design for many years. Investigations into the topic have often focused on product appearance and visual appeal. To create a positive emotional product experience, interior and exterior design is utilised to support certain brand images or create a specific emotional automotive experience (Pope, 2010). Human-like attributes have been integrated into automobile designs (Windhager et al., 2008), e.g. the BMW Mini with its “happy-face grill” and “eye-like round headlights” (Elliott, 2009, para. 15). Widely-used expressions, such as ‘the thrill of driving’ and ‘road rage’, point to the connection between human emotional values and the automotive environment. Furthermore, the automotive experience is closely connected to human senses; ‘the smell of the seat’s leather’, ‘hearing the sound of the engine’, ‘feeling the vibration’ imply a sensual connection between humans and their automobiles (Sheller, 2004).

While the aforementioned aspects may have a direct impact on the product experience and purchase choice, research about emotion related to the actual driving task and usage of the automobile has only recently been a highly-investigated topic (Dant, 2004; Michael, 2001; Miller, 2001; Motavalli, 2014; Sheller, 2004; Thrift, 2004). In this chapter, the importance of emotion in automotive driving is discussed by providing an overview of which emotional states may have an impact in the automotive environment and what their possible consequences are. Furthermore, a literature review of approaches for the measurement of emotional states during driving was conducted. Different measurement techniques and the investigated states, research approaches, research environments and their limitations are reviewed.

3.1 The Role of Emotional States in Automobile Driving

3.1.1 Introduction

In recent years, the automotive environment has been called emotional, multi-layered and complex (Jeon, 2015b; Motavalli, 2014; Sheller, 2004). The complexity of the influences of emotions and affective states on the driving task, perception, comprehension, projection and decision making has been visualised in a driving behaviour research model by Jeon (Figure 14).

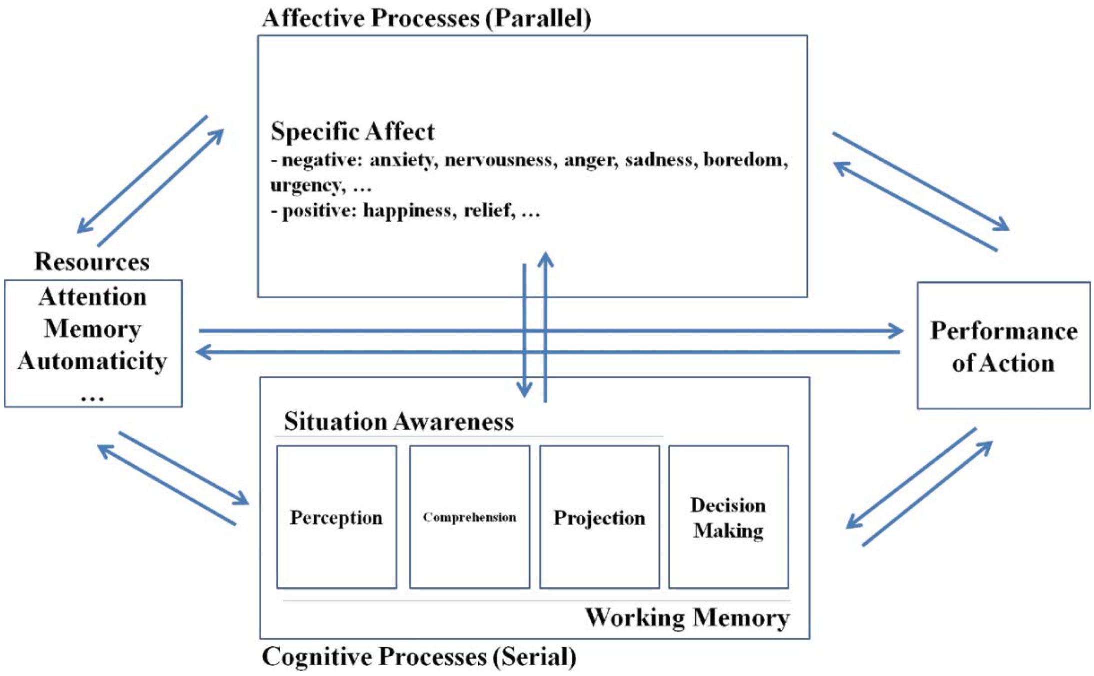


Figure 17 Proposed affect-integrated driving behaviour research model (Jeon, 2015b)

Affective processes play a major role in automobile driving; the model links affective processes, cognitive processes, resources and performance and divides these into subcategories of high significance in the automotive environment. The impact of affective processes during driving has been widely researched, for instance to increase driving performance, decrease risk and prevent human error (Dement, 1997; Jones and Jonsson, 2007; Li and Ji, 2005; Lyznicki et al., 1998; Wells-Parker et al., 2002), and more recently to address future automotive challenges (Healey, 2000; Jeon, 2015b; Jeon, Walker and Gable, 2015; Lisetti and Nasoz, 2005).

To create an overview of emotional states that may influence automobile driving, a systematic literature review was conducted. Articles, publications and papers from the main sources IEEE Explore, Brunel Library, PubMed and Google Scholar were reviewed. For all sources, a set of simple search strings was used: emotion/feelings/emotional/affective states *AND automobile/vehicle/automotive/driving AND influence/impact/danger/risk.* The primary selection criterion for the choice of material to be reviewed was an evaluation of the abstract towards the relevance of the material for this research. In a second review of all sources (82 sources), more specific secondary inclusion and exclusion criteria were applied.

Criteria for inclusion of the identified source were:

- Provides information about the impact of the introduced state on the driver
- Impact on driving is of value for this research
- Information has been validated

Criteria for exclusion of the identified source were:

- Provides no new or additional information

The information from all remaining sources (18 sources) was structured following similar approaches; states closely connected and having similar impacts have been paired (Grimm et al., 2007; Jeon, 2015b; Li and Ji, 2005).

3.1.2 Summary of the Most Significant Emotional States and Their Impact on Automobile Driving

A large number of emotional states potentially influencing automobile driving have been identified. The impact of and approaches for the prevention of potential negative effects are discussed in Table 2.

Emotional/ Affective State	Potential Impact on Automobile Driving	Source
Aggressiveness and anger	Disrupt attention; road rage; increased risk of accident	Jeon, 2015b; Jones and Jonsson, 2007; Li and Ji, 2005; Wells-Parker et al., 2002
Fatigue, boredom and drowsiness	Low levels of activation; influence on concentration, alertness; decreased reaction time; increased risk of accident	Dement, 1997; Jeon, 2015b; Lyznicki et al., 1998
Stress	Dangerous driving behaviour; distraction; aggressive driving	Matthews et al., 1998; Rakauskas, Gugerty and Ward, 2004
Confusion	Influence on self-control; can lead to traffic violations; increases reaction time	Ball and Rebok, 1994
Anxiety and nervousness	Narrowed attentional focus; difficulty of focusing attention; increased attention to threatening stimuli	Jeon, 2015b; Li and Ji, 2005
Frustration and sadness	Decreased awareness; can lead to aggressive driving; decreases level of attention	Dula and Geller, 2003; Jeon, 2015b; Lee, 2010
Happiness	Medium/low level can improve, high level can decrease driving performance	Isen, 2001; Jeon, Walker and Yim, 2014; Storbeck and Clore, 2005

Table 2 Potential emotional states and their impacts during automobile driving

Aggressiveness and anger can cause road rage and accidents (Wells-Parker et al., 2002). Even low levels of anger disrupt attention and higher levels of anger can lead to aggressive driving behaviour. Approaches towards less aggressive driving and the avoidance of anger have been taken in research, for example using voice response systems, relaxation techniques or improved user assistance (Jones and Jonsson, 2007; Li and Ji, 2005).

Fatigue, boredom and drowsiness can cause low levels of activation and impact the ability to drive safely (Jeon, 2015b). Fatigue and boredom influence concentration and alertness, as well as perception, and the capacity for quick, accurate judgements. Critically, fatigue decreases reaction time, a serious hazard (Lyznicki et al., 1998). Related to fatigue is drowsiness; driver drowsiness is the cause of serious accidents (Dement, 1997). To prevent accidents caused by drowsiness or fatigue, research addresses ways to improve driver alertness and highway safety (Moore-Ede, Campbell and

Baker, 1988). A concept designed for their prevention is a supportive function build into the automobile (Jones and Jonsson, 2005; Lyznicki et al., 1998). The system engages when fatigue or drowsiness are detected, and acts as a co-driver, completing tasks such as preventing the driver from falling asleep.

Stress has a direct impact on driving performance (Matthews et al., 1998) and is a common problem in automobiles. Stress is often caused by a high mental or physical workload; factors such as information overload, multi-tasking, high traffic density, and miscommunication can trigger an increased stress level. This can lead to dangerous driving behaviour, aggressive driving and distraction due to attention sharing (Matthews et al., 1998; Rakauskas, Gugerty and Ward, 2004). Driving performance has been shown to decrease with increasing workload (Rakauskas, Gugerty and Ward, 2004). Numerous approaches have been taken to decrease driver stress. For instance, Uchiyama et al. developed a voice information system, which adapts to driver stress (Hoch et al., 2005; Uchiyama et al., 2002), only allowing voice messages when the current workload allows for sufficient information processing. Thus, the information flow is limited by the driver's workload, and the driver is only confronted with information if the stress level is sufficiently low and the situation is considered appropriate. To design the system a workload estimation technique was developed, based on car diagnostic data, specifically use of the acceleration pedal. Although the research reveals some usable insights, many issues remain unsolved and further investigation is required (Hoch at al., 2005; Uchiyama et al., 2002).

Confusion can influence self-control and lead to traffic violations and accidents. Potential causes include poorly designed software applications (e.g. the navigation system), providing wrong information and poor road infrastructure or route diversions. Comparable to stress, confusion can negatively influence the driver's performance and decrease attention, impair sensible decision-making and increase reaction time. Confusion is particularly problematic in older drivers (Ball and Rebok, 1994). Approaches have been taken towards improving human-automobile communication to prevent confusion, particularly aimed at supporting elderly drivers. When confusion or irritation is detected the automobile supports the driver to alleviate symptoms and assist with complicated tasks (Jonsson et al., 2005).

Anxiety and nervousness are other emotional states which can influence decision-making and strategic planning. Common effects of anxiety include increased sensitivity to potential threats, and a narrowed attentional focus, potentially leading to overlooking critical tasks (Jeon, 2015b). Nervousness is related to anxiety and has similar effects on driving behaviour. Nervousness can negatively influence concentration and is one of the most dangerous states during automobile driving. Li and Ji therefore conducted research aiming to detect and prevent nervousness (Li and Ji, 2005).

Frustration can lead to decreased awareness (Lee, 2010) and trigger more dangerous emotional states such as aggressiveness (Jeon, 2015b). Sadness has a strong negative influence on driving performance. Sadness is associated with low arousal which can decrease the level of attention significantly (Dula and Geller, 2003). This can have a negative impact on reaction time. So far, no approaches directly addressing frustration and sadness in the driving environment have been taken (Jeon, 2015b).

Happiness has been reported to produce fewer accidents (James, 2000). Positive emotions in general were stated to have a diverse range of impacts on numerous cognitive aspects (Isen, 2001; Storbeck and Clore, 2005). While a very high level of happiness might have a negative impact on the driver's performance, a moderate level could lead to ideal performance (Yerkes and Dodson, 1908). The influence of positive emotional states on the driving experience and performance needs further validation (Jeon, Walker and Yim, 2014).

The aforementioned influences emotional and affective states can have on automobile driving make the importance of further investigation of emotion during driving and the measurement of multiple emotional states apparent.

3.2 Emotion Measurement in Automobile Research

3.2.1 Introduction

This section reviews different techniques and approaches for the measurement of emotional states during driving. An overview of a selection of research studies is provided, investigating the measurement method applied, the emotional and affective states investigated, the research approach, the study environment and research limitations. The aim of this section is a better understanding of emotion measurement in the automotive environment, as well as awareness of potential limitations through the choice of technology or methodology. A literature review of articles, publications and papers from the main sources IEEE Explore, Brunel Library, PubMed and Google Scholar was conducted. A set of simple search strings was used: emotion/feelings/emotional/affective states *AND automobile/vehicle/simulator/driving AND measurement/detection.* The primary selection criterion for the choice of material to be reviewed was an evaluation of the abstract towards the relevance of the material for this research. In a second review of all sources (72 sources), more specific secondary inclusion and exclusion criteria were applied.

Criteria for inclusion of the identified source were:

- Research not older than 20 years
- Study in an automotive environment (automobile or driving simulator)
- Use of at least one of the above introduced measurement techniques
- Investigation of at least one of the above mentioned emotional/affective states

Criteria for exclusion of the identified source were:

- Provides no new or additional information

3.2.2 Summary of Automotive Research Studies

A total of 24 publications have been identified as being of high value for this thesis (Table 3).

Measurement Method	Emotional/ Affective States Measured	Research Focus	Study Environment	Limitations	Source
GSR, heart activity, respiration, ECG	Neutral, anger, hate, grief, love, joy, reverence	Development and test of a wearable system for emotion recognition	Simulator	Limited applicability of sensors in real setting	Healey, 2000; Healey and Picard, 2005
	Stress-level		On-Road		
GSR, heart rate, temperature	Panic/fear, frustration/anger, amusement	Affective intelligent car interfaces for driving safety	Simulator	Not real-time, controlled environment	Lisetti and Nasoz, 2005
Speech analysis	Boredom, sadness, anger, happiness, surprise, neutral	Richer interaction between automobile and driver	Simulator	Driver reluctant to communicate with vehicle	Jones and Jonsson, 2005;2007; 2008
Self-report	Anger, fear (2011)	Detection of the driver's state; relationship between affect, cognition, driving behaviours	Simulator	Limited emotions (2011), main focus on self-report	Jeon, Yim and Walker, 2011; Jeon, 2015a
	Anger, fear, happiness, sadness, and neutral (2015)				
Speech analysis	Valence, dominance, activation	Detection of the driver's state, possibilities to respond	On-Road	Detection difficulties due to car noise, not real-time	Grimm et al., 2007
Speech analysis and FEA	Joy, anger, neutral	Detection of driver's state, improving infotainment interfaces	Stationary car	No real driving condition	Hoch et al., 2005
ECG, verbal self-reports, observed facial expression	Anger, anxiety, happiness	Detection, frequencies and occurrence of emotional states	On-Road	Technique unsuitable for setting, observed only by one coder	Mesken et al., 2007
FEA, speech analysis, GSR, heart rate	Joy	Detection and occurrence of joy	On-Road (separated proving ground)	Limited detection due to driver alone, problems with sensors	Tischler et al., 2007
FEA	Stress-detection (anger, disgust)	Detection of the driver's stress level	Simulator and on-road	Limited emotional states investigated	Gao, Yüce and Thiran, 2014
Observed facial expressions, self-report, GSR, pedal movement	Frustration	Detection driver's frustration level	On-road	Main focus on self-report	Malta et al., 2011
Self-report	Anger	Context, causes, characteristics, frequencies of anger	On-road	Main focus on self-report	Parkinson, 2001

Self-report	Anger	Causes and frequencies of anger	On-road	Main focus on self-report	Underwood et al., 1999
Self-report	Joy, affection, surprise, anger, sadness, fear	Detection, causes, frequencies of emotions	On-road	Main focus on self-report	Levelt, 2003
EEG, GSR, ECG, respiration rate, self-report	Tiredness, stress	Emotion detection for driver safety	On-road	Highly intrusive sensor application	Rebolledo-Mendez et al., 2014
FEA, EEG	6 basic emotions and neutral, contempt, confusion, frustration	Driver performance, emotions and use of a use of assistance systems	On-road (parking lot)	Difficulties of sensor application in a real setting, only tested in a parking lot	Izquierdo-Reyes et al., 2018
ECG, EMG, GSR, EEG	distraction	Effects of driving condition on driver	On-road	Intrusive measurement	Dehzangi and Williams, 2015
Saccadic intrusion (type of eye gaze movement)	Cognitive Load	Relation on cognitive load and road hazards	Driving simulator	Test only in the simulator environment, only one state	Biswas and Prabhakar, 2018
ECG, self-assessment	Joy, anger, neutral	Accident avoidance	Lab-lased	Not real-time, lab environment, difficulties with sensors	Minhad, Ali and Reaz, 2017
EEG	Drowsiness, drunkenness, emotional state disorders, distraction	Accident avoidance	On-road	High intrusiveness	Reyes-Muñoz et al., 2016
FEA through thermal camera sensors	Aggressiveness, relaxation	Accident avoidance	Simulator	Simulator environment, limited emotional states	Lee et al., 2018

Table 3 Review of literature investigating measurement techniques for emotional/affective states

Healey developed systems and algorithms for investigating affective patterns in physiological measurements. Research was conducted in different environments, including both simulated and real-driving environments. Eight emotions were investigated by applying physiological measurement tools (electromyogram, electrocardiogram, skin conductance, respiration and blood volume pressure sensors). Data was analysed using a combination of two different algorithms, the Fisher Projection and the Sequential Forward Floating Selection. A large dataset was created, and in the controlled environment 81% of measurements successfully identified the correct member of the eight emotions. Next, a wearable system was developed and tested in an uncontrolled automotive setting. Data collection issues arose due to the real-driving environment and the limited applicability of the sensors in an uncontrolled setting. Nevertheless, success was achieved in some emotion channels; the system correctly identified 96% of instances of stress in the uncontrolled driving setting (Healey, 2000). In 2005 Healey and Picard conducted further driving research, implementing their previous measurement technique but differentiating between three different stress levels. Through the new approach, 97.4% accuracy was achieved for stress measurement at 5-minute intervals. The combination of the measurements of Galvanic Skin Response and heart rate was proven to deliver the best results in the real-driving setting. Healey and Picard suggested that the stress detection system could be combined with an algorithm capable of managing software applications in response to the driver's stress-level, for example through stress coping techniques such as selection of appropriate music (Healey and Picard, 2005).

Lisetti and Nasoz explored the application of physiological measurement tools (GSR, heart rate, temperature) to investigate three emotional states to improve driver safety though affective intelligent car interfaces. The simulator study aimed to improve human-computer interaction in future cars. Different scenarios including a variety of traffic events were applied to trigger the measured emotion events. Three pattern-recognition algorithms (k-Nearest Neighbor, Discriminant Function Analyses and Marquardt Backpropagation) were used for the data analysis and recognition rates of up to 91.9% were reached. Success rates were relatively high compared to similar approaches, and the study was conducted in a controlled environment with data analysis completed after the study, therefore no data was processed in real-time (Lisetti and Nasoz, 2005).

Jones and Jonsson investigated emotional states through three different approaches. All three studies investigated a set of emotional states though speech analysis in driving simulators, with the aim to improve interactive speech based systems to create a richer verbal interaction between automobile and driver. The automatic acoustic emotion recognition system used multiple acoustic features (e.g. volume and pitch) to detect changes representative for certain emotional states (e.g. boredom, frustration, happiness). Changes in emotional states over time were presented through a numerical indicator of the degree of emotional cues present in speech. The evaluation of a human listener was compared to that of the system, with up to 70% accuracy for 7 emotion categories. Issues arose due to the drivers' reluctance to communicate with the automobile system (Jones and Jonsson, 2005; Jones and Jonsson, 2007; Jones and Jonsson, 2008).

Jeon, Yim and Walker (2011) and Jeon (2015a) conducted simulator studies exploring multiple emotional states to investigate the relationship between affect, cognition and driving behaviours. The studies utilised self-report techniques (using a seven-point Likert-type scale, NASA TXL) for the measurement of two emotional states (2011) and later four emotional (2015) states out of a total of nine states previously identified as important in a driving context (Jeon, Yim and Walker, 2011). In both studies affect induction techniques were applied, and integral and incidental affect were considered to recreate realistic situations. Jeon et al. describe the limitations of their method and the need to include more measurement techniques in future work (Jeon, Yim and Walker, 2011; Jeon, 2015).

Grimm et al. investigated the measurement of emotions through speech analysis to detect and accurately respond to the driver's emotion in an on-road study aimed at combining the engineering and psychological aspects of human-computer interaction. Speech signals, superimposed on automobile background noise, were separated and mapped to emotional states in a three-dimensional emotion space covering positive and negative valence, weak and strong dominance, and high and low activation. Grimm et al. relied on the three-dimensional emotion model to focus on three emotions previously identified as states of interest in an automotive environment. Kernel-based Support Vector Regression was used as a classifier with the output consisting of one real-valued estimate for each emotion primitive. Two different approaches for the algorithm training in a noisy environment were compared and correlations of up to 82% were reached between measurement and self-assessment. Limitations were a non-real-time measurement and complications due to noise on certain road types (Grimm et al., 2007).

Hoch et al. researched emotion in the automotive environment using an acoustic and a visual monomodal recognizer and combining the individual results on an abstract decision level. Facial expressions were located through the Viola & Jones algorithm with feature selection performed though the AdaBoost algorithm. Acoustic parameters (e.g. power, duration) were extracted in the acoustic model and the Snack Sound Toolkit was used for the processing of those which was based on the statistics of commonly known low level features. The results collected through the bimodal approach were then combined on an abstract decision level. Results were fused and a 90.7% recognition rate was reached, showing that better results can be reached when different channels are combined. Limitations arose due to the experiment being conducted in a stationary car, therefore not under real driving conditions (Hoch et al., 2005).

Mesken et al. investigated three emotions in their on-road driving study using a combination of a physiological measurement tool (heart rate), self-reports and observed behaviour data. The frequency of emotions was investigated and occurrence of the emotional events was related to traffic events to gain deeper insights into the causes of driver emotions. In an observational analysis, collected video data was reviewed, and participants' facial expressions manually analysed. Participants reported an average of 5.1 emotions during a 50-minute drive. Heart rate measurement data was analysed by using the profiled function of the program CARSPAN. Results were analysed as measures of workload but not directly related to the reported emotional states. Causes were successfully assigned to 60.1% of the reported emotions. Technical issues arose with the physiological measurement, potentially due to measurement difficulties associated with use in the natural environment and the measurement technique being unsuitable for the automotive setting (Busso et al., 2004; Eyben et al., 2010). Mesken et al. reported the data being coded by a single person as a limitation (Mesken et al., 2007).

Tischler et al. conducted an on-road driving study to quantify driving pleasure between different car models and road types. FEA, speech analysis, GSR and heart rate were combined for the investigation of joy. Speech analysis was conducted investigating parameters such as pitch and intensity. Valence and arousal measures were collected. Results of the speech data reveal increased joy for the newer car model and higher arousal for faster driving. A system localising facial features in order to interpret expressions was developed for the FEA. A previously learned classifier using facial motion information and the Cohn-Kanade Facial Expression Database was utilised. Since joy is commonly attributed to social interaction, joy was infrequently detected due to the driver being alone in the automobile. Detection difficulties with all methods were encountered due to driver movement and changes in the intensity and direction of light. The collected physiological data was not taken into account due to measurement difficulties and a limited amount of training data for emotion classifiers. Tischler et al. suggest modifying available emotion measurement techniques for the application in the automotive environment (Tischler et al., 2007).

Gao, Yüce and Thiran investigated the use of stress detection via FEA as a non-intrusive, real-time tool to improve driving safety. A NIR-camera (near infrared camera) was applied in the study to compensate for illumination effects by ambient lighting conditions. The software modules included image acquisition, face tracking (supervised descent method), feature extraction and emotion detection through model training. The Viola & Jones algorithm was applied for the initialisation. The stress detection through FEA was based on the six basic emotions and two data sets (FACES and Radboud). Good performance was achieved with local descriptor-based feature representation. While only a limited number of emotional states was investigated, the system was successful for 90.5% of simulator tests and 85% of on-road data.

Measurement difficulties occurred due to driver movement and light intensity changes. Gao, Yüce and Thiran recommended further investigation of head motion and emotion measurement in speech (Gao, Yüce and Thiran, 2014).

Malta et al. conducted a study attempting to estimate frustration levels through observed facial expressions, self-assessed frustration measurement, GSR-measures and pedal movement. To enhance the complexity of the driving task, participants were asked to interact with an automatic speech recognition system. Self-assessed frustration measurement of the participants on a frustration scale was correlated with pedal movement and the driver's response measured through GSR and observed facial expressions. A Bayesian network was used to infer the drivers' frustration level given pedal movement data, GSR data and self-assessed measures. The combination of all collected data led to the design of a frustration prediction tool with a true positive detection rate of 80%. Malta et al. suggest expanding the proposed comprehensive model, which takes environment into account, to a wider variety of emotional states. Furthermore, pedal movement data positively contributed to the overall result (Malta et al., 2011).

Parkinson investigated the context, causes, characteristics and frequencies of anger during driving through self-report. The self-report technique applied for this study used questionnaires investigating previous driving experiences of participants. Frequencies of the emotional states supported the hypothesis that anger is more likely to be present during driving than during non-driving. While Parkinson states that the desire of participants to communicate emotion was high (Parkinson, 2001), solely relying on self-report as a measurement technique for emotions has been criticised in other research (Mesken et al., 2007).

Underwood et al. conducted a similar study, investigating causes and frequencies of anger during driving through self-report. In this study drivers were asked to keep diaries reporting anger experienced. The diary approach was combined with questionnaires, showing high anger due to congestion or narrowly-avoided accidents (Underwood et al., 1999). Comparable to the above-mentioned study of Parkinson, relying on self-report as the only measurement tool can be criticised (Mesken et al., 2007).

Levelt (2003) conducted a driving research study investigating multiple emotional states through self-report to inform on frequencies, causes and road safety effects of driver emotions. After applying the diary method for a week, a frequency of one emotion per 23 minutes was noted. Most emotions were triggered by other people, and less frequently by objects. The results of the study show joy more frequently occurring in the driving environment than other emotions.

Rebolledo-Mendez et al. developed a body sensor network for the investigation of two emotional states (tiredness and stress). An on-road study was conducted, aiming to detect human emotion in order to enhance driver safety. Physiological and neural measures (EEG, GSR, ECG, respiration rate) were combined with self-report techniques. Two commercially available sensors (Q sensor, NeuroSky device) were applied for data collection during on-road driving to investigate correlations with self-assessed data. Preliminary models of emotional reactions were built based upon all collected data in two different classification models employing logistic regression and a K-means algorithm. Two driving conditions (highway and city driving) were compared and an architecture for the integration of body sensor networks into vehicle ad hoc networks for accident prevention through driver emotion was proposed. The agreement of measured and self-assessed data was evaluated resulting in substantial to almost perfect agreement (Rebolledo-Mendez et al., 2014). Limitations of the study were the high intrusiveness of the chosen sensors for emotion measurement.

Izquierdo-Reyes et al. applied commercial technologies to introduce an approach for the implementation of FEA to measure the driver's emotional states. The use of an advanced driver assistance system (ADAS) was investigated for the improvement of driver performance. The iMotions FACET module was used to detect the 6 basic emotions through FEA and the Emotiv Epoc sensor was applied for the EEG measurement. A combination of different mathematical models was applied for the development of personalised driving assistance. Results of the study suggest that the ADAS in its current state is not sufficient for the improvement of driver performance. Further results, including FEA and EEG data, are currently being analysed by a team of researchers and will be published in a subsequent research paper. Izquierdo-Reyes et al. propose a new framework for driver assistance based on the driver's emotions (Izquierdo-Reyes et al., 2018).

Dehzangi and Williams investigated multi-model driver monitoring to investigate the impact of road conditions on driver distraction. A monitoring platform exploring the driver's attention level was developed, capturing driving information and driver biometrics (EEG, ECG). In the on-road driving study the same route was followed twice during non-peak and rush hour periods in order to investigate changes in the drivers' attention levels. For the EEG signal a processing procedure was combined with a visual assessment to compare attention levels. Results showed a correlation between road conditions and the power of theta and beta bands in the frontal cortex and suggest that features from brain dynamics could be applied for early detection of driver distraction (Dehzangi and Williams, 2015). Limitations of the study include the intrusiveness of the EEG measurement and a limited number of participant which have contributed to the study.

Biswas and Prabhakar conducted a study aiming to achieve detection of the driver's cognitive load from saccadic intrusion (a type of eye-gaze movement analysed through an eye-tracker). For this purpose, an algorithm was developed using the eye gaze fixation points as input, returning amplitude, duration and velocity of saccadic intrusion. After initial data collection in a laboratory setting, the experiment was conducted in a driving simulator. In the study, Biswas and Prabhakar evaluated, in three different scenarios, whether distraction during completion of a secondary task could be measured. Results confirmed the hypothesis that saccadic intrusion can be associated with the drivers' perception of road hazards. They suggested constant measurement of saccadic intrusion to predict developing hazards and use the data to help the driver take action. While the measurement tool is appropriate for application in the automotive environment due to its low intrusiveness, further research in an on-road setting needs to be conducted to validate results from the simulator study (Biswas and Prabhakar, 2018).

Minhad, Ali and Reaz developed an experimental protocol and computational model to investigate patterns of emotions. The aim of the research was to identify stimuli to evoke emotions, and classify emotions using ECG signals. Signals were filtered and features were extracted to determine meaningful behaviour in the data, and algorithms were selected for classification. A stimuli database was created to collect emotion-evoking triggers, such as sound and audio-video clips. The stimuli were presented to the study participants in a laboratory environment while collecting ECG data. Support vector machine classification results showed a successful classification of the emotions anger and happiness. Use of the developed system to eliminate driving risk factors in rescue teams and commercial vehicles was suggested as an avenue for future investigation (Minhad, Ali and Reaz, 2017). Limitations of the research include the fact that the study was conducted in a laboratory environment and the intrusiveness of the measurement method.

Reyes-Muñoz et al. investigated physiological behaviour states (drowsy, drunk, driving under emotional state disorder and distracted driving) through the integration of body sensor networks and vehicular ad-hoc networks for traffic safety. A middleware architecture was proposed for communication with emergency services, road and street facilities and the car dashboard. An improvement of the driving experience and an extension of security mechanisms for surrounding individuals was aimed for. A real-time attention level detection application was developed as a proof of concept, measuring the driver's degree of attention through EEG signals. Data was collected from participants in an on-road study where people drove in their own cars. Attention and mediation signals were collected in two scenarios, both with and without the completion of a secondary task. Through the integration of the application the drivers' state could be detected (Reyes-Muñoz et al., 2016). Reyes-Muñoz et al. suggest including further emotional and behavioural states in future research. A major limitation of the research is the high intrusiveness of the chosen measurement method.

Lee et al. propose a convolutional neural network-based method using input images of the driver's face for emotion detection. In order to avoid driver contact and intrusiveness, near-infrared light and thermal camera sensors were used. The near-infrared light camera was used to capture eye and mouth movement, the thermal camera was used for the middle-forehead and cheek areas. The two outputs were then fused to enhance the classification accuracy for aggressive and smooth driving situations. The experiment was performed in a driving simulator, in an autonomous setting simulating two different driving situations (smooth and aggressive driving). Using their own database, Lee et al. reached a high classification accuracy for emotion detection (aggressive, relaxed). While the results of this research indicate better performance than other approaches (Lee et al., 2018), results are limited due to the study being conducted in a simulated driving environment.

In the following the measurement method and investigated states, the research focus, the study environment as well as potential limitations of the literature were systematically compared and discussed.

3.2.2 Measurement Method and Investigated Emotional/Affective States

The emotional states investigated in research studies are often determined by the applied measurement method (Table 4).

Measurement Method	Emotional/ Affective States Measured	Source
GSR, heart activity, respiration, ECG	Neutral, anger, hate, grief, love, joy, reverence	Healey, 2000; Healey and Picard, 2005
	Stress-level	
GSR, heart rate, temperature	Panic/fear, frustration/anger, amusement	Lisetti and Nasoz, 2005
Speech analysis	Boredom, sadness, anger, happiness, surprise, neutral	Jones and Jonsson, 2005;2007; 2008
Self-report	Anger, fear (2011)	Jeon, Yim and Walker, 2011; Jeon, 2015a
	Anger, fear, happiness, sadness, and neutral (2015)	
Speech analysis	Valence, dominance, activation	Grimm et al., 2007
Speech analysis and FEA	Joy, anger, neutral	Hoch et al., 2005
ECG, verbal self-reports, observed facial expression	Anger, anxiety, happiness	Mesken et al., 2007
FEA, speech analysis, GSR, heart rate	Joy	Tischler et al., 2007
FEA	Stress-detection (anger, disgust)	Gao, Yüce and Thiran, 2014
FEA, self-report, GSR, pedal movement	Frustration	Malta et al., 2011
Self-report	Anger	Parkinson, 2001
Self-report	Anger	Underwood et al., 1999
Self-report	Joy, affection, surprise, anger, sadness, fear	Levelt, 2003
EEG, GSR, ECG, respiration rate, self-report	Tiredness, stress	Rebolledo-Mendez et al., 2014
FEA, EEG	6 basic emotions and neutral, contempt, confusion, frustration	Izquierdo-Reyes et al., 2018
ECG, EMG, GSR, EEG	distraction	Dehzangi and Williams, 2015
Saccadic intrusion (type of eye gaze movement)	Cognitive Load	Biswas and Prabhakar, 2018
ECG, self-assessment	Joy, anger, neutral	Minhad, Ali and Reaz, 2017
EEG	Drowsiness, drunkenness, emotional state disorders, distraction	Reyes-Muñoz et al., 2016
FEA through thermal camera sensors	Aggressiveness, relaxation	Lee et al., 2018

Table 4 Measurement methods and investigated emotional states

In past automotive research, most investigations were focused on anger/stress, as well as valence and arousal dimensions or Ekman's six basic emotions (Ekman and Friesen, 1971). Nevertheless, it is necessary for researchers to identify which emotions are of high importance to their research (Jeon, Walker and Yim, 2014; Jeon, 2015b). Jeon, Walker and Yim suggest adjustment of the existing taxonomies to the research context, approach and specific research needs. Many of the selected research studies are limited to one or only a small number of emotional states, in-depth investigations of a set of emotions are currently limited. Many studies combine different measurement methods, and while this is proven to deliver more valuable result, the amount of data should not be underestimated and has to be controlled by the researcher (Lima et al., 2012). Furthermore, multiple of the aforementioned research studies state difficulties with one or more of the selected methods for emotion measurement (Grimm et al., 2007; Healey, 2000; Jones and Jonsson, 2005).

3.2.3 Research Focus

While the selected research studies all share the approach to investigating emotional states, their research focus varies greatly (Table 5).

Research Focus	Source
Development and test of a wearable system for emotion recognition	Healey, 2000; Healey and Picard, 2005
Affective intelligent car interfaces for driving safety	Lisetti and Nasoz, 2005
Richer interaction between automobile and driver	Jones and Jonsson, 2005;2007; 2008
Detection of the driver's state; relationship between affect, cognition, driving behaviours	Jeon, Yim and Walker, 2011; Jeon, 2015a
Detection of the driver's state, possibilities to respond	Grimm et al., 2007
Detection of driver's state, improving infotainment interfaces	Hoch et al., 2005
Detection, frequencies and occurrence of emotional states	Mesken et al., 2007
Detection and occurrence of joy	Tischler et al., 2007
Detection of the driver's stress level	Gao, Yüce and Thiran, 2014
Detection driver's frustration level	Malta et al., 2011
Context, causes, characteristics, frequencies of anger	Parkinson, 2001
Causes and frequencies of anger	Underwood et al., 1999
Detection, causes, frequencies of emotions	Levelt, 2003
Emotion detection for driver safety	Rebolledo-Mendez et al., 2014

Driver performance, emotions and use of a use of assistance systems	Izquierdo-Reyes et al., 2018
Effects of driving condition on driver	Dehzangi and Williams, 2015
Relation on cognitive load and road hazards	Biswas and Prabhakar, 2018
Accident prevention	Minhad, Ali and Reaz, 2017
Accident avoidance	Reyes-Muñoz et al., 2016
Accident avoidance	Lee et al., 2018

Table 5 Research focus

While some of the studies mentioned focus mainly on the investigation and measurement of one or more emotional states, others aim to improve future driving experiences (e.g. richer verbal interaction between automobile and driver) or safety (e.g. affective intelligent car interfaces for driving safety). Despite the differences in approach, all mentioned research studies share a human-centred approach towards automotive design and the application of affective computing, applying systems able to recognise, interpret and process human affect (Picard, 2003). Nevertheless, a lack of research literature regarding the natures, frequencies of occurrence and event triggers in the driving environment becomes evident. In fact, the lack of driving research which describes the causes and influences of emotions has been specifically noted by previous researchers (Huguenin and Rumar, 2001; Mesken, 2006).

While some of the aforementioned research studies (Levelt, 2003; Parkinson, 2001; Underwood et al., 1999) have investigated the natures, frequencies of occurrence and event triggers of emotions during automobile driving, major limitations have to be stated due to the focus on often only one emotional state and the main focus on self-report as a measurement tool. Moreover, study results were highly depended on the choice and application of the self-report method, no reliable estimates of emotion frequencies have therefore been reached (Mesken et al., 2007).

3.2.4 Study Environment

The planning and procedure of automotive case studies depends highly on the study environment, e.g. driving simulator or on-road driving. In the following both driving simulator studies and on-road studies are introduced.

Driving Simulator Studies

The development of driving simulators started during the Second World War, with the purpose of training large numbers of people in the tactical use of war machinery (Blana, 1996). In the 1960s their use shifted towards research of human behaviour and human-machine interaction (Roberts, 1980). Due to swift development of the computer and visual display technology, the use of simulators increased considerably in the United States and Europe. From 1985, driving simulators in private/academic research and the automotive industry were standardised and saw use in a number of disciplines, including psychology, ergonomics, intelligent transport systems, driver behaviour and vehicle dynamics research (Blana, 1996). Driving simulators are ideally suited for automotive research, offering easy data collection, low cost testing, driver safety, adaptability and a fully controllable environment (Bella, 2014; Blana, 1996; De Winter, Van Leuween and Happee, 2012). Furthermore, simulators are interactive and allow manipulation by the researcher (e.g. remote pedal movement), and the use of driving scenarios covering a range of situations (e.g. different road types or traffic conditions) extending the scope of the research. Moreover, simulators are connected to computer systems, allowing direct data storage, processing and formatting (Blana, 1996). Consequently, driving simulators are used frequently for automotive research (Bella, 2014).

Disadvantages of driving simulators compared to a real-driving environment include limited physical, behavioural and perceptual fidelity. This may cause unrealistic driving behaviour, loss of the participant's motivation for the study and hazards not taken seriously by the driver, impacting the outcome of the research (De Winter, Van Leuween and Happee, 2012). The highly complex automobile transport system cannot be accurately imitated to date, even by the most advanced driving simulators (Bella, 2014). Simulator sickness can be a common side-effect amongst participants during driving simulator studies, leading to blurred vision, migraine, epilepsy, motion sickness and vertigo, negatively effecting the simulator's usability (De Winter, Van Leuween and Happee, 2012). In order to avoid these effects and ensure participant safety a risk assessment has to be conducted and a simulator sickness protocol needs to be followed when any of the above-mentioned symptoms occur. Additionally, participants with certain conditions such as fatigue, sleep loss and pregnancy should be excluded from any simulator studies (Brooks et al., 2010). These disadvantages create major limitations for research in driving simulators, particularly concerning behavioural research (Blana, 1996).

On-road Studies

In automotive research, on-road studies often follow simulator driving studies to validate results or test equipment in a real-world setting (Healey, 2000; Mesken et al., 2007). Especially for the investigation of human emotions and behaviour it is necessary to test in a real-world scenario. While many approaches have been taken to induce or elicit emotions in laboratory environments (Cohen et al., 2016), participant's emotions and behaviour are highly influenced by controlled settings (Yu et al., 2015). It is therefore advised to test on-road and many researchers do so at an advanced stage of research (Healey, 2000; Mesken et al., 2007). No framework for the planning of on-road studies for the investigation of human emotion exists at this point. Researchers are therefore following different approaches for testing such as conducting studies in only one research car (Healey, 2000), multiple research cars (Grimm et al., 2007) or peoples' own cars (Parkinson, 2001; Levelt, 2003). Generally, when deciding on a route for a driving study, participants are often asked to drive along a route familiar to them (Riener, Ferscha and Aly, 2009) or a route is pre-planned to cover different driving situations and road types (Clarion et al., 2009; Healey, 2000). Previous automotive studies recommend the combination of three different road types for either the planning of road circuits or the comparison between them: rural, urban and major (Miller, 2013; Schweitzer and Green, 2007). Human factors and ergonomics research recommends a ratio of 40% rural, 40% urban and 20% major roads (Giacomin and Bracco, 1995).

3.2.5 Limitations

Limitations in driving studies investigating emotional responses are often caused by the choice of measurement method, the application and/or the study environment. As shown below in Table 6, most research limitations are the application, usability or intrusiveness of the sensors, the laboratory environment and/or the investigation of only one or a small number of emotional states. In order to minimise these limitations, the application of sensors and emotion measurement tools which are highly intrusive should be avoided (Kapoor, Qi and Picard, 2003).

Limitations	Measurement Method	Study Environment	Source
Limited applicability of sensors in real setting	GSR, heart activity, respiration, ECG	Simulator On-Road	Healey, 2000; Healey and Picard, 2005
Not real-time, controlled environment	GSR, heart rate, temperature	Simulator	Lisetti and Nasoz, 2005
Driver reluctant to communicate with vehicle	Speech analysis	Simulator	Jones and Jonsson, 2005;2007; 2008
Limited emotions (2011), main focus on self-report	Self-report	Simulator	Jeon, Yim and Walker, 2011; Jeon, 2015a
Detection difficulties due to car noise, not real-time	Speech analysis	On-Road	Grimm et al., 2007
No real driving condition	Speech analysis and FEA	Stationary car	Hoch et al., 2005
Technique unsuitable for setting, observed only by one coder	ECG, verbal self-reports, observed facial expression	On-Road	Mesken et al., 2007
Limited detection due to driver alone, problems with sensors	FEA, speech analysis, GSR, heart rate	On-Road	Tischler et al., 2007
Limited emotional states investigated	FEA	Simulator and on-road	Gao, Yüce and Thiran, 2014
Main focus on self-report	FEA, self-report, GSR, pedal movement	On-road	Malta et al., 2011
Main focus on self-report	Self-report	On-road	Parkinson, 2001
Main focus on self-report	Self-report	On-road	Underwood et al., 1999

Main focus on self-report	Self-report	On-road	Levelt, 2003
Highly intrusive sensor application	EEG, GSR, ECG, respiration rate, self-report	On-road	Rebolledo-Mendez et al., 2014
Difficulties of sensor application in a real setting, only tested in a parking lot	FEA, EEG	On-road (parking lot)	Izquierdo-Reyes et al., 2018
Intrusive measurement	ECG, EMG, GSR, EEG	On-road	Dehzangi and Williams, 2015
Test only in the simulator environment, only one state	Saccadic intrusion (type of eye gaze movement)	Driving simulator	Biswas and Prabhakar, 2018
Not real-time, lab environment, difficulties with sensors	ECG, self-assessment	Lab-lased	Minhad, Ali and Reaz, 2017
High intrusiveness	EEG	On-road	Reyes-Muñoz et al., 2016
Simulator environment, limited emotional states	FEA through thermal camera sensors	Simulator	Lee et al., 2018

Table 6 Limitations

In fact, research suggests solely using non-contact sensors and minimising their visibility to achieve reliable results (Busso et al., 2004). Furthermore, as mentioned in Chapter 3.2.4 Study Environment, driving simulators should only be used in early-stage testing due to their limitations (Abdu, Shinar and Meiran, 2012; Yu et al., 2015). In later stages investigations of the drivers' emotions and behaviours should take place in a real-driving environment.

3.3 Summary of the Findings

In this chapter, emotional states which have a significant impact on automobile driving have been introduced and summarised. The 12 identified affective/emotional states have major influences of the on the driving experience, driving behaviour and safety: this has emphasised the need for further in-depth investigations of emotions in the automotive habitat. A literature review of automotive research studies investigating emotions was conducted, and measurement method and investigated states, research focus, study environment and limitations were discussed in detail. Results highlighted the following points:

- Necessity for researchers to identify which emotions are of high importance to the specific research purpose (Jeon, Walker and Yim, 2014; Jeon, 2015b), and the requirement for specification of a suitable emotion taxonomy to be included in the study planning (Chapter 3.2.2 Measurement Method and Investigated Emotional/Affective States).
- Importance of investigation of multiple emotional states in order to collect multi-layered insights on emotions in the automotive habitat (Chapter 3.2.2 Measurement Method and Investigated Emotional/Affective States).
- Lack of comparability between existing studies due to major differences in the research focus, thus necessitating further investigations of natures, frequencies and causes of emotional responses during driving (Chapter 3.2.3 Research Focus).
- Study planning, procedure and results are highly dependent on the chosen study environment. Major limitations of the driving simulator environment create the need for study results to be validated in a natural setting. Investigations of human emotions need to take place in a real-world scenario (Chapter 3.2.4 Study Environment).
- Limitations are often applied by the measurement method. Application of sensors and tools which are highly intrusive should be avoided (Kapoor, Qi and Picard, 2003). Ideally the measurement method chosen for automotive studies should be non-contact and non-intrusive (Chapter 3.2.5 Limitations).

In order to conduct an in-depth investigation of emotions during automobile driving and address the research questions defined in Chapter 1, all of the aforementioned points were addressed in this research. In the following chapter, the chosen emotion taxonomies, research approach, choice of study environment and choice of measurement tool are introduced.

The requirements defined for this research were the following:

- Definition of an emotion taxonomy, investigating multiple emotional states and suitable for the research purpose
- Early-stage testing in a driving simulator, and further studies on-road
- Non-contact and low-intrusiveness application of the measurement tool

Based on the requirements defined for this research Facial-Expression Analysis (FEA) was chosen for the measurement of emotions during driving.

4 Research Methodologies

The research conducted in Chapter 3 highlights the need for a better understanding of and deeper insights into the drivers' emotions in the automotive habitat. The research objectives defined in Chapter 1 are addressed through three different studies and a study comparison (Chapter 5-8). In the following the research paradigm, approach, strategy and research design, data collection and analysis methods, as well as sampling, ethics, reliability and validity and limitations of this research are described. More detail on specific research methods, research design and data collection methods is given in the individual study chapters.

4.1 Research Paradigm

According to Terre Blanche and Durrheim a research paradigm is defined as an all-encompassing system of interrelated thinking and practice, defining the nature of enquiry along its three dimensions: ontology, epistemology and methodology (Terre Blanche and Durrheim, 1999). Kuhn first used the term paradigm in 1962 to describe a conceptual framework providing a community of scientists with an appropriate model for the investigation of problems and the finding of solutions. The term paradigm therefore implies a framework and structure of ideas, values and assumptions (Kuhn, 1962). The following section describes the research paradigm and its three dimensions informing the research methodology selected. The three most frequently adopted research paradigms are: positivism, post-positivism and interpretivism (Gray, 2013).

Positivism

From 1930-1960 positivism was the most common stance in social science. Positivism is the application of the natural science model to social research, as the point of departure for the explanation of the social world and the investigation of social phenomena (Denscombe, 2008). For positivists both the natural and social world operate with a defined set of laws, which science should determine through empirical inquiry (Gray, 2013). Positivists believe that research is independent from the researcher (Guba, 1990). Positivism was widely argued to be fundamentally mistaken in its assumptions about scientific enquiry. May and Williams argue that while science aims for theoretical explanations, these cannot be based on observation and must stem from theory (May and Williams, 2002). Popper agrees that theory cannot ever be proven solely by observation, suggesting it can only be proven to be false (Popper, 1968).

Post-positivism

Criticism of applying a positivist approach to the development of new theories and to complex human issues led to post-positivism. Post-positivism has therefore been applied more frequently in recent research (Gratton and Jones, 2010). Post-positivism can be described as a modern form of positivism, critiquing and amending the original paradigm (Guba, 1990). In contrast to positivism, post-positivism does not see the experiment as independent from the researcher, but understands that observation has errors and can be imperfect. Post-positivism is therefore critical towards the idea of knowing reality with certainty, instead it can only be known probabilistically and imperfectly (Robinson, 2002). Gratton and Jones agree that it is impossible to gain understanding solely through measurement; post-positivism is open to the combination of different methodological approaches, often including qualitative and quantitative research methods (Gratton and Jones, 2010). A more creative research approach is hence appropriate to gather information about multiple perspectives of participants instead of a single reality (Creswell and Zhang, 2009).

Interpretivism

Interpretivism is strongly critical of positivism, aiming to explore “culturally derived and historically situated interpretations of the social life-world” (Crotty, 1998, p.67). The paradigm sees no direct one-to-one relationship between subjects and objects (ourselves and the world). Instead the world is interpreted through classification schemas of the mind (May and Williams, 2002). The stance is based on the view that natural and social reality are different and hence different methodologies need to be applied for their investigation. The focus of interpretivism therefore lies in the exploration of social phenomena to gain understanding. Interpretivism clearly differentiates social from natural sciences and interprets the world through the meanings people give to it. This meaning can solely be discovered subjectively through people and their language, implying the use of qualitative research methodologies (Schwandt, 2014).

The original research presented in this thesis takes a post-positivist stance. This approach supports methodological pluralism and the idea that a method should be selected based on the research question (Wildemuth, 1993). When utilising a research paradigm it is necessary to define the ontological, epistemological and methodological frame of reference outlining the researcher's relation and attitude to the data collection and selection of research methods and tools.

Epistemology is defined as "a way of understanding and explaining how we know what we know" (Crotty, 1998, p.8) and the theory of knowledge rooted in the theoretic perspective of the research (Gray, 2013). The epistemology embedded in the post-positivism approach of this research is *modified dualism/objectivism*. While objectivity remains the ideal, the modified dualism/objectivism approach accepts that full independence of the investigation from the researcher is not possible. Nevertheless, objectivity is the goal and therefore, the verification of results is emphasised (Lincoln and Guba, 1985). Ontology can be defined as "the science or study of being" (Blaikie, 2010, p.20) and is a system of belief reflecting the interpretation of facts (Blaikie, 2010). The ontology underlying the research approach is *critical realism*, stating that there is no ultimate truth. Critical realists believe in a social reality but accept that knowing this reality will always be influenced by imperfections in the detection of its nature. According to critical realism it is impossible for humans to accurately perceive it, hence imperfections are the result of human fallibility (Lincoln and Guba, 1985). The research methodology applied in this research is a *modified experimental* one, with an emphasis on multiple methods of both quantitative and qualitative nature, including the use of natural contexts.

Post-positivism is compared to positivism and interpretivism for epistemology, ontology and methodology below (Table 7).

	Positivism	**Post-positivism**	**Interpretivism**
Ontology	*Realism* Belief in social reality, which exists independent from creator of reality. No differentiation between social and natural reality.	***Critical Realism*** **Social reality exists but detecting its nature is inhibited by imperfections caused by human fallibility.**	*Relativism* Belief in multiple, constructed realities existing in a social context. Realities vary in nature and are context and time bound.
Epistemology	*Objectivism/Dualism* Independence of investigation from investigator.	***Modified Objectivism/Dualism*** **Acceptance that investigation is not independent from investigator, but objectivity is the goal and achieved through verification.**	*Transnationalism/ Subjectivism* Product of interaction between subject and investigator are the result of the investigation. Knowledge is the result of interaction.
Methodology	*Experimental/ Manipulative* Hypothesis testing, variables identified before the investigation. Empirical testing to establish the 'truth'. **Quantitative Approach**	***Modified Experimental/ Manipulative*** **Hypothesis testing but emphasis placed on context.** **Quantitative and Quantitative Approach**	*Empathetic Interaction* Investigator interacts with object of investigation. Construct of reality is interpreted by investigator. Analysis is case-specific. **Qualitative Approach**

Table 7 Characteristics of the three major research paradigms (adapted from Guba, 1990)

4.2 Approach

Modified experimental research is defined as a methodology in which the researcher studies a phenomenon which has not been manipulated by the researcher. Real-world phenomena, more specifically relationships between two variables (e.g. behaviours and their causes), are investigated. The methodology is often applied to human subjects and behavioural research and involves a qualitative and quantitative approach (Hall et al., 1998). Qualitative and quantitative research are defined as two different interpretative frameworks. While the approaches have previously been defined through the type of research data, non-numerical (qualitative) and numerical (quantitative), definitions of both approaches often address their different claims to knowledge and interpretive frameworks. Quantitative studies apply numerical analysis to examine relations of magnitude between variables describing quantities, such as numbers of behaviours. Qualitative studies employ descriptive knowledge about meaning through descriptive data (Landrum and Garza, 2015). Both domains and their main characteristics are visualised below in Figure 18.

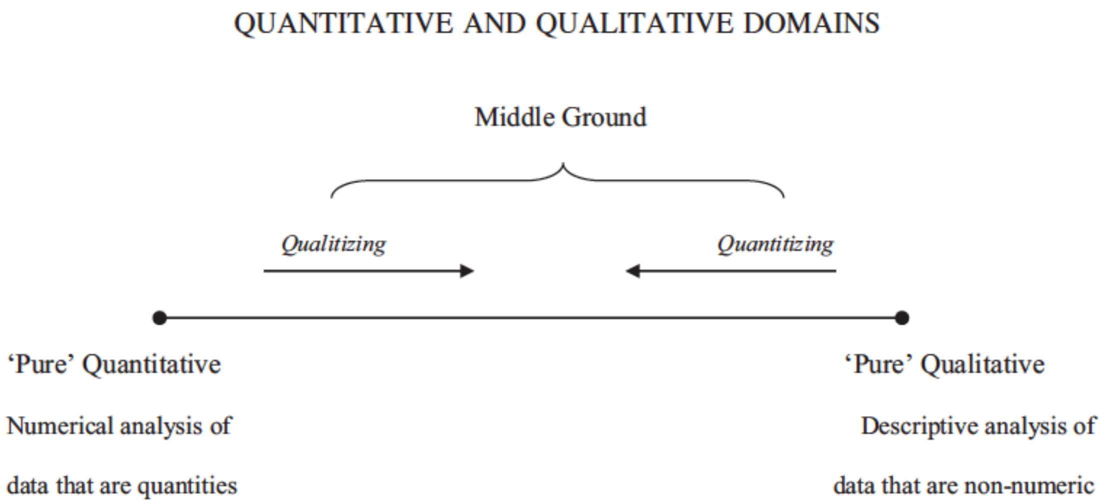


Figure 18 The possible configurations of data and interpretative frame of references represented as a continuum. The middle ground is of special interest for the practice of mixed methods (Landrum and Garza, 2015)

In this research both a qualitative and a quantitative strategy have been applied. While the positions of researchers on the combination of both strategies vary considerably (Hughes, 2006), qualitative and quantitative approaches have more frequently been combined in recent research and the approach has been called the "best of both worlds" (Bryman, 1988, p.130-

131). Triangulation, defined as "the combination of methodologies in the study of the same phenomenon" (Denzin, 1973, p.291), takes the approach that quantitative and qualitative methods should be used complementarily, with the benefit of combining the strengths of both approaches (Jick, 1979).

The triangulation approach stems from military strategies applying multiple reference points in order to find the exact position of an object, referring to the research approach of combining multiple viewpoints to achieve greater accuracy (Jick, 1979).

Denzin (1973) defined the following four types of triangulation:

- Data triangulation – using a variety of sources for a study
- Investigator triangulation – using several researchers
- Theory triangulation – using multiple theories and perspectives for the interpretation of results
- Methodological triangulation – using multiple methods to study the same research problem

For this research, methodological triangulation was applied.

4.3 Strategy and Research Design

Multiple authors call for a combination of research methods to improve research quality (Kaplan and Duchon, 1988). A post-positivist approach aims for methodical pluralism and the selection of method based on the specific research question (Wildemuth, 1993). Saunders identified two approaches for conducting research: inductive and deductive (Saunders, 2011). Using the inductive approach, the researcher collects data, conducts data analysis and develops a theory based on the results. The deductive approach is based on hypothesis testing through a research strategy developed by the researcher. While this research mainly follows a deductive approach (Chapter 5-7; Study

1-3), study results are compared (Chapter 8 Comparison) following an inductive approach (Figure 19).

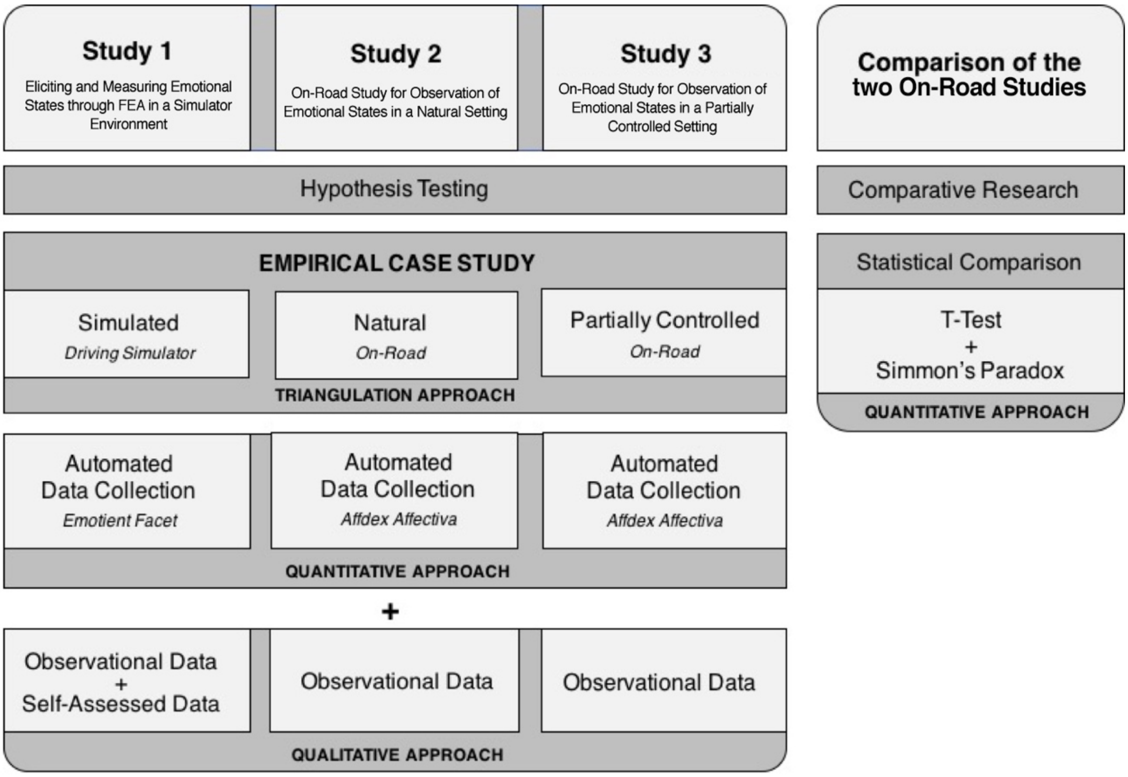


Figure 19 Strategy and research design for this thesis

The research employed in Study 1-3 is built on the research questions and hypotheses underlying each study (Chapter 1.5 Research Questions). All three studies are empirical case studies, defined as research methods investigating a contemporary phenomenon in its real-life context (Yin, 1981) and are ideal when a holistic, in-depth investigation is needed (Feagin, Orum and Sjoberg, 1991). The method was chosen in order to investigate the drivers' emotional states in the automotive environment. Case studies are a common tool in automotive research and have been conducted frequently for the investigation of driver safety, states, behaviour or emotion (Chapter 3.2 Emotion Measurement in Automobile Research). Furthermore, studies investigating human emotions are recommended to be conducted in an environment appropriate for the researcher to collect real insights on emotional responses and ensure a natural behaviour of the participants (Chapter 3.2.4 Study Environment).

The case studies were conducted in three different automotive environment settings: simulated, natural and partially controlled. Study 1 was conducted in a driving simulator, while Study 2 and 3 were conducted in an on-road environment. Study 2 utilised people's own automobiles in a familiar environment, with Study 3 in a research automobile on a pre-planned route. The data collection method for all three studies followed a triangulation approach covering qualitative and quantitative data collection and analysis methods. The quantitative data collection and aspects of the analysis were conducted through an automated data collection tool. The tool chosen was the data acquisition and integration platform *iMotions AttentionTool* (iMotions, 2013), combined with *Emotient Facet* for Study 1 and *Affectiva Affdex* for Study 2 and 3. Due to unforeseen and unavoidable circumstances the FEA tool was changed from *Emotient Facet* to *Affectiva Affdex* for Study 2 and 3. The choice of *Affectiva Affdex* was based on the same criteria and the almost identical function. The only difference was the available selection of emotion taxonomy (introduced in the individual study chapters).

In order of priority the criteria for the choice of *iMotions and Emotient Facet/Affectiva Affdex* were the following:

- Real-time FEA measurement
- Ease and robustness of multi-channel application
- Open API for integration of further tools (e.g. real-time thresholding application)
- Field portability
- Customisable and highly visual interface
- Data collection synchronised with multiple video recordings
- Low cost
- Technical support

An in-depth discussion of both tools can be found in the individual study chapters.

For the qualitative data collection, self-assessment was combined with researcher observation in the first study, and purely observational data was used in Study 2 and 3. In order to answer the final research question and compare the collected data, a comparison was conducted in Chapter 8.

4.4 Data Collection and Analysis Methods

In the following, the data collection and analysis methods applied for this thesis are introduced, and separated into qualitative and quantitative approaches:

Quantitative data collection and analysis methods

All studies share the same broad objective of exploring the driver's emotional states in the automotive environment (Chapter 1 Motivation). In order to identify a suitable tool for the measurement of emotional states a literature review was conducted (Chapter 3 Emotions in an Automotive Context). Facial-Expression Analysis (FEA) was identified as the most suitable tool for the automotive environment due to its non-contact and low intrusive application (Kapoor, Qi and Picard, 2003). Both FEA tools (Facet Emotient and Affdex Affectiva) applied in the studies originate in Ekman's research on human facial expressions and his development of the Facial Action Coding System (FACS) which is the most comprehensive and widely used taxonomy for the coding of facial behaviour (McDuff et al., 2016). Most applications measure the six basic emotions: happiness, sadness, fear, anger, disgust, and surprise. Some tools also provide insights on a selection of action units, contractions or relaxations of one or more facial muscles (Ekman, Friesen and Ellsworth, 2013). Both tools give binary information (an emotion is present or not present) in real-time. For Study 1 the collected FEA data had to be post-processed, while Study 2 and 3 utilised a software application customised to the automotive environment. This real-time emotion thresholding application was a slight adaptation of the measurement tool, required due to a high number of expressions, lighting changes (therefore false detections) and head movements of the driver and allowed real-time information with no need for post-processing.

To gain deeper insights on emotion during driving and potential influences of the settings, the two on-road studies were compared in Chapter 8. To identify which emotions and action unit channels are significantly different between the two studies an independent samples t-test was conducted.

The quantitative data collection and analysis methods applied for each study are explained in detail in the individual chapters.

4.5 Participant Selection and Recruitment, Ethics, Reliability and Validity, Limitations

4.5.1 Participant Selection and Recruitment

The choice of sample size in research is determined by multiple factors such as resources, study time, objectives and study methodology. The choice of number of participants to include in a study is made with the intention of reaching data saturation. Saturation is defined as the point when additional data cannot bring any new insights to the collected data (Mack et al., 2005). In order to achieve data saturation a researcher should aim for appropriate quality and quantity of data (Dibley, 2012) and chose a suitable study design (Fusch and Ness, 2015). It is recommended that an existing methodology is applied (Porte, 2013), and the research process is documented carefully and correctly as evidence (Kerr et al., 2010). To ensure a high quality of data, a purposive sampling strategy was applied. Factors (age, gender and driver type) identified in previous research as affecting driving behaviour, performance and attitude (Gwyther and Holland, 2012; Turner and McClure, 2003) were therefore controlled. As recommended in previous research, the choice of sample size for this mixed method research was determined through a review of research suggesting sampling sizes for qualitative, quantitative and mixed method research approaches, and literature considering validity of sampling size for data analysis (Creswell and Poth, 2017; Guo et al., 2013; Morse, 1994; Teddlie and Yu, 2007; VanVoorhis, Wilson and Betsy, 2007). When following a purposive sampling strategy in mixed method studies, 20-30 participants has been suggested as an appropriate sampling size (Creswell and Poth, 2017; Teddlie and Yu, 2007). For stable data analysis, sample sizes of 8-20 have been identified as sufficient (Morse, 1994). Furthermore, studies taking repeated measurements (in this case FEA data) allow the detection of changes over time within participants, and therefore reach saturation at a lower sample size and have high statistical power (Guo et al., 2013).

Based on the literature reviewed above, a minimum of 20 participants was recruited for all studies. The recruitment process was conducted internally at Brunel University. An announcement was posted on the Brunel website and a group of three researchers selected the final participants in such a manner that a relatively uniform distribution of participant characteristics was achieved.

For Study 1 all participant where asked to answer screening questions to minimise the incidence of simulator sickness (Appendix C, D). For Study 2 and 3 participants were asked to complete the Multidimensional Driving Style Inventory (Appendix J), a self-report questionnaire assessing five driver types which has been used as a standard driving style assessment tool for the last ten years. The questionnaire was used to ensure the participation of different driver types (Taubman-Ben-Ari, Mikulincer and Gillath et al. 2004). In both studies all five driver types (angry, anxious, dissociative, distress-reduction, careful driver) were represented. Participants were asked to answer a set of screening questions to ensure their confidence and full driving abilities (Appendix H, I).

4.5.2 Ethics

In this research the four key ethical rules of veracity (truthfulness or absence of deception), privacy (freedom from unwarranted public intrusion), confidentiality (non-disclosure) and fidelity (accuracy in recording and reporting data) have been carefully considered and implemented throughout the design and conduct of all studies, following both international standards and common ethics literature and guidelines (Anonymisation: managing data protection risk code of practice, 2012; Data Protection Act, 1998; Denzin and Lincoln, 2011; Gupta, 2011; Punch, 1994; UK Clinical Ethics Network, 2011).

To ensure that no person involved in the research could be harmed in any way, all possible preventative measures were taken. All studies conducted were performed in compliance with the Brunel University's ethics policy and ethics approval for all studies has been granted prior to recruitment and study execution (Appendix E, F, G). In the following, all topics which have been considered as potentially problematic from an ethical perspective and methods for the prevention of any negative outcome are explained.

Informed Consent (Appendix A, B)

For all studies involved in this research the issue of consent to participate in the research was addressed through the use of information sheets and consent forms. The information sheet (including purpose, requirements duration and risks) was provided to the participant prior to the study, including name and contact details of the researcher, and the participants were allowed to retain the information sheet for future reference. The opportunity to ask any questions was given prior to all studies. Furthermore, informed consent from participants was sought prior to each study. The participants' right to withdraw from the study at any point was made clear in the information sheet.

Confidentiality of Data

All participants were assured of confidentiality. At the earliest possible stage all names were deleted from transcripts. Prior to any study participants were asked to fill in a consent form; only when signed consent from the participant was given a study was conducted. No names or personal information was used or will appear in any internal or external report, and all data was anonymised. For the few cases where personal data was used (e.g. screenshot of video footage collected) only participants who prior volunteered to allow the sharing of their personal data were asked for full, written consent.

Data Protection

Information and data collected during studies was used solely for the purposes of the research. Personal data from participants was limited to the consent form. An identification number was then allocated to each participant which was associated with the study data. No names or personal information was used outside those directly involved in the collection, transcription and analysis of the data and will not appear in any internal or external reports or publications. All hard copy forms (e.g. simulator sickness questionnaire) were securely locked in a filing cabinet and destroyed at the end of the data collection phase. Electronic files including all collected video and audio data were kept securely in restricted-access folders on password-protected Brunel University computer systems. All personal data was anonymised at the earliest possible stage. After completion of the studies all electronic data was destroyed. The researcher who supervised all studies for this thesis completed a health and safety research integrity course.

Simulator Sickness (Appendix C, D)

As previously explained (Chapter 3.2.4 Study Environment) simulator sickness is known to be a common side-effect amongst participants during simulator studies. To avoid potential side effects (e.g. blurred vision, migraine) and ensure participant safety all participants were screened during the recruitment process to exclude those who may be more susceptible. Furthermore, a risk assessment was conducted prior to any simulator studies. Participants with certain conditions (e.g. fatigue, sleep loss), have been excluded from all studies (Brooks et al., 2010). An adjustment period in an easy scenario setting (e.g. no challenging road types) of ten minutes was added prior to each study to give the participant time to adjust to the setting and avoid sickness. After the adjustment period participants were screened again prior to the start of the main study. Moreover, the length of all simulator studies was restricted to a maximum of 30 minutes. After the completion of a simulator study all participants were asked to fill in a simulator sickness questionnaire. The departmental first aider was made aware of the potential risk and was available to assist during all studies.

On-Road Study Risk Assessment (Appendix H, I)

Prior to all on-road studies participants were asked to answer a number of screening questions (e.g. are you confident with driving in the UK?) in order to ensure their driving ability and suitability for the study. An information sheet and consent form were given to the participant, including information about camera placement, the recording of personal data and the right to withdraw from the study. A risk assessment was carried out prior to each study, including the screening of documents (ID, License, MOT, insurance) and a ten-minute-long driving period for adjustment to the vehicle and allowing the researcher to assess the participant's driving ability. All participants who did not clearly pass all aspects of the risk assessment were not accepted as participants. To ensure the researcher's safety a timetable was shared with the project manager. The length of all on-road driving studies was restricted to a maximum of 60 minutes in order to avoid fatigue or loss of concentration.

4.5.3 Reliability and Validity

To ensure reliability of the research, all components of the study (e.g. FEA data, observational data, video feed) were recorded in a rigorous data transcription process. The recorded data was then examined to ensure it was aligned with the nature of the investigation. To clarify the meaning of the collected data and minimise potential misinterpretations, the results of each study were discussed with academics and the industrial partner, and, subject to the agreement of all parties, fed into the subsequent study. The most obvious threats to validity were identified prior to the studies. All steps taken to ensure validity are explained below.

Researcher's Presence in the Simulator or Automobile

The presence of the researcher in the simulator or automobile throughout the study might have impacted the study results (experimenter bias). Possible effects can include alteration of the participant's normal driving style, changes in the participant's behaviour and restricted emotional expressions. To avoid a negative effect of the researcher's presence on the participant's behaviour, driving style and emotional responses, the researcher was seated on the back-seat of the automobile and all communication between researcher and participant was avoided throughout the study when possible.

Study specific threats to validity are discussed in detail in the individual study chapters.

4.5.4 Limitations

Certain limitations of the conducted research set the grounds for future research. Limitations specific to a certain study, are discussed in the individual study chapters.

Technology Selection

The selected technology for the measurement of emotional states was based on a review of existing technologies and the application of the method in the automotive environment. While the FEA tool was chosen in accordance with the requirements of a non-intrusive, non-contact application, the research was limited to only one measurement tool. In future studies a combination of multiple methods for the investigation of emotional states is suggested.

Limitations of FEA

While the creation of the real-time thresholding application increased the applicability of the software to the real automotive environment significantly, hardware limitations played a role. As discussed in previous research (Gao, Yüce and Thiran, 2014; Malta et al., 2011; Tischler et al., 2007), gaps in data collection may occur due to the drivers' head movement and changes in lighting (e.g. when entering or leaving a tunnel). Furthermore, the functionality of the method highly depends on the participants' personal features, such as facial hair or glasses. Use of only a single face camera led to interruption of the FEA measurement if too much head movement occurred. This also necessitated camera placement that had a minor impact on the participants' visual field. To alleviate interruption of the FEA measurement, and the camera's impact on the participants' visual field, two or more face cameras should be used for FEA in future studies.

Cultures

The participant selection for the conducted studies was restricted to students and staff members of Brunel University, therefore the sample was of limited cultural diversity. Nevertheless, the demographics fitted well with the typical driver's sample for such type of studies. In order to conduct in-depth investigations of the emotional response of drivers from a range of cultures during driving future studies need to include a more culturally diverse range of participants.

Limited Sample Sizes

All sample sizes were limited to 21-22 participants, decided in accordance with a review on sampling literature (Creswell and Poth, 2017; Guo et al., 2013; Morse, 1994; Teddlie and Yu, 2007; VanVoorhis, Wilson and Betsy, 2007). Nevertheless, a larger sampling size could lead to greater reliability and wider variety in the data collected. Future studies should therefore include more participants.

Length of Studies

Due to Brunel University ethics restrictions and to ensure participants safety all studies had time restrictions. Limited study length might have influenced participant behaviour and emotions. For instance, fatigue and drowsiness are known to occur more frequently during longer driving periods (Sheridan et al., 1991). Future studies should be of greater duration to observe a wider range of behaviours.

5 Study 1: Eliciting and Measuring Emotional States Through Facial-Expression Analysis in a Simulator Environment

Chapter 3 discussed the need for a better understanding of the drivers' and passengers' emotions to adequately respond to the technological and sociological developments occurring in the automotive sector (Chapter 1.1 Developments in the Automotive Industry). In order to take the first steps towards a better understanding of human emotions while driving, a study was conducted investigating both driver (n=11) and passenger (n=10) emotions. Both, the drivers' and passengers' emotional responses to a selection of stimuli, identified as typical for automobile driving, were investigated through Facial-Expression Analysis (FEA). The study was conducted in order to investigate emotion triggers and corresponding human responses in the automotive environment, and to evaluate how the triggered emotional states can be measured.

One of the first researchers to use the term 'trigger' in relation to emotion was James (1890), referring to emotion as the feeling in response to a specific triggering event. At present, a variety of differing theories and definitions of emotion triggers exist (Gendron and Feldman Barrett, 2009). For this research, an emotion trigger is defined as any event which causes an emotional reaction in the participant (e.g. navigation alert, traffic violation by another driver).

Following the approach of multiple similar studies (3.2.1 Literature Review of Automotive Research Studies), a simulator environment was identified as suitable for the early-stage testing; the laboratory environment was chosen as it is safe and fully controllable (Bella, 2014; Blana, 1996), allowing manipulation of test parameters by the researcher (e.g. through emotion elicitation). The simulator is more conducive to application of the chosen measurement tool as measurement limitations are often caused by the application in a real-driving setting (3.2.5 Limitations). To minimise the limitations of the simulated environment on the investigation of human emotion and behaviour, the application of emotion elicitation was investigated. The aim of the study was to identify the most influential triggers and their responses which occur while driving and to verify the applicability of FEA as a measurement tool for emotional expressions. This was intended to provide foundations of knowledge, study design, and methodology for subsequent on-road studies.

5.1 Introduction

Past research (Healey, 2000; Hoch et al., 2005; Jones and Jonsson, 2005) has investigated the use of affective computing in driving environments to study the influence of emotional states on driving behaviour and experience (Eyben et al., 2010). Most research, however, has focused on road rage, aggressive driving and accident prevention (Wells-Parker et al., 2002). Attention is now shifting towards the analysis of a wider range of scenarios and concerns as part of an effort to gain multi-layered insights about human reactions and behaviours within automotive habitats (Gkatzidou, Giacomin and Skrypchuk, 2016).

Driving simulators have been used for the investigation of human behaviour in automotive studies since the 1960s (Roberts, 1980). While simulators are ideally suited for automotive research due to easy data collection, low cost testing, high safety and a fully controllable environment (Bella, 2014; Blana, 1996), their usefulness in emotion research can be limited due to simulators being an artificial environment. Controlled environments which are recreated from real-world settings (e.g. driving simulators) may cause difficulties with the investigation of accurate emotional responses from study participants (Jones and Jonsson, 2005). Simulated environments are often characterised by limitations in their perceptual fidelity which can lead to difficulties when attempting to stimulate accurate emotional responses from test participants (Ray, 2007).

While emotion elicitation has been widely deployed in laboratory settings (Amodio, Zinner and Harmon-Jones, 2007; Coan and Allen, 2007; Ray, 2007) for purposes of psychological research, its use in driving simulation has rarely been documented (Jeon, 2015b). In particular, driving conditions which trigger emotional responses in participants while driving have not normally been defined. Although brute force approaches have occasionally been adopted, such as specific driving scenarios (e.g. the simulation of accidents), in order to generate a state of cognitive arousal (Ray, 2007), approaches for the general elicitation of a range of emotional states have not been developed for use in driving simulation.

This chapter describes Study 1, an empirical case study conducted in a driving simulator. The exploratory study introduced here is based on the hypothesis that emotion elicitation can be successfully achieved in a standard driving simulator, and that the emotions themselves can be detected by means of FEA. Successful emotion elicitation was defined as any instance when a detected emotion was the predicted reaction to a previously defined emotion trigger. Success rates in emotion elicitation differ significantly depending on the method applied. While certain methods (e.g. autobiographical recall) consider an elicitation rate above 75% successful, others (e.g. self-report, facial expression) aim for more than 50% (Martin, 1990). Since the research conducted in this chapter applies the method of self-report and FEA, a successful elicitation rate is defined as over 50%.

5.2 Methodology

5.2.1 Choice of Emotion Taxonomy

Emotion taxonomies should be chosen and adapted according to the defined research goals and hypotheses (Jeon, Walker and Yim, 2014). For this research, the basic emotions (joy, anger, surprise, fear, disgust and sadness) were combined with two composite higher emotions (confusion and frustration). The choice of including the two composite higher emotions was based on previous research noting frequent occurrences of confusion and frustration while driving (Boril et al., 2010; Carberry and de Rosis, 2008; Harris and Nass, 2011). For the investigation of the chosen emotional states, the Facial Action Coding System (FACS) (Ekman, Friesen and Ellsworth, 2013), the most common taxonomy for coding facial behaviour (McDuff et al., 2016), was applied.

5.2.2 Measurement Equipment

The data acquisition and integration platform chosen for the research was the *iMotions AttentionTool* (Chapter 4.4 Data Collection and Analysis Methods). The *FACET Emotient* software module, used to detect and quantify the six basic emotions (iMotions, 2013) and confusion and frustration, was integrated into the iMotions interface. For each video frame the software provided 'evidence scores' (Chapter 3.4 Facial-Expression Analysis – State of the Art), numerical values ranging from -4.0 to 4.0 which correspond to the probability of the presence of each emotion in the facial image. For all emotions measured in the current study the threshold value for evidence score (an emotion being present) was set at the numerical value of 1.0, as recommended previously by researchers (iMotions, 2013).

5.2.3 Self-Assessment Tool

A range of standard self-assessment tools is available for emotion research (Chapter 2.2.1 Self-Reports). When choosing the technique for use in the current study the following selection criteria were adopted:

- Non-verbal communication from the participant (e.g. unobtrusive, intuitive)
- Evaluation of more than one dimension of emotion

- Simplicity

The *Self-Assessment Manikin SAM* (Lang, 1980) was selected for use in the current study as it met these selection criteria and is widely adopted in many research contexts (Ekman, Friesen and Ellsworth, 2013; Smith et al., 2002). Its popularity provided opportunities for cross referencing the results of the current study with emotion data from other physical contexts. SAM involves a 5-point scale which combines a numerical value with a cartoon-like visual representation of the emotional state. For the purposes of the current study the arousal-valence space with SAM was used (Figure 20). The tool was created and validated in previous research (Healey, 2000) by combining the SAM tool with the Circumplex Model of Affect (Posner, Russell and Peterson, 2005). It was considered helpful to add the Circumplex's semantics, which were thought to likely be familiar to most participants, to the numerical and visual cues of the SAM.

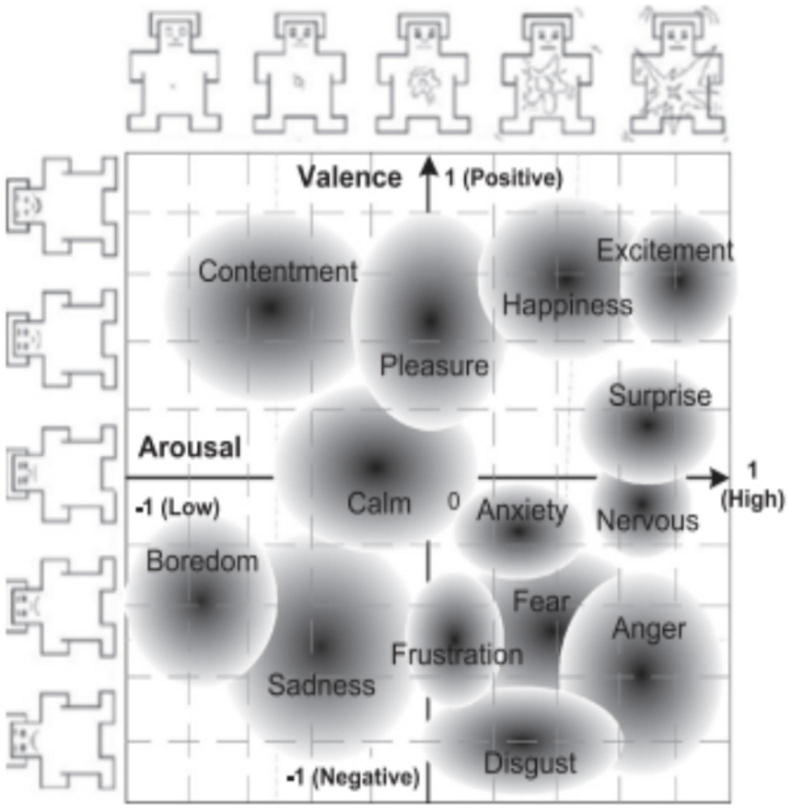


Figure 20 The arousal-valence space with self-assessment manikin (Healey, 2000)

5.2.4 Driving Simulator

The driving simulator used for this study was built upon a Jaguar S-type body shell. Visual stimuli were provided by means of a Toshiba TDP-T95 projection system, consisting of three viewing screens, each of 2.4m x 1.8 m, for a 105° horizontal and 45 ° vertical field of view. The resolution of each screen was 1024 by 768 pixels and the refresh rate was 60 Hertz. Sound stimuli were provided by means of a Creative Inspire 5800 sound reproduction system (72 Watts) with a 40 to 20,000 Hertz bandwidth and 8 speakers. The City Car Driving (Version 1.4, Forward Development) simulation software was chosen to simulate different driving conditions due to its relatively low cost and its flexibility of programming.

5.2.5 Participants and Recruitment

Following the previously suggested sampling strategy (Chapter 4.5.1 Sampling) a total of 21 participants (n=21), including 11 drivers and 10 passengers, took part in the study. The sample had an age range of 19-42, with an average age of 28.2. All participants were asked to answer screening questions in order to minimise the incidence of simulator sickness Appendix C, D). The selection of participants and all phases of the study were performed under the university's full ethics approval and in compliance with the university's ethics policy.

5.2.6 Scenario Design

A literature review was performed to identify potential triggers of emotion for automobile drivers and passengers (Boril, Sadjadi and Hansen, 2011; Brake report on safe driving, 2012; Capps, 2015; Deffenbacher et al., 2003; Di Stasi et al., 2010; Eyben et al., 2010; Gross and Levenson, 1995; Hansen et al., 2012; Schuller, Lang and Rigoll, 2006; Takeda et al., 2009; Underwood et al., 2009). Pre-defined methods of emotion elicitation (Amodio, Zinner and Harmon-Jones, 2007; Coan and Allen, 2007; Ray, 2007) were employed to transform the defined triggers into emotion elicitors (e.g. video, task-completion). Final selection was based on the following criteria:

- Ease of replication in the driving simulator
- Nature of the impact (physical, psychological or sociological)
- Expected strength of the emotion achieved

The selected triggers were adjusted to the physical limitations of the laboratory environment and the simulator equipment. A set of seven physical, psychological and sociological triggers of human emotion was defined.

The study was split into two sub-studies, one involving measurements performed on the drivers and the other involving measurements performed on passengers, as described in Table 8 below.

	Trigger Event	**Emotion Elicitor**	**Expected Emotion**
Driver Study	Distraction	Beeping sound	Anger
	Traffic violations of others	Scenario setting changed to high traffic violations	Anger, surprise, confusion
	High cognitive load	Scenario setting changed to high cognitive load	Confusion, frustration
	High traffic density	Scenario setting changed to high traffic density	Frustration, anger, sadness, disgust
Passenger Study	Bad weather conditions	Video of tornado	Fear, surprise, sadness, disgust
	Attention sharing	Navigation task	Confusion, frustration
	Infotainment	Infotainment task	Confusion, frustration

Table 8 Triggers of driver and passenger emotion used in the study

In the following, all trigger events are introduced in detail:

Distraction

Distraction during driving can cause emotional reactions in the driver (Sterkenburg, 2015) and is a causal factor for up to 50% of automobile crashes (Wang, Knipling and Goodman, 1996). Auditory inputs (e.g. ambulance, infotainment system) are particularly often the cause for distraction during driving (Strayer and Drew, 2004), therefore a beeping sound was chosen as an emotion trigger for distraction.

Traffic violations of others

Other road users and their behaviour are well-known to cause emotions while driving (Deffenbacher et al., 2003). The Brake report on safe driving (2009-2012) investigated the impact that the behaviour of other road users has on automobile drivers and concluded that 6 out of 10 drivers get emotionally upset because of other drivers (Brake report on safe driving, 2012). In order to trigger anger, surprise and confusion, the City Car Driving Software settings were set to 'high traffic violations of others'.

High cognitive load

High cognitive load is a common trigger for emotion during automotive driving (Boril, Sadjadi and Hansen, 2011) and is often the reason for driving errors (Takeda et al., 2009). In order to trigger a high cognitive load in the participant during the driving study, the City Car Driving Software settings were set to 'high cognitive load', including a high number of traffic signs and a high number of pedestrians.

High traffic density

Road rage, aggressive driving and other negative emotional states are frequently caused by high traffic density during driving (Capps, 2015; Underwood et al., 2009), and can lead to fatal accidents (Underwood et al., 2009). To trigger negative emotions in the study, the scenario setting was changed to 'high traffic density'.

Bad weather conditions

Weather conditions are a factor well-known to have a significant negative impact on driving performance, behaviour and emotion (Hansen et al., 2012) and can even lead to driving anxiety (How To Deal With Fear Of Driving In Bad Weather, 2015). As a widely-used method of emotion elicitation, a video was chosen to trigger negative emotions (Gross and Levenson, 1995). A video of a tornado shot from a car with audio was selected to simulate bad weather conditions as realistically as possible.

Attention sharing

Attention sharing in the automotive environment may influence affective states of the occupant (Eyben et al., 2010). As the navigation system is a frequent cause for attention sharing and anger (Sat-Nav Rage of British Motorists, 2011), a navigation system task was designed to trigger the participants' emotions.

Infotainment

A common trigger for frustration and confusion during driving is the infotainment system (Grimm et al., 2007; Harris and Nass, 2011). As infotainment applications become more complex and commonly used (Harris and Nass, 2011) the significance of this problem will only grow in the future. In order to trigger negative emotions in the study, an infotainment task was assigned to the participants.

Joy was not directly tested for since previous research (Tischler et al., 2007) suggested that joy is an emotion which is not expressed strongly when a driver is alone in an automobile. Thus, it was not considered critical for the purposes of the current study.

5.2.7 Study Protocol

For purposes of data collection two cameras (Logitech Lifecams) were placed in the driving simulator. One camera was used to directly view the participant's face to enable emotion detection. This 'face camera' was attached to the simulator dashboard and adjusted for each individual to achieve ideal conditions for FEA. The second camera was fixed to the roof of the simulator car-shell, pointed in the direction of the screens which provided the outside environment. This 'scene camera' was positioned to provide the widest possible view of the driving scene and was fixed in the same location for all tests. The video streams from both cameras were monitored in real-time by the researcher and were simultaneously stored on a research laptop (Lenovo ThinkPad t540p).

For the driver study: After a short introduction to allow the participant to become familiar with the driving simulator, the participant was asked to complete a 15-minute drive. The City Car Driving software settings for the driving environment were adjusted to the previously defined settings (Table 8). Points of interest were then marked manually by the researcher upon occurrence of a traffic violation, accident or other incident previously defined as one of the emotional triggers. Points of interest were saved by the software and were visible when reviewing the video material. After completing the driving task the video material was reviewed by the participants, who were asked to rate their emotion for every point of interest using the emotion map.

For the passenger study: Three separate activities were performed with each participant. The first activity was chosen based on methods suggested in literature on emotion elicitation, such as the use of video clips (Ray, 2007). A 60-second video clip, shot from an automobile in a tornado, was chosen based on the previously identified emotion trigger 'bad weather conditions'. The clip was shown to the participant seated in the front passenger seat of the driving simulator to recreate a realistic audio-visual experience. The second activity involved the researcher acting as the driver and the participant being requested to assist with a navigational task. The third activity was similar to the second, but instead each participant was given the infotainment system task of locating three destinations on a mobile device during the drive. As with the driver study, after completing each of the three activities the passenger was asked to review the video material and use the emotion map to rate the experienced emotion at every point of interest indicated by the researcher.

5.2.8 Data Analysis

After the real-time data collection by means of the *FACET Emotient* software, post-processing was performed by the researcher. The evidence scores were checked for possible overloads, offsets, biases or trends within each individual channel. Only data produced by the clear and obvious detection of a single face was analysed, and the selected data was smoothed via the application of a moving average filter, performed using a 0.2 second time-window as recommended by previous research (iMotions, 2013).

Since facial expression and structure differ significantly between participants, a personal baseline for each participant needed to be computed and applied to the FEA data to improve the comparability of the evidence scores across the group of participants (iMotions, 2013). Baseline evidence scores were computed from a resting facial expression lasting several seconds, which had been collected for each participant at the start of testing. The baseline provided by the given individual's natural expression (e.g. individual distances between facial action points) was subtracted from all FEA data collected from that individual. The emotions detected through FEA were then compared to the ratings obtained through self-assessment and the visual assessment of video data performed by the researcher.

The comparisons led to the definition of four data categories:

- *Accurate Detection* was defined as any instance in which the emotion detected by the software matched that detected through self-assessment and/or visual assessment.
- *Failed Detection* was defined as any instance in which an emotion trigger and emotional facial expression were visible but no emotion was detected by the software.
- *Erroneous Detection* was defined as any instance in which the emotion detected by the software did not match that detected through self-assessment and/or visual assessment.
- *False Alarm* was defined as any instance in which the software detected an emotion but no emotion trigger or facial expression were present.

Examples for all categories are shown in Table 9 below. All data was categorised to ensure that only ‘accurately detected’ data was analysed for successful emotion elicitation.

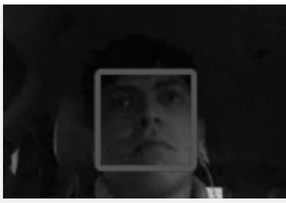
Examples	Face Camera	Scene Camera	Situation Description
Accurate Detection			Participant was stuck in traffic, the software detected frustration.
Failed Detection			Software did not detect any emotion when the participant self-assessed frustration.
Erroneous Detection			Software detected joy when the participant self-assessed shame.
False Alarm			Software detected joy when the participant’s facial expression was clearly not joyful.

Table 9 Four data categories defined in the study

Data defined as accurately detected required that emotion detected through FEA matched self-assessed and/or visually assessed emotion. Emotion events not fulfilling this requirement were categorised into ‘failed detection’, ‘erroneous detection’ or ‘false alarm’. Upon completion of post-processing it was found that 63% of the emotion data from the driver studies and 62% of the data from the passenger studies fell within the category of ‘accurately detected’. Failure to achieve ‘accurate detection’ was caused by environmental factors such as abrupt changes in lighting condition and occasional failures of the data acquisition chain which lead to gaps or noise in the video images. Other causes included difficulties associated with eye wear and head movement. Pantic and Rothkrantz provide a detailed treatment of several of the sources of error which were noted in the current study (Pantic and Rothkrantz, 2000).

5.3 Results

All 'accurately detected' emotions, acquired through FEA in combination with self-assessed and/or visually assessed data, were analysed to determine the total number of emotion events, the nature of emotion for each event and the average time duration of each event. Table 10 below provides a summary of the number of successful emotion elicitations, determined from the complete data set consisting of all participants and both the driver and the passenger studies.

	Trigger	**Trigger Event**	**Number of Successful Emotion Elicitations**
Driver Study	Distraction	Beeping sound	7 out of 11
	Traffic violations of others	Scenario setting changed to high traffic violations	7 out of 22
	High cognitive load	Setting changed to high cognitive load	18 out of 22
	High traffic density	Setting changed to high traffic density	20 out of 22
Passenger Study	Bad weather conditions	Video of tornado	9 out of 10
	Attention sharing	Navigation task	7 out of 10
	Infotainment	Infotainment task	9 out of 10

Table 10 Total number of successful emotion elicitations

For the driver study, 52 out of 77 attempts of emotion elicitation were successful, while for the passenger study 25 out of 30 attempts were successful. In total emotion elicitation was found to be successful in 77 out of 107 attempted emotion elicitation cases, i.e. for 72% of all the attempts.

Type of Emotion Expressed for Each Stimulus

Table 11 below provides a summary of the emotions expressed in relation to each trigger, determined from the complete data set consisting of all participants and both the driver and the passenger studies.

	Trigger	Triggered Emotion
Driver Study	Distraction	Confusion, frustration, anger
	Traffic violations of others	Frustration, surprise
	High cognitive load	Confusion, frustration, anger, surprise
	High traffic density	Confusion, frustration, anger, disgust
Passenger Study	Bad weather conditions	Confusion, frustration, anger, surprise
	Attention sharing	Confusion, frustration, surprise, disgust, joy
	Infotainment	Frustration, confusion, surprise, anger, joy

Table 11 Expressed emotions achieved with each trigger

Confusion and frustration were found to be the two most frequently expressed emotions, with anger, surprise and disgust occurring less frequently and only for a small number of triggers. As anticipated based on the data found in the research literature, joy was encountered only in the passenger study, when the participant was not alone in the simulator (researcher present).

Average Time Duration of Emotional Expression

Table 12 below provides a summary of the average time durations of the emotions expressed in relation to each trigger, determined from the complete data set consisting of all participants and both the driver and passenger studies.

	Trigger	Average Time Duration of the Emotion Expression
Driver Study	Distraction	4.3 sec
	Traffic violations of others	9.3 sec
	High cognitive load	7.1 sec
	High traffic density	5.9 sec
Passenger Study	Bad weather conditions	13.4 sec
	Attention sharing	20.2 sec
	Infotainment	9.6 sec

Table 12 Average time duration of the emotion expressions

As they are probability values, it is not generally recommended that evidence scores be interpreted as numerical estimates of emotion intensity. Instead, the average length of each emotion may be interpreted as an indication of its intensity (iMotions, 2013). This is due to the fact that intense emotions tend to have longer physiological time durations. For this study traffic violations were found to produce the longest and thus most intense emotions in the driver study. The infotainment task was found to produce the longest and thus most intense emotions in the passenger study.

5.4 Discussion

The aim of the current study was to investigate the applicability of emotion elicitation to the driving simulator environment as a tool to overcome the limitations of the artificial environment and consequent difficulties of emotion research conducted within. In order to do so, the study examined the application of Facial-Expression Analysis (FEA) in the driving simulator to measure the emotional states experienced by drivers and passengers. The hypothesis underlying this research was that emotion elicitation could be successfully achieved in a standard driving simulator, and that emotions could be detected through FEA.

In the current study, 11 drivers and 10 passengers conducted driving tasks and tasks connected to a passenger role respectively, which were identified as possible emotion elicitors in the automotive environment. It was found that 63% of the FEA data from the driver studies and 62% of the FEA data from the passenger studies fell into the category of ‘accurately detected’. It is important to note that the use of self-assessment might have negatively influenced the success rate of accurate detection. Self-assessment is based on the assumption that people are able to accurately rate their own emotions, which might not always be the case. Further typical limitations of self-assessment are reviewed in Chapter 2.3.2 Self-Reports. Within those accurate detections, emotions were successfully elicited by the trigger condition (emotion trigger caused predicted emotional response, e.g. traffic violation by others caused anger as intended) in 77 out of the 107 attempted cases, i.e. for 72% of all attempts. This confirmed the hypothesis that emotion elicitation could be successfully achieved (>50%) in a driving simulator and that emotions could be detected through FEA.

Multiple emotional states were successfully elicited over the course of the study. Confusion, frustration, anger, surprise and disgust were each detected on multiple occasions, and substantial variations in time duration were noted among the emotions elicited by the different triggers. Confusion and frustration were the most frequently triggered emotional responses (Table 11) which confirmed the findings in previous research that both emotional states are typical in a driving environment (Boril et al., 2010; Carberry and de Rosis, 2008; Harris and Nass, 2011). The frequent occurrence of confusion and frustration indicated that both states play a major role during automobile driving. This knowledge could be applied to future automotive design, for instance in the development of coping techniques (e.g. music selection, regulation of information flow) intended to alleviate confusion and frustration. The fact that confusion and frustration occurred in response to every single trigger in the study may be influenced by the fact that a driving simulator was used. As previously explained, laboratory environments can cause difficulties in achieving accurate emotional responses (Jones and Jonsson, 2005). Limitations in the simulator's perceptual fidelity (Chapter 3.2.4 Study Environment) might have been a cause for the frequent occurrence of confusion and frustration in this study.

The fact that joy only occurred in this study when the participant was not alone (researcher present) confirmed the statement in previous research (Tischler et al., 2007) that joy is not commonly experienced during driving when the driver is alone.

The FEA data suggested that the longest emotional expressions were found in the data of the passenger study. Distraction is a known means for the regulation of emotion (Kanske et al., 2010), therefore it can be hypothesised that the necessary focus on the complexities of the driving task may have detracted from the attention which the driver dedicated to the emotion elicitation triggers used in the study. Further research is necessary to confirm this hypothesis.

5.5 Limitations

Although adequate for purpose of automotive research, the current rate of accurate detection achieved during the study using FEA (62-63%) may not prove adequate for the application in a real-time automotive context. If automobiles are to be equipped with emotion detection systems for purposes of real-time system optimisation and real-time control, the sole use of FEA to detect emotion may prove a limitation. Multiple measures of emotion may need to be fused together to achieve higher detection rates and more accurate evaluations of emotional intensity. Preliminary research in this direction has been performed (Kanske et al., 2010) and further studies are likely to be required, including testing with greater numbers of participants and longer study durations. Moreover, the current detection and elicitation rates suggest the need for a substantial amount of trigger repetition in future investigations to provide an adequate statistical basis for drawing conclusions regarding emotion elicitation and measurement in the automotive environment.

Finally, the use of a driving simulator can never fully replace the real driving environment. While the application of emotion elicitation in simulator research might aid to improve the validity of emotion measurement results and provide important insights, accurate emotional responses need to be measured and investigated in a real-driving setting.

5.6 Conclusion

The motivation of the current study was to investigate whether emotion elicitation could be successfully applied in a simulated driving environment and if the triggered emotions could be measured through FEA. A set of emotion triggers was used to elicit emotions in both drivers and passengers during simulated driving. Results confirmed the hypothesis, provided insights on the importance of certain triggers during driving, and confirmed that emotion elicitation is a useful tool for the investigation of emotion under simulated conditions. Furthermore, study results indicated that FEA may deliver valuable results describing participants' emotional responses.

The application of emotion elicitation proved successful for the driving simulator study, leading to possible improvements for future studies in controlled automotive environments. Beyond the driving environment, emotion elicitation could be applied to any emotion or behavioural research which requires an initial investigation in a simulated setting. Limitations of the simulated setting, particularly the influence on accurate emotional responses of participants (Coan and Allen, 2007), could be mitigated through the application of emotion elicitation.

Confusion and frustration, as the most frequently triggered emotional responses during the study, indicated that both states had a significant influence on the in-study driving experience, and may also play a significant role during general automobile driving. This knowledge may be applied for the future design of system components, e.g. the navigation system or infotainment system could be redesigned to mitigate the negative influences encountered during this study and improve the driving experience. Influences on negative emotions which cannot directly be avoided could be alleviated through an alternative route selection (e.g. avoidance of high traffic density) or coping strategies (e.g. music selection).

Nevertheless, results of this study, and any similar studies in the future, may be influenced by the simulated environment. While this study delivered insights on the use of both emotional elicitation and FEA in a simulated driving environment, potential limitations and weaknesses of the methods, and information on possible causes for emotions while driving, further tests need to be conducted in a real driving setting to validate results.

6 Study 2: On-Road Study for Observation of Emotional States in a Natural Setting

The previous study investigated the application of emotion elicitation in a driving simulator and the measurement of the triggered emotional responses through Facial-Expression Analysis (FEA). The study delivered important insights on emotions and their triggers during driving, and results confirmed that both emotion elicitation and FEA as a measurement tool may be successfully applied to simulator-based automotive research. Use of a controlled environment, however, created major limitations for the investigation of emotions, i.e. through circumstances not fully representative of on-road driving (Jones and Jonsson, 2005; Ray, 2007). Despite the successful application of emotion elicitation, there was a clear need to conduct further research in a real driving environment to ensure the validity of results and mitigate influences of the experimental setting, which confirmed that simulator-based studies are only suitable for early-stage investigations. Consequently, FEA was applied to investigate emotional responses of participants driving in a natural, uncontrolled environment. The specific choice of participants (n=22) driving in their own automobiles on routes familiar to them was intended to create an environment as close to natural driving as possible. The aim of the study was to gain a better understanding of human emotions, their natures, frequencies and causes in a real driving environment, and to validate results from the previous study. Results of the study were expected to: provide information on the importance and effect of specific causes of emotions during driving, identify avenues of improvement to consider when designing subsequent studies, and deliver information applicable to future automotive design and research.

6.1 Introduction

The influence of emotions on the driving task and driving experience can be inferred from the role of human emotion in activities such as goal generation, decision making, focus and attention, motivation, and performance (Eyben et al., 2010). The variety of possible impacts of emotional states in the driving environment makes emotion research in the automobile a rapidly-growing area of investigation (Michael, 2001; Miller 2001). Although the automation of emotion capture has been investigated by some previous research studies (Hoch et al., 2005; Mesken, 2006), the driver's emotional states have not been measured and analysed in detail in terms of frequencies of occurrence, natures and event triggers of emotional expressions. In fact, the lack of driving research describing the causes and influences of emotions has been specifically noted by previous researchers (Huguenin and Rumar, 2001; Mesken, 2006).

While some research studies (Levelt, 2003; Mesken, 2006; Parkinson, 2001; Underwood et al., 1999) have investigated frequencies of occurrence and/or causes for emotional responses, the existing investigations were limited through reliance on the method of self-assessment (Mesken et al., 2007). Self-assessment as a measurement tool is known for limitations caused by influences of decaying memory strength, and fading affect bias due to the delay in the rating of the emotions (Cerin, Szabo and Williams, 2001). Furthermore, no reliable estimates of emotion frequencies were reached through either of the studies due to the results being highly influenced by the selected methods and their application (Mesken et al., 2007).

In this study, FEA was applied as a measurement tool for the investigation of the occurrences, natures and frequencies of emotional states in a natural, real driving environment. The possibility of attributing event triggers, i.e. accurately detecting the causes of the emotion events, was explored. For this study, a natural setting was defined as participants driving their own cars along a familiar route (e.g. their daily commute). In this research, natures of emotion events included the six basic emotions and a selection of action units (standardised classifications describing contractions or relaxations of one or more facial muscles). Frequencies were defined as emotion events (certain facial expression which met the software's detection criteria) per second/minute per person. Causes for emotion events were triggers such as *long wait on a traffic light* or *social interaction*.

A better understanding of natures, frequencies and event triggers of emotional expressions in the driving environment could aid future design approaches, e.g. by addressing the most frequent emotional expressions and their causes to avoid or emphasise potential effects. Furthermore, this knowledge could be used for the formulation of automotive design criteria, and for scenario-creation or user journeys, tools frequently applied in automotive research to improve future automotive design (Gkouskos, Normark and Lundgren, 2014). Considering future developments in the automotive industry (e.g. self-driving cars), knowledge about an individual's emotional responses to certain stimuli could be used to build a predictive model and personalise the driving experience based on the driver's emotions. Similarly, a better understanding of emotion during driving could be applied to create an improved human-machine interaction.

The research hypothesis of the study was that high numbers of emotion events could be automatically measured in a natural setting during an average driving study length of 20 minutes per participant, and that observational analysis could permit the detection of the causes of the emotions in the vast majority of cases.

6.2 Methodology

6.2.1 Choice of Emotion Taxonomy

Research suggests adapting existing taxonomies for emotion research to the specific research context (Jeon, Walker and Yim, 2014). The taxonomy underlying this research is the Facial Action Coding System (FACS), the most common taxonomy for the coding of facial behaviour (Ekman, Friesen and Ellsworth, 2013; McDuff et al., 2016), consisting of action units (AUs) and the basic emotions (joy, anger, surprise, fear, disgust, sadness).

Sole reliance on the measurement of basic emotions has been criticised in previous research because of the relatively infrequent occurrence of basic emotions, and corresponding facial expressions varying significantly between participants (Shah et al., 2013; Tian, Kanade and Cohn, 2001). In practice, human emotions are often communicated through changes in only one or two discrete facial features (Tian, Kanade and Cohn, 2001). For this reason, several previous studies have combined research of the basic emotions with individual AUs in order to investigate the importance of both, major and minor changes in emotional expressions (Namba et al., 2017; Shah et al., 2013; Tian, Kanade and Cohn, 2001; Velusamy et al., 2011). In this research a combination of the investigation of the basic emotions and 6 AUs (lip press, inner brow raise, brow furrow, brow raise, lip pucker, lip corner pull) was chosen. The decision of which AUs to include in the analysis was based on the knowledge that AUs consisting of movement around the mouth or eyes are the strongest indicators of human emotion (Wegrzyn et al., 2017). In fact, the chosen individual AUs are known to communicate certain emotional states (Table 13).

Action units (corresponding FACS code)	**Basic emotions including the action unit**	**Indicated Emotion**	**Source**
LIP PRESS (24)	-	Anger Concentration	Cienki and Mittelberg, 2013; Duenwald, 2005; Tian, Kanade and Cohn, 2001
INNER BROW RAISE (1)	Sadness Surprise Fear	Surprise	Elliott and Jacobs, 2013
BROW FURROW (4)	Sadness Fear Anger	Displeasure	Russell and Fernández-Dols, 1997
BROW RAISE (2)	Surprise Fear	Surprise	Elliott and Jacobs, 2013
LIP PUCKER (18)	-	Anger Annoyance	Cienki and Mittelberg, 2013
LIP CORNER PULL (12)	Joy	Pleasure	Russell and Fernández-Dols, 1997

Table 13 Choice of action units

A visual of all measured AUs can be seen below (Figure 21).

Figure 21 Action units measured in this study (iMotions, 2013)

6.2.2 Measurement Equipment

As explained in Chapter 4.4 Data Collection and Analysis Methods, the quantitative data collection and analysis was conducted through the data acquisition and integration platform *iMotions AttentionTool* (iMotions, 2013). *iMotions* offers the integration of the *Affdex Affectiva* FEA tool, which was applied in this study. Like most FEA applications, the *Affdex Affectiva* tool is based on Ekman and Friesen's Facial Action Coding System (FACS) (McDuff et al., 2016). The FACS codes each observable facial movement as an action unit (AU), and a specific combination of these AUs represents one of the six basic emotions (joy, anger, surprise, disgust, fear, sadness). While facial expressions were coded by hand in the past, FACS has been well-established as a computed, automated system, avoiding subjectivity and time consumption issues (Ekman, Friesen and Ellsworth, 2013).

Affdex Affectiva is a real-time FEA tool kit, capable of observing the basic emotions as well as a collection of AUs which provide more information, and therefore deeper insights, on emotional facial expressions (Namba et al., 2017; Tian, Kanade and Cohn, 2001). The *Affdex Affectiva* face detection is performed through the Viola-Jones face detection algorithm and has been calibrated using an independent set of tens of thousands of facial images from around the world. Taken in natural conditions with different posture and lighting, they were subsequently coded by experts (McDuff et al., 2016). The software provides scores from 0 (absent) to 100 (present) with a suggested threshold of 50-70 (iMotions, 2013).

Although the software offers real-time measurement of emotional expressions, a customised additional application was created for use with the software. The need stemmed from the application of the software in the automotive environment; previous experience suggested this requires a slight adaptation of the measurement tool due to a high number of expressions, lighting changes (therefore false detections) and head movements of the driver. The purpose of the bespoke application was to identify emotion events and notify the researcher when they occur. Emotion events were identified when one of the basic emotion or AU channels was above threshold for a predefined amount of time (1 second). When the threshold condition was met, noise and anomalies were mitigated through an immediate median correction of the last 3 samples.

6.2.3 Vehicle Set-Up and Route

All participants were asked to drive in their own cars on a familiar route, such as their daily commute, for 20 minutes. To allow testing in a natural setting participants were asked to behave as they usually would during driving, and if possible ignore the researcher seated on the back-seat of the vehicle. In order to capture the driving environment and the driver's face, two cameras (Logitech C920 HD) were fixed in the automobile. The face camera (used for the FEA) was attached to the windshield with a suction cup and a flexible arm to allow it to be adjusted to suit each participant. The scene camera (to capture the driving environment) was fixed with a clamp and a flexible arm on the front passenger's head rest, facing towards the windshield of the automobile to capture the driving environment and parts of the dashboard (Figure 22).

Figure 22 Camera placement

Both cameras were placed such that they fulfilled the following requirements, listed with decreasing importance (Figure 23):

- Minimal intrusiveness and impact on the participant's visual field
- Robust placement, avoiding camera movement through vibration or car movement
- Face camera: ideal location to avoid interruption of data transfer due to the participant's head movement and minimise impact on the visual field
- Scene camera: Wide angle covering parts of the dashboard and the driving environment to collect as much information about the driving environment and potential event triggers as possible

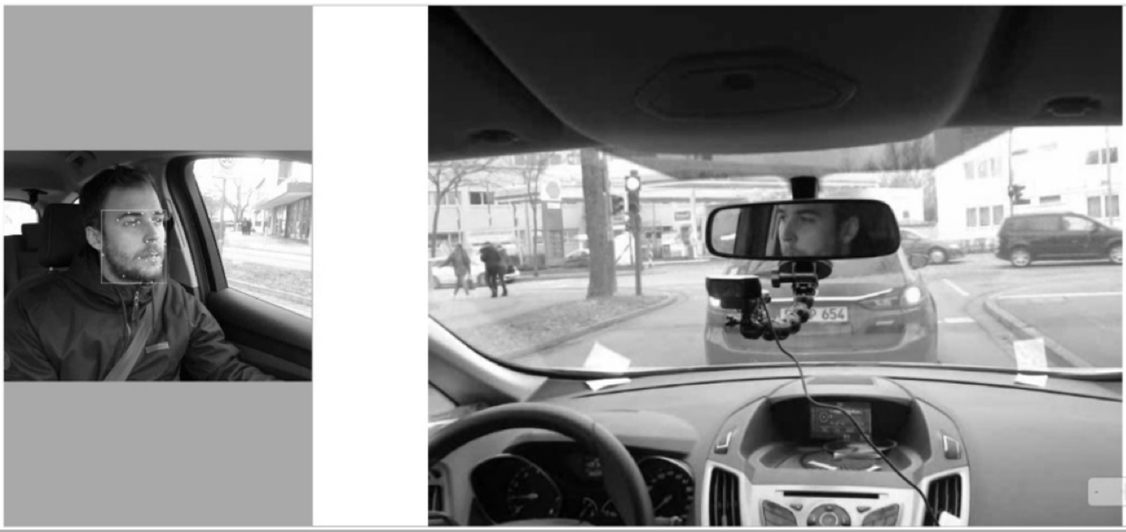


Figure 23 View of the face and scene camera during the study

Incoming data was analysed in real-time through the FEA software combined with the real-time thresholding application (6.2.2 Measurement Equipment). Binary values were recorded for emotion events occurring or not occurring. The six basic emotions (joy, anger, surprise, disgust, fear, sadness) and six AUs (brow raise, lip corner pull, lip press, brow furrow, inner brow raise, lip pucker) were reported. The video and FEA data was collated on a laptop (Lenovo ThinkPad t540p) by the researcher, seated in the back of the car.

6.2.4 Participant Selection and Recruitment

Following the previously suggested sampling strategy (Chapter 4.5.1 Sampling) a total of 22 participants took part in the study. All five driver types (angry n=2, anxious n=4, dissociative n=2, distress-reduction n=1, careful driver n=13) were represented in the study. A total of 14 male and 8 female participants took part in the study, covering four age groups (18-25, 26-34, 36-45, 46-55). Prior to all studies, the researcher performed a risk assessment of the participant's driving abilities and confidence in driving. The selection of participants and all phases of the study have been performed under the university's full ethics approval and in compliance with the university's ethics policy.

6.2.5 Data Analysis Approach

Quantitative Data Analysis: Statistical Analysis

Analysis was performed on the data set of emotion event occurrences. Following the initial real-time automated data collection, the full set of emotion events for all participants was collated and the frequencies of basic emotions and AU per minute/second were calculated separately. The full set of emotion events was then categorised into the six basic emotions and AUs to investigate their individual frequencies, which were then expressed as a percentage of total basic emotion events and AU events respectively.

Qualitative Data Analysis: Assignment of Triggers

Triggers were assigned to the emotion events by the researcher, both during and after the study and in an observational analysis. All triggers assigned during the study were revised afterwards, reviewing both the FEA and video data. If the researcher was unable to assign a trigger during the study due to the high volume of data, triggers were assigned afterwards. If no obvious event trigger could be identified through the observational analysis, the event was categorised as *no trigger assigned* (NTA). All emotion events and their triggers were collated in order to identify triggers which most frequently caused specific types of emotion events during the study.

6.3 Results

The total number of emotion events in the collective study time of 440 minutes with 22 participants was 730 emotional expressions. The total number of emotional expressions was divided in 218 basic emotional expressions (joy, anger, surprise, disgust, fear, sadness) and 512 AUs (brow raise, lip corner pull, lip press, brow furrow, inner brow raise, lip pucker). On average, one basic emotion was detected every 2 minutes, and one AU every 51 seconds. The frequencies of all emotion events are shown in Table 14 and 15.

Basic emotion event	n	% of all Emotion Events (total=218)
JOY	77	35
ANGER	13	6
SURPRISE	59	27
FEAR	0	0
DISGUST	62	28
SADNESS	7	3

Table 14 Frequencies of basic emotion events

Action units	n	% of all Emotion Events (total=512)
LIP PRESS	97	19
INNER BROW RAISE	122	24
BROW FURROW	72	14
BROW RAISE	115	22
LIP PUCKER	71	14
LIP CORNER PULL	35	7

Table 15 Frequencies of action units

All triggers assigned to the individual emotion events were then collected. Event triggers were assigned to 672 of the total of 730 (92%) emotion events. The most frequent trigger events are shown in Table 16, 17, 18 and 19 below.

Basic emotion event	JOY		ANGER		SURPRISE	
	n	Assigned trigger	n	Assigned trigger	n	Assigned trigger
Most frequently assigned trigger events	28	Interaction with another person	3	High traffic density	9	Interaction with another person
	17	Music/radio	3	Sun/light blinding	8	Bump on road
	7	NTA	2	Long wait at traffic light	5	Cut off by another driver
	3	Spotting friend	2	NTA	5	Traffic light changing

Table 16 Basic emotion events (joy, anger, surprise) with their most frequently assigned trigger events

Basic emotion event	FEAR		DISGUST		SADNESS	
	n	Assigned trigger	n	Assigned trigger	n	Assigned trigger
Most frequently assigned trigger events	-		8	Sun/light blinding	2	Sun/light blinding
			7	Long wait at traffic light	2	NTA
			4	High traffic density		
			2	NTA		

Table 17 Basic emotion events (fear, disgust, sadness) with their most frequently assigned trigger events

Action Units	LIP PRESS		LIP CORNER PULL		BROW RAISE	
	n	Assigned trigger	n	Assigned trigger	n	Assigned trigger
Most frequently assigned trigger events	14	High traffic density	9	High traffic density	27	Checking mirror
	13	Tight road passage	4	Roundabout	20	NTA
	9	Long wait at traffic light	4	NTA	9	High traffic density
	7	NTA			5	Speedbump

Table 18 Action units (lip press, lip corner pull, brow raise) with their most frequently assigned trigger events

Action Units	LIP PUCKER		INNER BROW RAISE		BROW FURROW	
	n	Assigned trigger	n	Assigned trigger	n	Assigned trigger
Most frequently assigned trigger events	8	High traffic density	10	Checking mirror	10	High traffic density
	7	NTA	10	Long wait at traffic light	9	NTA
	5	Sun/light blinding	9	Roundabout	9	Sun/light blinding
			9	Slow driver ahead	7	Infotainment change

Table 19 Action units (lip pucker, inner brow raise, brow furrow) with their most frequently assigned trigger events

6.4 Discussion

Technological and sociological influences are transforming the automotive industry (Gao et al., 2016). Previous developments in automotive research have suggested a growing importance of an improved understanding of driver's emotions, desires and needs (Gkatzidou, Giacomin and Skrypchuk, 2016). The aim of this study was to take the first steps towards developing a framework for modern human-centred automotive design by investigating the driver's emotional states through FEA. The on-road study investigated the natures, frequencies and event triggers of emotional expressions of 22 participants in a total study time of 440 minutes in a natural setting. The research hypothesis of this study was that high numbers of emotion events could be automatically measured in a natural setting and causes could be detected in the vast majority of cases through observational analysis.

6.4.1 Discussion of Natures and Frequencies of Action Units and Basic Emotions

A high number of emotional expressions in this study (n=730) and their frequencies, both of basic emotional expressions (one basic emotion every 2 minutes), and AUs (one AU every 51 seconds), confirmed the hypothesis that high numbers of emotion events could be automatically measured during driving in normal conditions. The high average frequencies of basic emotion (one basic emotion every 2 minutes), and AUs (one AU every 51 seconds) reinforced the notion that emotions may play a significant role during automobile driving. Comparable studies investigating natures and frequencies of emotions during driving recorded significantly less frequent emotional expressions (Levelt, 2003; Mesken et al., 2007; Parkinson, 2001; Underwood et al., 1999). While the significantly greater frequency of emotion detection in the current study may have appeared questionable, direct comparisons with the previous research were difficult due to the sole use of self-assessment in the previous studies and the choice of a different emotion taxonomy (Mesken et al., 2007). Self-assessment has well-known limitations caused by the delay in the rating of the emotions, due to influences of decaying memory strength and fading affect bias (Cerin, Szabo and Williams, 2001).

Most event triggers assigned to emotional responses were related to automobile driving which suggests that the results of this research are directly applicable to automotive design, for instance for the formulation of automotive design criteria to improve future automotive design (Gkouskos, Normark and Lundgren, 2014).

The investigation of frequencies of emotion events in the dataset suggested that joy was the most frequently occurring emotional expression (39% of all basic emotions), followed by disgust, surprise, anger, sadness and fear, in order of decreasing frequency. After reviewing similar research studies this is an unexpected outcome, as joy was previously found to be a rarely occurring emotion during driving (Tischler et al., 2007). When reviewing the event triggers, it was apparent that the high frequency of joy could be attributed to interactions with other people; for 38% of joy events the trigger event *interaction with another person* was assigned. Even though participants were asked to ignore the researcher seated in the back-seat, some interaction inevitably took place, often triggering joy or surprise. Furthermore, the comfort of participant driving in their own cars on familiar routes may have increased the likelihood of friendly interaction with other road users.

While surprise and disgust shared similar frequencies of occurrence (26-28%) in this dataset, anger and sadness occurred very rarely (2-5%) and fear was not detected at all. This could possibly have been caused by the fact that participants were driving in their own cars on familiar routes and therefore not being confronted with major challenges. The lack of occurrence of fear in this dataset was surprising, and should be investigated in further studies, for instance through the inclusion of more challenging road types or traffic situations.

The frequencies of AUs in this dataset were the highest for inner brow raise (24%) and brow raise (22%), followed by lip press (19%). Brow furrow and lip pucker shared the same frequencies (14%), and lip corner pull occurred the least frequently (7%). The most frequently measured AUs indicated high frequencies of surprise, followed by anger or concentration, and lower frequencies of displeasure, and anger or annoyance, with pleasure as the least frequent indicated state.

6.4.2 Comparison of AUs and Basic Emotion Events

Inner brow raise and brow raise (both indicating surprise) had higher frequencies than the basic emotion event surprise, indicating that the emotion of surprise may be more likely to be communicated through only one or two action units instead of the full basic emotional expression. In future work, it might be valuable to investigate how frequently both brow movements occur at the same time, to determine whether their frequencies can be compared directly. In this dataset lip corner pull occurred significantly less frequently than joy. As it is indicative of pleasure, it suggested that joy may be more likely to occur as the full basic emotion rather than individual constituent AUs. It could even be suggested that lip corner pull may not necessarily be an indication of pleasure, but instead an action of polite communication for example.

Lip press and lip pucker were ambiguous in that they both indicated anger, and also indicated concentration and annoyance respectively. When compared to anger in this dataset, both numbers of occurrences and frequencies were considerably higher. This might have indicated that anger is more likely to be communicated through single action units. This may also have suggested that anger may rarely occur in isolation in the automotive environment, but may be paired with other emotions, such as concentration or annoyance. This idea requires further investigation, as there is some ambiguity in what is indicated by both AUs.

Brow furrow, indicating displeasure, is included in the facial expression of most negative basic emotions (sadness, fear, anger). Compared to the three negative basic emotions, numbers of occurrences and frequencies of brow furrow were significantly higher in this dataset. It may be concluded that brow furrow is a better indicator for negative emotions than the negative emotional events themselves, as negative emotions may not necessarily result in a full emotional expression detected through FEA.

Results of the comparison of occurrence and frequencies of AUs and basic emotional expressions provided a degree of confidence that it is necessary to include AUs in emotion taxonomies for emotion research in automotive environments. Specific meanings and occurrences of AUs in comparison to basic emotions should be further investigated in future research.

6.4.3 Discussion of Event Triggers

Event triggers were successfully assigned to 672 of the 730 total emotion events (92%), which confirmed the hypothesis that a cause could be assigned to the vast majority of emotion events during automobile driving. In a similar study only 57% of event triggers were successfully assigned (Mesken et al., 2007). Although the exact cause of the discrepancy is unclear, this could be due to more information available on the interior and exterior driving environment, provided by superior camera placement in this research.

The most frequently occurring event triggers (and number of occurrences) for the basic emotions and AUs in this dataset were as follows:

- Joy: Interaction with another person (28), music/radio (17)
- Anger: High traffic density (3), sun/light blinding (3)
- Surprise: Interaction with another person (9), bump on road (8)
- Sadness: Sun/Light blinding (2)
- Disgust: Sun/Light blinding (8), long wait at traffic light (7)
- Lip press (indicating anger or concentration): High traffic density (14), tight road passage (13)
- Lip corner pull (indicating pleasure): High traffic density (9), roundabout (4)
- Brow Raise (indicating surprise): Checking mirror (27), high traffic density (9)
- Lip pucker (indicating anger or annoyance): High traffic density (8), sun/light blinding (5)
- Inner brow raise (indicating surprise): Checking mirror (10), long wait at traffic light (10)
- Brow furrow (indicating displeasure): High traffic density (10), sun/light blinding (9)

The most frequently assigned event triggers in this dataset indicated some of the main causes for both positive and negative emotion during driving. Knowledge of those could be applied for the development of affective human-machine interaction to avoid potential causes for negative emotions as well as enhance those for positive emotions to improve the driving experience. The most frequently assigned trigger events which triggered any of the basic emotional expressions included *interaction with another person*, *high traffic density*, *sun/light blinding* and *checking mirror*. *Interaction with another* *person* as one of the most frequent triggers did not seem surprising considering the automotive environment being highly interactive. *High traffic density*, *sun/light blinding* and *checking mirror* are emotion triggers closely connected to the driving task and therefore a logical result. In this dataset the most frequently occurring event triggers for the AUs included *high traffic density, tight road passage, checking mirror, sun/light blinding* and *long wait at traffic light*, which was a clear indication of those triggers, once again connected to the driving task, having had a significant impact on human emotion while driving. Similar conclusions could be drawn about the remaining trigger events. In future studies, more road types, potentially challenging traffic situations and use of infotainment could be included to investigate the influence of other possible stimuli connected to automobile driving.

When AUs and basic emotion events were compared for this dataset, it became evident that the three out of four of the most frequently assigned event triggers are identical for anger, lip pucker and lip press, which indicated that the anger basic emotion and the AUs lip pucker and lip press were associated with a similar emotional experience. In contrast, triggers for joy and lip corner pull could not be compared. In fact, triggers for lip corner pull matched those of negative emotions. Similarly, triggers were not shared for surprise, inner brow raise and brow raise. Similarities in the causes of both basic emotional expressions and their constituent (separately occurring) AUs should be investigated in further research, to identify links or discrepancies.

The collected data suggested *that high traffic density* was one of the major event triggers for negative emotions during driving. This knowledge could be used for future design ideas, e.g. intelligent systems avoiding high traffic density in order to prevent negative emotions occurring during driving. Furthermore, the insight that positive emotions in this dataset were often triggered through *interaction with another person* and the *use of the radio* could be investigated and incorporated into future automobile design for the enhancement of a positive driving experience.

These results suggest that through on-road studies aiming for an investigation of natures, frequencies and event triggers, valuable information on emotional responses in the automotive environment can be collected. The research may be used for the improvement of the emotional experience in existing and future automotive design, for instance through the prevention of negative impacts and the enhancement of positive effects. Another future application of the knowledge gained through this research could be the creation of an emotion framework for affective human-machine interaction, to help create a better communication, decrease workload and improve the driving experience.

6.5 Threats to Validity

In the following, the most obvious threats to validity are listed and explained, including the researcher's presence in the automobile, bias in the assignment of trigger events and the experimental setting.

Researcher's Presence in the Automobile

The researcher being present in the automobile throughout the study might have impacted the study results (experimenter bias). Possible effects could have included, alteration of the participant's normal driving style, changes in the participant's behaviour and restricted emotional expressions. To avoid negative effects of the researcher's presence in the automobile on the participant's behaviour, driving style and emotional expressions, the researcher was seated on the back-seat of the automobile and all communication between researcher and participant was avoided throughout the study when possible.

Assignment of Trigger Events

The assignment of trigger events to the emotional expressions during the study was conducted by only the researcher. The experimenter bias may have influenced the study results. In future studies the researcher's assignment should be validated by multiple researchers through an inter-observer reliability test.

Experimental Setting

The experimental setting may have influenced the research results, leading to the rare occurrence of fear and sadness, possibly due to covering a route familiar to the participant and a relatively safe and comfortable driving environment with no major challenges. To avoid possible effects of the experimental setting, a larger variety of routes, road types and driving situations should be tested in the future.

6.6 Conclusions

In this research, 22 participants' emotions and their causes were explored in a real-driving environment under natural circumstances. High frequencies of emotion events in this dataset confirmed the theory that emotions are of high importance in the automotive environment. The study results helped gain a better understanding of the natures, frequencies and event triggers of emotional responses in the automotive environment. The study explored which emotional expressions occur most frequently and which triggers had the most significant influence on the emotional experience in the automobile in a normal setting. The successful assignment of trigger events to the emotional expressions delivered insights which can be directly applied to future automotive design.

In this dataset, joy was the most frequently occurring emotional expression, triggered primarily through interaction with other people. The rare occurrence of anger and sadness, and complete lack of measurements of fear, were surprising, as these may be expected in an on-road study. The most frequently occurring AUs indicated that surprise and anger or concentration played significant roles during the study, although these links cannot be made with absolute certainty due to lack of research specifically addressing AUs in the automotive environment. Contradictory results in the frequencies of AUs and basic emotions (i.e. the emotion indicated by the most commonly occurring AU was not the most commonly measured basic emotion) emphasised the need to include AUs in emotion taxonomies for emotion research in the automotive environment. The most frequently assigned trigger events in the study were *interaction with another person* and *use of the radio* for positive emotional responses, and *checking mirror* and *high traffic density* for negative emotional responses. This confirmed the possibility that emotions could be directly linked to their causes during automobile driving.

The outcome of this research can help to create datasets or design scenarios which could be applied in research for automotive design (Gkouskos, Normark and Lundgren, 2014). Furthermore, information on influences of the driver's interaction with the environment, and the environment affecting the driver can help with the formulation of automotive design criteria. An improved understanding of the driver's emotions and their triggers in the automotive habitat presents the first steps towards a more human-centred approach to automotive design. In consideration of recent and future developments in the automotive field and the need for a transformation of the traditional automotive design process, this research created an opportunity for the application in both current and future design decisions.

In future research studies, more road types and driving situations should be included in the study. The investigation of emotions on a larger variety of roads and in different situations could deliver further insights on the driver's responses. Additionally, tests should take place in only one research automobile, travelling along the same road circuit, in order to make emotional responses more comparable between participants. The impact of certain road types on the emotional experience should be further investigated.

7 Study 3: On-Road Study for Observation of Emotional States in a Partially Controlled Setting

In the previous study, the natures, frequencies and triggers of emotion events were investigated. Key limitations of the previous study included difficulties in the comparison of emotional responses between participants; these were attributed to the natural setting. Additionally, the results might have been influenced by bias introduced by the fact that a single researcher performed the assignment of trigger events. Another possible limitation was that the specific choice of a familiar driving environment might not have triggered the same responses that a less familiar environment would have triggered. The results of the study indicated that an investigation into the influences of different road types on emotional responses during driving was feasible and likely to be highly informative. The research discussed in this chapter addressed most suggestions and limitations introduced in the previous chapter through a partially controlled study in a research automobile on a pre-planned road circuit. Results of the qualitative data analysis were validated.

7.1 Introduction

The automotive industry is undergoing large developments and major changes. These include the development of more sophisticated infotainment systems, connected automobiles, partly autonomous features such as self-parking systems and lane keeping systems, and the research and testing of fully autonomous and self-driving software (Lardinois, 2012). The integration of features such as growing numbers of sensors and cameras, artificial intelligence, advanced GPS systems, and vehicle to vehicle communication, are producing ever-increasing volumes of information and data (Manyika et al., 2013); effective integration and compatibility with occupants calls for a transformation of the traditional design approach of the automotive industry.

A general understanding of emotions is not only a topic of great interest for private and academic researchers, but more importantly necessary for the future of the automotive industry. With the automobile increasingly taking over traditionally manual driving tasks, enabled by increasing the amount of technology in the automobile, the importance of human-machine interaction is reaching new highs. In order to improve this interaction, it is necessary for the automobile to understand human behaviour and emotion and respond on an affective level (Shaikh and Krishnan, 2013).

Multiple approaches have been taken to improving the understanding and knowledge of human emotion in the automotive habitat. Affective computing has been applied with high success rates (Healey, 2000; Lisetti and Nasoz, 2005). No standardised framework for the investigation of emotions has been developed until this point in research, owing to the use of a variety of measurement techniques, the investigation of different sets of emotions and differences in approaches (Chapter 3.2 Emotion Measurement in Automobile Research). Results vary considerably, and cannot be compared due to significant limitations or differences between methodologies. This issue is currently preventing progress being made towards the required understanding of human emotion during automobile driving. Furthermore, research specifically investigating natures, frequencies of occurrence and causes of emotional states is limited (Huguenin and Rumar, 2001) and highly influenced by the applied methods and their corresponding limitations (Mesken et al., 2007). The need was therefore found to investigate a set of emotional states systematically through Facial-Expression Analysis (FEA), a non-intrusive, non-contact measurement tool on a road circuit covering different driving situations and road types.

This study's research hypothesis was that high numbers of emotion events could be automatically measured in a partially controlled setting during an average driving study length of 40 minutes per participant, and that observational analysis could permit the detection of the causes of the emotions in the vast majority of cases. Natures, frequencies and causes of emotional states for different road types were observed.

7.2 Methodology

7.2.1 Choice of Emotion Taxonomy

The emotion taxonomy chosen for this study was the Facial Action Coding System (FACS) (Ekman, Friesen and Ellsworth, 2013). The FACS consists of action units (AUs) and the basic emotions (joy, anger, surprise, fear, disgust, sadness). As recommended in previous research (Namba et al., 2017; Shah et al., 2013; Tian, Kanade and Cohn, 2001; Velusamy et al., 2011), the investigation of both AUs and the basic emotions was combined for this study. The choice of AUs (lip press, inner brow raise, brow furrow, brow raise, lip pucker, lip corner pull) was based on previous research (Introduced in Chapter 6.2.1 Choice of Emotion Taxonomy; Table 13).

7.2.2 Measurement Equipment

The *iMotions Attention Tool* data acquisition and integration platform (iMotions, 2013) with the integrated FEA tool *Affdex Affectiva* was chosen as a software tool for the on-road study. A customised additional application was created for the real-time use of the tool in the automotive environment (Introduced in Chapter 6.2.2 Measurement Equipment). Following the same approach as the previous chapter, a selection of basic emotions (joy, anger, surprise, disgust, sadness, fear) and AUs (brow raise, lip corner pull, lip press, brow furrow, inner brow raise, lip pucker) was analysed in this study.

7.2.3 Test Vehicle and Set-Up

The research automobile was a Land Rover Discovery Sport SE eD4 150PS, provided by Jaguar Land Rover for the duration of the study and insured by

Brunel University for all students and staff members. The 4-wheel drive automobile had a 2.0L 4-cylinder diesel engine and a manual transmission. Two cameras (Logitech C920 HD) were fixed in the automobile to capture the driver's face and the driving environment. Flexible fixtures were chosen to allow easy adjustment of placement and angle of the camera to suit the different physical dimensions of participants. More detailed information on the camera placement is given in Chapter 6.2.3 Vehicle Set-Up and Route. The FEA software, in combination with the real-time thresholding application (6.2.2 Measurement Equipment) analysed incoming data in real-time and recorded binary values for an emotion event occurring or not occurring. The six basic emotions (joy, anger, surprise, disgust, fear, sadness) and six AUs (brow raise, lip corner pull, lip press, brow furrow, inner brow raise, lip pucker) were reported. The video and FEA data was collated on a laptop (Lenovo ThinkPad t540p) by the researcher, seated in the back of the car.

7.2.4 Road Circuit Selection

Existing automotive studies (Miller, 2013; Schweitzer and Green, 2007) recommend the combination of three different road types for either the planning of road circuits or the comparison between them: rural, urban and major roads. A ratio of these three road types recommended in human factors and ergonomics research is 40% rural roads, 40% urban roads and 20% major roads (Giacomin and Bracco, 1995). When planning the road circuit, the definition of road types (major, urban, rural) according to the UK Department for Transport (DFT, 2017, p.1-2) was followed (Table 20).

Road Type	**Definition**
Major roads	Includes motorways and all 'A' roads. These roads usually have high traffic flows and are often the main arteries to major destinations.
Urban roads	These are major and minor roads within a settlement of population of 10,000 or more. The definition is based on the 2001 Communities and Local Government definition of Urban Settlements.
Rural roads	These are major and minor roads outside urban areas (these urban areas have a population of more than 10,000 people).

Table 20 Definition of road types according to the UK Department for Transport (DFT, 2017, p.1-2)

An attempt was made to not only cover the suggested three road types but also to respect the suggested ratio in the restricted study time. The obligation to comply with Brunel University legal and ethical protocols (i.e. study length restricted to a maximum of one hour, any route point was required to be within 30 minutes of the university campus in case of emergency) placed restrictions on the routes available for use during the study. Optimisation of available routes within the required 30 minute radius of the university, permitted a final configuration of (Figure 24):

1. Urban roads: 4.5 miles (30%)
2. Rural roads: 4.0 miles (26%)
3. Major roads: 6.7 miles (44%)

Figure 24 Road types (white – urban roads, black – major roads, grey – rural roads)

Furthermore, the following driving and road situations were covered in the planned road circuit (Figure 25, Table 21):

1. Roundabouts

2. Poor road conditions (e.g. potholes, eroding roads)
3. Limited visual field (e.g. dense vegetation, winding road)
4. Speed Bumps
5. Bus stops and pedestrians crossing road

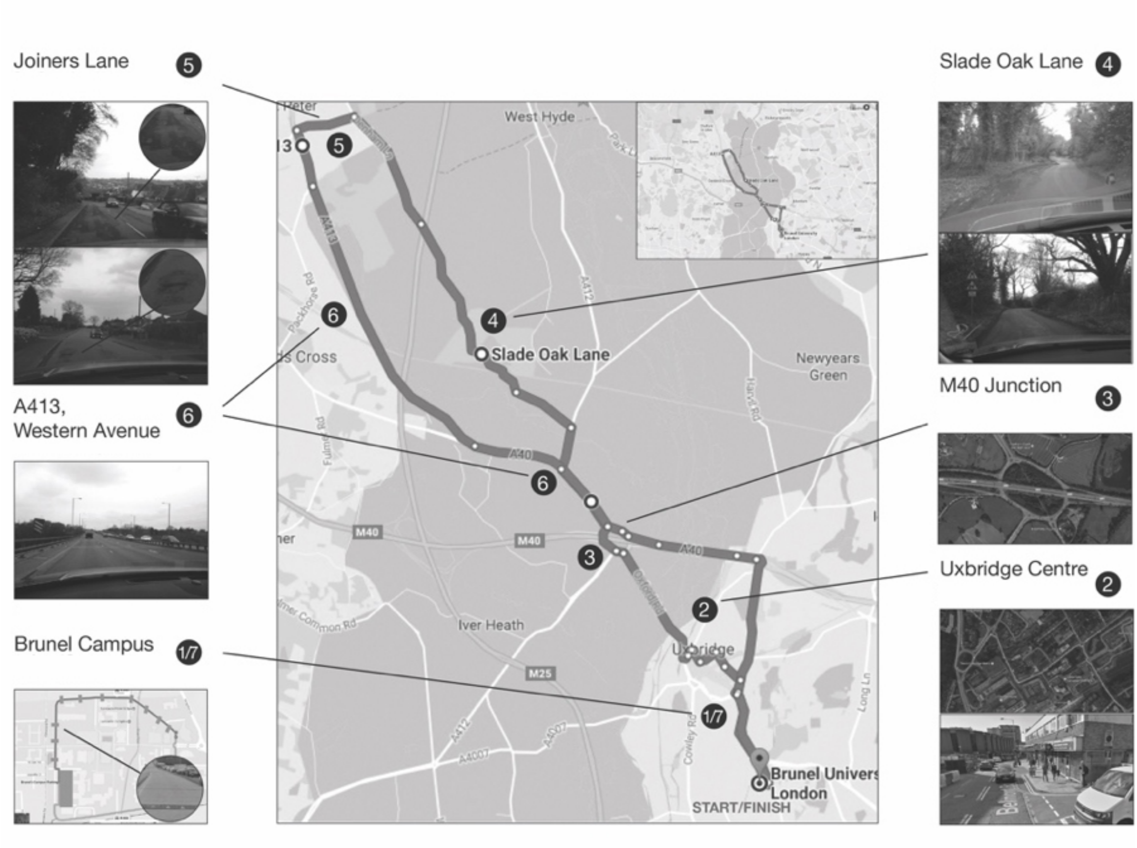


Figure 25 Explanation of the road circuit

Number	**Explanation**
1 (Starting Point)	The starting point was at the university car park. Leading over 11 speed bumps, leaving university through 3 roundabouts
2	Urban road leading towards and through the town centre, with high traffic density, pedestrians crossing and buses blocking the road
3	Oxford Road towards the M40 Junction
4	Slade Oak Lane: a rural road with poor road conditions and a limited visual field due to dense vegetation and a winding road lay-out
5	Joiners Lane: a road with very poor road conditions and a narrow road often blocked by parked vehicles
6	The driver is navigated back to university over the major roads A412 and Western Avenue
7 (End)	University car park

Table 21 Detailed explanation of the road circuit

7.2.5 Participant Selection and Recruitment

Following the previously suggested sampling strategy (Chapter 4.5 Sampling, Ethics, Reliability and Validity, Limitations), a total of 21 participants took part in the study. All five driver types (angry n=4, anxious n=2, dissociative n=1, distress-reduction n=1, careful driver n=13) were represented in the study. A total of 14 male and 7 female participants took part in the study, covering 4 age groups (18-25, 26-34, 36-45, 46-55). Prior to all studies the researcher performed a risk assessment of the participant's driving abilities and confidence in handling the research automobile. The selection of participants and all phases of the study have been performed under the university's full ethics approval and in compliance with the university's ethics policy.

7.2.6 Data Analysis

A multi-method approach of combining quantitative and qualitative data analysis was applied for this research (Figure 26).

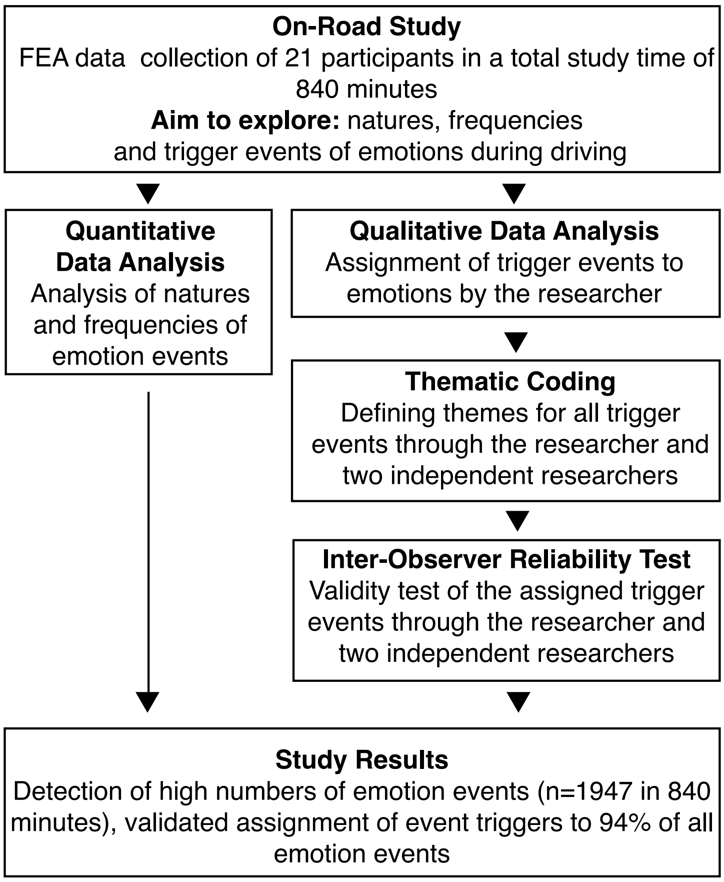


Figure 26 Visual of the qualitative and quantitative data analysis

Both the quantitative and quantitative data analysis steps are explained in detail below.

7.2.7 Data Analysis Approach

Quantitative Data Analysis

Analysis was performed on the data set of emotion event occurrences. Following the initial real-time automated data collection, the full set of emotion events for all participants was collated, and the frequencies of the total numbers of basic emotions and AUs per minute/second were calculated separately. The full set of emotion events was categorised into the six basic emotions and AUs in order to investigate their individual frequencies, which were then expressed as a percentage of total basic emotion events and AU events respectively.

Qualitative Data Analysis: Assignment of Event Triggers

Triggers were assigned to each individual emotion event by the researcher. The assignment was conducted both during the study by the researcher, seated in the back seat of the automobile, and after the study when all video and FEA material was reviewed. Triggers were assigned to investigate causes of specific emotion events in the collected data set. If no obvious event trigger was evident, the event was categorised as *no trigger assigned* (NTA). All emotion events and their triggers were collated to identify triggers which most frequently caused specific types of emotion events during the study.

Qualitative Data Analysis: Thematic Coding of the Qualitative Data

The method of thematic coding was chosen for purposes of qualitative data analysis in order to adopt a grounded theory approach for the identification of important themes (Gray, 2013). The aim of the chosen approach was to categorise the event triggers which were assigned to the basic emotional expressions and AUs into themes and subthemes (Boyatzis, 1998; Braun and

Clarke, 2006). The themes were identified to simplify the inter-observer reliability test as suggested in previous research (Armstrong et al., 1997).

In addition to the researcher, two independent researchers familiar with coding and theme generation were asked to complete the thematic coding in order to reduce bias and subjectivity (Burnard, 1991). To obtain a range of perspectives, the coders were drawn from different backgrounds, age groups and genders (Berends et al., 2005). As suggested in previous research (Braun and Clarke, 2006) the following procedure was applied:

1. Familiarisation of all researchers with the data
2. Creation of initial codes across the entire data set
3. Search for themes by collating the codes
4. Reviewing of the themes with respect to steps 1, 2
5. Defining and naming the themes

Qualitative Data Analysis: Validation Through Inter-Observer Reliability (IOR) Test

To ensure validity and minimise experimenter bias (Armstrong et al., 1997) of the assignment of event triggers to emotion events, an IOR test was chosen. For this task, the two independent researchers who completed the thematic coding were asked to complete the same assignment exercise as the researcher for 10% of the total sample (Armstrong et al., 1997). As suggested in previous research (Armstrong et al., 1997; Marques and McCall, 2005) the following procedure was followed:

1. Training in the assignment of triggers was provided to all researchers
2. Camera footage showing the five seconds prior to and after the identified emotion event was reviewed in order to assign one of the previously defined themes
3. The degree of agreement was evaluated between the observers

7.3 Results

7.3.1 Nature, Frequencies and Triggers of Emotional Events

In the collective study time of 840 minutes for all 21 participants, the total number of emotion events was 1947 emotional expressions. The total number of emotional expressions was divided into 556 basic emotional expressions (joy, anger, surprise, disgust, fear, sadness) and 1387 AUs (brow raise, lip corner pull, lip press, brow furrow, inner brow raise, lip pucker). On average one basic emotion was detected every 1.5 minutes, and one AU every 36 seconds. The frequencies of all emotion events are shown in Table 22 and 23.

Basic emotion event	n	% of all emotion events (n=556)
JOY	147	26
ANGER	112	20
SURPRISE	115	21
FEAR	12	2
DISGUST	121	22
SADNESS	53	9

Table 22 Frequencies of basic emotion events

Action unit	n	% of all emotion events (n=1387)
LIP PRESS	274	20
INNER BROW RAISE	270	20
BROW FURROW	252	18
BROW RAISE	268	19
LIP PUCKER	112	8
LIP CORNER PULL	211	15

Table 23 Frequencies of Action units

Furthermore, all triggers assigned to the individual emotion events were collected. Event triggers were assigned to 1834 of the total of 1947 (94%) emotion events. The most frequent trigger events are shown in Table 24, 25, 26 and 27 below.

Basic emotion event	JOY		ANGER		SURPRISE	
	n	Assigned trigger	n	Assigned trigger	n	Assigned trigger
Most frequently assigned trigger events	64	Enjoying driving car	22	Poor road conditions	23	Checking navigation
	28	NTA	13	Navigation alert	21	Navigation alert
	22	Interaction with another person	11	Car passing close	12	High traffic density
	4	High traffic density	9	Scratching face	9	Navigation recalculating
	3	Poor road conditions	8	Sun blinding	7	NTA
	3	Navigation problems	7	NTA	23	Checking navigation

Table 24 Basic emotion events (joy, anger, surprise) with their most frequently assigned trigger events

Basic emotion event	FEAR		DISGUST		SADNESS	
	n	Assigned trigger	n	Assigned trigger	n	Assigned trigger
Most frequently assigned trigger events	5	NTA	28	High traffic density	8	Navigation alert
	3	Navigation alert	22	Poor road conditions	6	Poor road conditions
	2	Scratching face	12	Checking navigation	6	NTA
	1	Problems reversing	10	Scratching face	5	Sun blinding
	1	Check navigation	9	Interaction with another person	4	Check navigation
	5	NTA	8	Navigation alert	3	High traffic density

Table 25 Basic emotion events (fear, disgust, sadness) with their most frequently assigned trigger events

Action unit	LIP PUCKER		INNER BROW RAISE		BROW FURROW	
	n	Assigned trigger	n	Assigned trigger	n	Assigned trigger
Most frequently assigned trigger events	16	Checking navigation	45	Poor road conditions	43	Checking navigation
	14	High traffic density	36	Checking navigation	33	Navigation alert
	7	Roundabout	35	High traffic density	32	High traffic density
	5	Car passing close	20	Limited visual field	20	Roundabout
	4	Poor road conditions	13	Navigation alert	17	Poor road conditions
	4	Limited visual field	13	NTA	14	NTA

Table 26 Action units (lip pucker, inner brow raise, brow furrow) with their most frequently assigned trigger events

Action unit	LIP PRESS		LIP CORNER PULL		BROW RAISE	
	n	Assigned trigger	n	Assigned trigger	n	Assigned trigger
Most frequently assigned trigger events	42	Checking navigation	39	Checking navigation	37	Poor road conditions
	40	High traffic density	15	Poor road conditions	18	Checking navigation
	20	Poor road conditions	12	High traffic density	14	High traffic density
	13	Limited visual field	12	NTA	11	NTA
	10	Navigation alert	11	Limited visual field	9	Scratching face
	9	Roundabout	9	Car passing close	8	Car passing close

Table 27 Action units (lip press, lip corner pull, brow raise) with their most frequently assigned trigger events

7.3.2 Typical Frequencies of Emotional Events on Different Roads

In order to compare the frequencies of emotional events on different road types, all emotional events on the urban, rural and major roads were collected and compared (Table 28).

Road type	Total time (seconds)	Total basic emotional events and action units	Emotional expressions per second	% difference from average
URBAN	22650	812	0.036	1%
MAJOR	21998	626	0.028	-20%
RURAL	12521	529	0.042	19%
		Average emotional expressions per sec	0.036	

Table 28 Frequencies of emotional expressions and action units on different road types

To test the reliability of the data, the standard deviation (σ) was calculated as $\sigma = 0.0160498$. Since a low standard deviation suggests a reliable mean, it could be more confidently concluded that, in order of decreasing frequency of emotional expression, road types were: rural, urban, major (Lazar, Feng and Hochheiser, 2017). To further investigate the frequencies of emotional expressions on different road types, the nature of emotional expressions and trigger events for those were explored. In the following, these are shown for the individual road types.

Urban Roads

The tables below describe the frequencies of basic emotional events (Table 29) and AUs (Table 30) as well as the most frequent event triggers (Table 31) on urban roads.

Basic emotional event	n	% of all emotional events (n=197)
JOY	48	24
ANGER	36	18
SURPRISE	48	24
FEAR	5	3
DISGUST	43	22
SADNESS	17	9

Table 29 Frequencies of basic emotional events on urban roads

Action units	n	% of all emotional events (n=615)
LIP PRESS	173	28
INNER BROW RAISE	140	23
BROW FURROW	83	13
BROW RAISE	91	15
LIP PUCKER	32	5
LIP CORNER PULL	96	16

Table 30 Frequencies of action units on urban road

Most frequent event triggers (urban roads)

n	Assigned Trigger
27	Navigation alert
21	Enjoying driving car
20	NTA
14	High traffic density
13	Checking navigation
9	Interaction with another person

Table 31 Most frequent event triggers on urban roads

Major Roads

The tables below describe the frequencies of basic emotional events (Table 32) and AUs (Table 33) as well as the most frequent event triggers (Table 34) on major roads.

Basic emotional event	n	% of all emotional events (n=223)
JOY	50	22
ANGER	44	20
SURPRISE	42	19
FEAR	0	0
DISGUST	70	31
SADNESS	17	8

Table 32 Frequencies of basic emotional events on major roads

Action units	n	% of all emotional events (n=397)
LIP PRESS	79	20
INNER BROW RAISE	74	19
BROW FURROW	93	23
BROW RAISE	53	13
LIP PUCKER	27	7
LIP CORNER PULL	71	18

Table 33 Frequencies of action units on major roads

Most frequent event triggers (major roads)

n	Assigned Trigger
91	Checking navigation
69	High traffic density
23	NTA
29	Poor road conditions
18	Navigation alert
15	Interaction with another person

Table 34 Most frequent event triggers on major roads

Rural Roads

The tables below describe the frequencies of basic emotional events (Table 35) and AUs (Table 36) as well as the most frequent event triggers (Table 37) on rural roads.

Basic emotional event	n	% of all emotional events (n=136)
JOY	31	23
ANGER	19	14
SURPRISE	40	29
FEAR	1	1
DISGUST	31	23
SADNESS	14	10

Table 35 Frequencies of basic emotional events on rural roads

Action Unit	n	% of all emotional events (n=393)
LIP PRESS	100	25
INNER BROW RAISE	90	23
BROW FURROW	56	14
BROW RAISE	77	20
LIP PUCKER	18	5
LIP CORNER PULL	52	13

Table 36 Frequencies of action units on rural roads

Most frequent event triggers (rural roads)	
n	Assigned Trigger
37	Poor road conditions
21	Enjoying driving car
16	Car passing close on narrow road
14	Interaction with another driver
11	Checking navigation
9	Limited visual field

Table 37 Most frequent event triggers on rural roads

7.3.5 Event Trigger Themes

In order to categorise all collected event triggers into event trigger themes, a thematic coding task was performed (Boyatzis, 1998; Braun and Clarke, 2006). As well as the researcher, two independent researchers familiar with thematic coding categorised all event triggers independently following thematic analysis guidelines (Braun and Clarke, 2006). The assigned event triggers were then discussed between the researchers and finalised into the following themes (Figure 27) based mainly on the logical criteria of:

1. Define what initiated the action.
2. Define where the initiator was.
3. Define what was affected by the action.

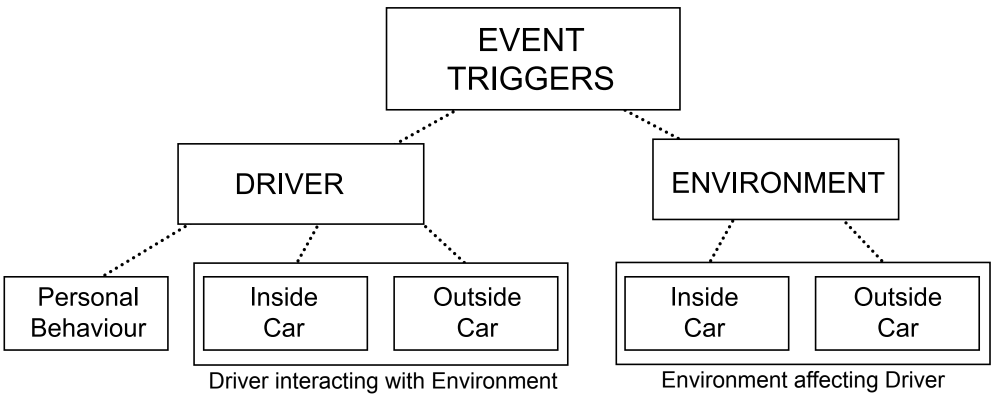


Figure 27 Event trigger themes

7.3.6 Inter-Observer Reliability (IOR)

To ensure validity and avoid experimenter bias (Armstrong et al., 1997) for the assignment of event triggers, the same two independent researchers were chosen to complete an IOR task alongside the researcher. Event trigger themes were defined through a previous coding exercise to simplify the task (Marques and McCall, 2005). After receiving training and detailed instructions, all researchers completed the coding of 10% of the basic emotional expressions recorded. Due to the large volume of the data collected, the decision was made to focus solely on the basic emotional expressions for this task. One of the five event themes (created using thematic coding) was assigned to each expression. All researchers agreed on coding themes for 46 of 67 expressions, 68.7% of the sample (Table 38). Thus, the target reliability rate minimum of 66.7%, suggested in previous research (Butler et al., 1998), was met.

	Sample	**All researchers agreed**	**One or more disagreements between all researchers**
n	67	46	21
Percent of sample	100	68.7	31.3

Table 38 Results from the IOR task

7.4 Discussion

The aim of this research was to take the first steps towards developing a framework for modern human-centred automotive design by investigating the driver's emotional states through FEA. The on-road study investigated the natures, frequencies and event triggers of the emotional expressions of 21 participants, in a total study time of 840 minutes on a predefined road circuit covering different driving situations and road types. The research hypothesis was that high numbers of emotion events could be automatically measured in a partially controlled setting during an average driving study length of 40 minutes per participant, and that observational analysis would permit the detection of the causes of the emotions in the vast majority of cases. Natures, frequencies and causes of emotional states could be assigned to different road types.

The high number of emotional expressions in this study (1947) confirmed the research hypothesis that high numbers of emotion events could be automatically measured in a partially controlled driving study. The high average frequencies of basic emotion (one basic emotion every 1.5 minutes), and AUs (one AU every 36 seconds) reinforced the notion that emotions play a significant role during automobile driving. Results of comparable studies investigating natures and frequencies of emotions during driving differ considerably, with significantly less frequent emotional expressions (Levelt, 2003; Mesken et al., 2007; Parkinson, 2001; Underwood et al., 1999). While the approach of a frequency investigation in previous studies was similar to this research, the methodology of this study cannot be compared to previous studies due to other research mainly focusing on self-assessment and different emotion taxonomies (Mesken et al., 2007).

7.4.1 Discussion of Natures and Frequencies of Action Units and Basic Emotions

Upon considering the frequencies of the individual types of emotion events detected during the study, it became apparent that joy (26%) was the most frequently occurring emotion. Compared to similar research studies this is an unexpected outcome, as joy was previously found to be a rarely occurring emotion during driving (Tischler et al., 2007). Similarly surprising were the low frequencies of fear (2%) and sadness (9%), especially as fear is an emotion typically associated with automobile driving (Sheller, 2004). The percentages of total emotion events measured were very comparable for disgust (22%), surprise (21%) and anger (20%). Individual percentages of the AUs were relatively evenly distributed between lip press (20%), inner brow raise (20%), brow furrow (18%) and brow raise (19%). Both lip corner pull (15%) and lip pucker (8%) occurred less frequently. The most frequently measured AUs indicated high frequencies of anger or concentration, surprise and displeasure (Table 13). Less frequently occurring AUs (lip pucker, lip corner pull) indicated lower frequencies of pleasure and anger or annoyance.

7.4.2 Comparison of AUs and Basic Emotion Events

Similarly to results in Study 2 (Chapter 6.4.2 Comparison of AUs and Basic Emotion Events), inner brow raise and brow raise (both indicating surprise) had higher frequencies than the basic emotion event surprise, indicating that the emotion surprise might be more likely to be communicated through only one or two action units instead of the full basic emotional expression. Unlike in Study 2, lip corner pull (n=211) occurred more frequently than joy (n=147). Contradictory results might indicate major influences of the different study settings. Potential influences were investigated in Chapter 8. Brow furrow, indicating displeasure, is included in most negative basic emotions (sadness, fear, anger). Numbers of occurrences and frequencies of brow furrow seemed comparable to those of the three negative basic emotions. As mentioned in Study 2, results of the comparison of occurrence, and frequencies, of AUs and basic emotional expressions provided a degree of confidence that it might be necessary to include the measurement of AUs in FEA for automotive environments. Further research is needed to investigate the specific meanings and occurrences of AUs compared to basic emotions.

7.4.3 Discussion of Event Triggers

Event triggers were successfully assigned to 1834 of the 1947 total emotion events (94%), which confirmed the hypothesis that triggers could be accurately attributed to their corresponding emotions during automobile driving. Once again this was a higher success rate than previous studies reached and could possibly be attributed to superior camera placement.

The most frequently occurring event triggers for the basic emotions were as follows:

- Joy: Enjoying driving the car (64), interaction with another person (22)
- Anger: Poor road conditions (22), navigation alert (13)
- Surprise: Checking navigation (23), navigation alert (21)
- Sadness: Navigation alert (8), poor road conditions (6)
- Disgust: High traffic density (28), poor road conditions (22)
- Fear: Navigation alert (3)
- Lip press (indicating anger or concentration): Checking navigation (42), high traffic density (40)
- Lip corner pull (indicating pleasure): Checking navigation (39), poor road

conditions (15)

- Brow Raise (indicating surprise): Poor road conditions (37), checking navigation (18)
- Lip pucker (indicating anger or annoyance): Checking navigation (16), high traffic density (14)
- Inner brow raise (indicating surprise): Poor road conditions (45), checking navigation (36)
- Brow furrow (indicating displeasure): Checking navigation (43), Navigation alert (33)

This displayed a clear indicator of some of the primary causes of both positive and negative emotion during driving. These insights could be used to direct the development of affective human-machine interaction by avoiding causes of negative emotions and enhancing causes of positive emotions in order to improve the driving experience. Upon inspecting the most frequently assigned trigger events, significant effects of the type of car, social interaction, the road conditions, the infotainment system, and the traffic density were visible. The most frequently occurring event triggers for the AUs included *checking navigation* and *poor road conditions*, which again was a clear indication of both triggers having had a significant impact on human emotion while driving.

A comparison of the most frequently assigned event triggers between the AUs and basic emotional events showed, as with the previous study, a high similarity in event triggers for anger, lip pucker and lip press. Lip corner pull and joy again did not share the same most frequent trigger events. In contrast to results of Study 2, event triggers of surprise, inner brow raise and brow raise were highly similar. Similarly, triggers for anger, fear, sadness and brow furrow were shared. While many of the event triggers were highly comparable between the basic emotions and the indication of the AUs, similarities should be investigated in further research.

7.4.4 Discussion of Study Results for Different Roads

The investigation of frequencies of emotional events on different road types suggested a frequency of emotion events on rural roads that was 19% above average, mainly caused by *poor road conditions*. Major roads were 20% below the average frequency of emotion events, with *checking navigation* as the major trigger event. Urban roads were close to the average frequency of emotion events with *navigation alert* as the most frequent trigger. This knowledge could be used for the creation of design criteria for coping with stressful driving through e.g. the avoidance of certain road types through an alteration of the navigation route, personalised to the emotional reactions of the driver. Depending on the driver's preference and emotional responses a more pleasurable driving experience could be created.

7.4.5 Discussion of Qualitative Research Results

Results of the thematic coding task suggested separating event triggers into driver-related and environment-related, and subdividing into personal behaviour, driver interacting with the inside/outside of the car, and the inside/outside of the car affecting the driver. The coding suggested a direct influence of automobile driving and the automobile environment on emotional expressions. This information can assist automotive designers to identify components to optimise and detect key issues to consider.

The assignment of event triggers was validated with an agreement of 68.7% of the data sample between all researchers, reliable results could therefore be inferred. These results suggested that events triggers could be successfully assigned to emotional responses in the automotive environment, and could provide insights on direct positive and negative emotional impacts on the driving experience.

7.5 Threats to Validity

The most obvious potential threats to validity in this study are explained and discussed in the following section. These include the researcher's presence in the automobile, assignment of trigger events, the experimental setting, the technology used and the route selection. Methods applied for the prevention of a negative impact are listed below.

Researcher's Presence in the Automobile

The presence of the researcher as an observer might have had an impact on the participant's behaviour and emotional expressions (experimenter bias). To avoid the negative impact of the researcher's presence, the researcher was seated on the back-seat of the research automobile, only interrupting the study if necessary (Chapter 6.5 Threats to Validity).

Assignment of Trigger Events

The initial assignment of trigger events to the emotional expressions during the study was conducted by only the researcher. The researcher's potential bias could have an influence on the study results. In order to mitigate research bias and ensure the validity of the collected data, the IOR test was applied.

Experimental Setting

The experimental setting might have influenced the research results. For instance, the high frequency of joy may have been due to the research automobile having been a new, luxury model. The infrequent occurrence of fear and sadness may have been caused by the requirement for the route to be within a 30 minute radius of the university, therefore including only a limited number of challenging driving situations. In order to avoid possible effects of the experimental setting, in the future a range of automobiles should be tested on a larger variety of routes.

Technology

The choice of technology may have influenced the study results. The restriction of using one face camera, which limited data collection and needed to be placed relatively centrally, impacting the participant's field of view, should be addressed in future studies. Additionally, multiple measurements may lead to more reliable results. In order to minimise software and hardware limitations, the real-time thresholding application was created (Chapter 6.2.2 Measurement Equipment).

Route selection

Due to the location of Brunel University and restrictions on the length of on-road studies, the route selection was restricted. All efforts have been made to include major, rural and urban roads in the ratios recommended in ergonomic research (Giacomin and Bracco, 1995). Nevertheless, more extreme situations and road types than any of those included in the planned road circuit are likely to occur during real-world driving (e.g. a busier city centre than Uxbridge Town Centre). In future studies, wider varieties of road types in more extreme environments should be included.

7.6 Conclusions

This research combined quantitative and qualitative methods using FEA for the investigation of emotional responses during an on-road driving study, the assignment of event triggers, thematic coding and an inter-observer reliability task. The most frequently occurring emotional expressions and their individual most frequent event triggers were investigated for a number of road types and driving situations.

As with the results of Study 2, joy was the most frequently observed emotion for this dataset. The low frequencies of fear and sadness were surprising, as indicated previously (Chapter 6.6 Conclusions). The AUs which occurred most frequently indicated anger or concentration, surprise and displeasure. Once again, as mentioned in Chapter 6.6 Conclusions, results comparing AUs and basic emotional expressions suggested that it might be necessary to include the measurement of AUs in FEA for automotive environments. For positive emotional responses *enjoying driving the car* was the most frequently assigned trigger, while *navigation, high traffic density* and *poor road conditions* were the most frequent triggers of negative emotions. Significant differences in frequencies of emotional expressions on different roads became apparent for this dataset, with frequencies 19% higher than average for this dataset on rural roads, approximately average frequencies on urban roads and frequencies 20% below average on major roads. *Poor road condition* and *navigation* were the emotion triggers most frequently assigned for this dataset.

This knowledge is a first step towards a better understanding of natures, frequencies and event triggers of emotional responses in the automotive environment and can be used as a scientific starting point for the creation of design scenarios for future automotive design (Gkouskos, Normark and Lundgren, 2014). Moreover, the knowledge gained through the study could be used for data sets and the formulation of automotive design criteria. Results of the frequencies and triggers of the emotional events can assist automotive designers in identifying key issues for consideration and key components to optimise.

In consideration of recent and future developments in the automotive field and the need for a transformation of the traditional automotive design process, this research creates an opportunity for the application to both current and future design decisions. To gain a deeper understanding of natures, frequencies and causes for emotions in the automotive habitat, a larger variety and number of participants, longer driving duration and the inclusion of more route types and driving situations should be investigated in future research.

8 Comparison of the Two On-Road Studies (Study 2 and 3) for Investigation of Emotional Responses in Different Settings

In order to investigate how the different settings (natural and partially controlled) might have influenced natures and frequencies of emotional events and their triggers in the two studies, this chapter contains a comparison including a statistical analysis. In the following, the two on-road driving studies, *Chapter 6 Study 2: On-Road Study for Observation of Emotional States in a Natural Setting* and *Chapter 7 Study 3: On-Road Study for Observation of Emotional States in a Partially Controlled Setting* are compared through evaluation of their qualitative and quantitative results, interpretation of the results and statistical analysis. The comparison aims to investigate which parameters of the different studies might have influenced natures, frequencies and causes of emotional responses during driving.

While both studies share a similar approach, procedure, methodology and hypothesis the comparison of differences between the results may provide insights into how the setting might have influenced the participants' emotional responses. Study 2 was conducted in a natural setting; participants drove their own cars along a familiar route (e.g. their daily commute), following previous research approaches (Healey, 2000). In contrast, Study 3 was conducted in a research automobile on a pre-planned road circuit following standards defined though literature on human factors and ergonomics (Giacomin and Bracco, 1995). To lead the participant through the road circuit a navigation system was used.

Study 2 was conducted with 22 participants with an average study duration of 20 minutes, therefore a total 440 minutes of study time and Study 3 was conducted with 21 participants with an average study duration of 40 minutes, with 840 minutes of total study time. Initially, the same number of participants (n=22) was recruited for both studies, but due to failed data collection for one participant during Study 3, the data had to be discarded, resulting in the use of data for only 21 participants for Study 3. The need to critically compare and analyse the results of both studies was evident, providing deeper insights on emotional responses of drivers during on-road driving in different settings.

8.1 Comparison of Qualitative and Quantitative Results

8.1.1 Natures and Frequencies of Emotional Events

In Study 2, 218 instances of basic emotional expressions (joy, anger, surprise, disgust, fear, sadness) and 512 action units (AUs; brow raise, lip corner pull, lip press, brow furrow, inner brow raise, lip pucker) were measured. Detection rates were on average one basic emotion every 2 minutes, and one AU every 51 seconds. In Study 3, 556 instances of basic emotional expressions and 1387 AUs were measured, resulting in detection rates of on average one basic emotion every 1.5 minutes, and one AU every 36 seconds. It is striking that the frequencies of basic emotional expressions and AUs are higher in Study 3 in comparison to Study 2. It can be assumed that this might be due to the different study circumstances, such as the planned route, the research automobile and the use of a navigation system. Participants may have felt more comfortable in their own cars on routes familiar to them, and were therefore less sensitive to emotions triggered by the driving setting. Divided into their natures and specific frequencies a direct comparison of the basic emotional events can be seen in Table 39.

Basic emotion event	STUDY 2	STUDY 3	STUDY 2	STUDY 3
	n	n	% of all emotion events (n=218)	% of all emotion events (n=556)
JOY	73	147	39	26
ANGER	11	112	5	20
SURPRISE	57	115	26	21
FEAR	0	12	0	2
DISGUST	60	121	28	22
SADNESS	5	53	2	9

Table 39 Frequencies of basic emotion events of Study 2 and Study 3

While joy, surprise and disgust were the most frequently expressed emotions in both studies, it became apparent that both joy and anger had the largest variation in frequencies of occurrence between the two studies. Joy comprised 39% of all emotion events in Study 2 and only 26% in Study 3. The frequency of occurrence of anger were relatively low, at only 5% of all emotion events in Study 2 and 20% in Study 3.

Frequencies of occurrence of action units (AUs) can be compared in Table 40 below. No major differences in individual percentages of the total number of AUs were apparent between the two studies. Small differences in occurrence of lip pucker and lip corner pull were noted however.

Action unit	**STUDY 2**	**STUDY 3**	**STUDY 2**	**STUDY 3**
	n	n	% of all Emotion Events (n =512)	% of all Emotion Events (n=1387)
LIP PRESS	97	274	19	20
INNER BROW RAISE	122	270	24	20
BROW FURROW	72	252	14	18
BROW RAISE	115	268	22	19
LIP PUCKER	71	112	14	8
LIP CORNER PULL	35	211	7	15

Table 40 Frequencies of action units of Study 2 and Study 3

8.1.2 Trigger Events

To compare natures and frequencies of trigger events in both studies, the most frequently occurring trigger events (≥10% of total trigger events for each emotion) have been summarised in Table 41 below.

Basic emotion events	JOY	ANGER	SURPRISE	SADNESS	DISGUST	FEAR
Study 2 Most frequent trigger events (% of all event triggers)	Interaction with another person (36%)	High traffic density (23%)	Interaction with another person (15%)	Sun/light blinding (28%)	Sun/light blinding (13%)	-
	Music/radio (22%)	Sun/light blinding (23%)	Bump on road (14%)		Long wait at traffic light (11%)	
		Long wait at traffic light (15%)				
Study 3 Most frequent trigger events (% of all event triggers)	Enjoying driving car (44%)	Poor road conditions (20%)	Checking navigation (20%)	Navigation alert (15%)	High traffic density (23%)	NTA (42%)
	No trigger assigned (19%)	Navigation alert (11%)	Navigation alert (18%)	Poor road conditions (11%)	Poor road conditions (18%)	Navigation alert (25%)
	Interaction with another person (15%)		High traffic density (10%)		Checking navigation (10%)	Scratching face (17%)

Table 41 Basic emotion events with their most frequently assigned trigger events of Study 2 and 3

When comparing the most frequently assigned trigger events between the two studies, few similarities can be identified. It can therefore be assumed that the nature of trigger events which induced an emotional response was determined by the different study conditions. This could potentially be generalised to all driving. Frequencies for event triggers of joy could be explained by restricted social interaction in Study 3 and the research automobile having been a luxury model. Furthermore, participants in Study 3 were asked not to listen to music during the drive. A navigation system was used in Study 3 which may have determined the nature of the most frequent negative trigger events (e.g. *navigation alert, checking navigation*). In Study 3, trigger events such as *poor road conditions* or *car passing close* could be attributed to the nature of the planned road circuit, which included a very narrow street with a limited visual field and poor road conditions. In Study 2, which took place on a familiar route in a familiar environment, emotions were triggered through events such as *high traffic density*, *sun/light blinding* and *long wait on traffic light*. These are triggers which may frequently occur in a general automotive environment, and are potentially unlikely to be determined by the nature of the route used for the study. It can therefore be assumed that specific emotions can be triggered by certain factors (e.g. navigation system, a particular route). With the application of this knowledge, the occurrence of certain emotions could potentially be avoided through alterations to automotive design.

In the following (Table 42) the most frequent event triggers of AUs in both studies are presented.

Action unit	LIP PUCKER	INNER BROW RAISE	BROW FURROW	LIP PRESS	LIP CORNER PULL	BROW RAISE
Study 2 Most frequent trigger events (% of all event triggers)	High traffic density (11%)	Checking mirror (8%)	High traffic density (14%)	High traffic density (14%)	High traffic density (13%)	Checking mirror (12%)
	Sun/light blinding (7%)	Long wait at traffic light (8%)	Sun/light blinding (13%)	Tight road passage (13%)	Roundabout (6%)	High traffic density (11%)
		Roundabout (7%)	Infotainment change (10%)	Long wait at traffic light (9%)		Checking navigation (7%)
Study 3 Most frequent trigger events (% of all event triggers)	Checking navigation (14%)	Poor road conditions (17%)	Checking navigation (17%)	Checking navigation (15%)	Checking navigation (18%)	Poor road conditions (14%)
	High traffic density (13%)	Checking navigation (13%)	Navigation alert (13%)	High traffic density (15%)	Poor road conditions (7%)	Checking navigation (7%)
	Roundabout (6%)	High traffic density (13%)	High traffic density (13%)	Poor road conditions (6%)	High traffic density (6%)	High traffic density (5%)

Table 42 Action units with their most frequently assigned trigger events of Study 2 and 3

As with the findings for triggers of basic emotions, AU triggers which relate to the specific circumstances of the study became apparent for Study 3 (use of navigation system, inclusion of road with poor road conditions). As previously mentioned, the most frequent event triggers in Study 2 could be attributed to events that occur in a general automotive environment, and are potentially not specific to the study conditions.

8.2 Interpretation of Results

Certain assumptions can be made when comparing differences between frequencies of emotional events for Study 2 and 3 and investigating their causes. To enable interpretation of the results of the comparison between the two studies, potential influences of the different study conditions are investigated. The following interpretations are based on the investigation into the differences between individual basic emotional events in the two studies, as no major differences are evident in either frequencies or trigger events for individual AUs. For the basic emotional events, differences of >5% were investigated individually. Furthermore, differences of all negative emotion events are compared.

Joy (Table 43)

Joy	**Frequencies of occurrence**	**Most frequently assigned trigger events (Frequencies in %)**
Study 2	39%	Interaction with another person (36%)
		Music/radio (22%)
Study 3	26%	Enjoying driving the car (44%)

Table 43 Frequencies and trigger events of joy in Study 2 and Study 3

Frequencies of joy in Study 2 were 13% higher than in Study 3, with 61% of trigger events defined as *interaction with another person* and *music/radio*. *Enjoying driving the car* was assigned to 44% of trigger events in Study 3. Since both *interaction with another person* and *music/radio* were conditions restricted in Study 3, and, as a luxury model, the research automobile may have caused *enjoying the car*, the following was inferred:

***Interaction with another person, music/radio* and *enjoying driving the car* triggered joy during automobile driving in this research.**

Anger (Table 44)

Anger	Frequencies of occurrence	Most frequently assigned trigger events (Frequencies in %)
Study 2	5%	High traffic density (23%)
		Sun/light blinding (23%)
Study 3	20%	Poor road conditions (20%)
		Navigation alert (11%)

Table 44 Frequencies and trigger events of anger in Study 2 and Study 3

Frequencies of anger in Study 3 were 15% higher than in Study 2. *Poor road conditions* and *navigation alert* together comprised 31% of trigger events causing anger. For Study 2, which featured less frequent instances of anger than Study 3, the main causes of anger were *high traffic density* and *sun/light blinding*. Since a road with poor road conditions and the use of a navigation system were deliberately included in the study design of Study 3, and the absence of both triggers led to substantially lower frequencies of anger, the following was inferred:

***Poor road conditions* and *navigation alerts* triggered anger during automobile driving in this research.**

Sadness (Table 45)

Sadness	Frequencies of occurrence	Most frequently assigned trigger events (Frequencies in %)
Study 2	2%	Sun/light blinding (28%)
Study 3	9%	Navigation alert (15%)
		Poor road conditions (11%)

Table 45 Frequencies and trigger events of sadness in Study 2 and Study 3

The frequency of sadness in Study 3 was 7% higher than in Study 2, and the assigned trigger events were attributed to the navigation and poor road conditions. The following was inferred:

The use of a navigation system and poor road conditions triggered sadness during automobile driving in this research.

Disgust (Table 46)

Disgust	Frequencies of occurrence	Most frequently assigned trigger events (Frequencies in %)
Study 2	28%	Sun/light blinding (13%)
		Long wait at traffic light (11%)
Study 3	22%	High traffic density (23%)
		Poor road conditions (18%)

Table 46 Frequencies and trigger events of disgust in Study 2 and Study 3

The frequency of disgust in Study 2 was 6% higher than in Study 3. No obvious conclusions could be drawn from the results.

All negative emotions (anger, disgust, fear and sadness; Table 47)

All negative emotions	Frequencies of occurrence	Most frequently assigned trigger events (Frequencies in %)
Study 2	35%	Others (no significant percentage)
Study 3	55%	Navigation system (32%)
		Poor road conditions (16%)

Table 47 Frequencies and trigger events of all negative emotions (anger, disgust, fear and sadness) in Study 2 and Study 3

When comparing the frequencies of negative emotions in both studies, it is apparent that frequencies in Study 3 were 20% higher. Similarly to the previously mentioned trigger events for anger the following was inferred:

The use of a *navigation system* and *poor road conditions* triggered negative emotions during automobile driving in this research.

8.3 Statistical Analysis

8.3.1 Independent Samples T-Test

To investigate the relationship between the data collected in Study 2 and 3 and determine if a specific cause for their differences might exist, the statistical significance was investigated. As one of the most widely adopted procedures for the comparison of two data sets, a t-test was chosen (Lazar, Feng and Hochheiser, 2017). Since the two data sets are unrelated and contributed by different groups an independent-samples t-test was conducted.

Results of all individual basic emotions and action units as well as the total of basic emotional events, the total of action units and all negative basic emotional events were compared between Study 2 and 3. For the calculation of the significance, frequencies (emotion events/sec) of the binary values for emotion events occurring (1) or not occurring (0) were used. The null hypothesis underlying the independent-samples t-test was: There is no significant difference between the emotion events (individual emotions and total emotion events) in both studies. A 95% confidence interval was applied. The null hypothesis was accepted if there was a ≥95% chance that the difference between the two data sets was due to random chance. If the null hypothesis was rejected the cause of the difference in frequencies of emotion between Study 2 and 3 may be explained through the previously made inferences.

In the following (Table 48) results and significances can be viewed.

Emotion events	**t-value**	**df**	**Sig. (2-tailed)**	**Statistically significant (95% confidence interval)/ not significant**	**Null hypothesis accepted/ rejected**
JOY	-0.235	40.000	0.815	Not significantly different	accepted
ANGER	-1.702	20.337	0.104	Not significantly different	accepted
SADNESS	**-2.529**	**40.000**	**0.016**	**Significantly different**	**rejected**
DISGUST	-0.511	40.000	0.612	Not significantly different	accepted
FEAR	-1.706	20.000	0.104	Not significantly different	accepted
SURPRISE	-0.549	40.000	0.586	Not significantly different	accepted
BROW FURROW	-1.167	21.143	0.256	Not significantly different	accepted
BROW RAISE	0.950	40.000	0.348	Not significantly different	accepted
INNER BROW RAISE	-1.248	23.011	0.210	Not significantly different	accepted
LIP PRESS	-1.011	20.002	0.324	Not significantly different	accepted
LIP PUCKER	1.855	32.704	0.073	Not significantly different	accepted
LIP CORNER PULL	-1.420	22.953	0.169	Not significantly different	accepted
ALL BASIC EMOTION EVENTS	-1.347	199.302	0.180	Not significantly different	accepted
ALL AUs	**-1.064**	**250.000**	**0.029**	**Significantly different**	**rejected**
ALL NEG EMOTIONS (FEAR; SADNESS; DISGUST; ANGER)	0.030	166.000	1.000	Not significantly different	accepted

Table 48 Independent samples t-test results of Study 2 and Study 3

The results suggested no significant difference between the results of Study 2 and 3 for the emotional states joy, anger, disgust, fear and surprise. It could therefore not be certain that a cause for the difference between the listed emotional states existed, instead it might be the case that the changing circumstances in both studies had no statistically significant influence on the listed emotions. In future studies this hypothesis should be investigated.

For the emotion sadness, the independent t-test suggested that there is a significant difference in the natures and frequencies of occurrence between the two studies. Based on the interpretation of results it could be inferred that the theory '*the use of a navigation system and poor road conditions triggered sadness during automobile driving in this research'* may be applicable. As well as most of the basic emotions the sum of all basic emotion events and the sum of all negative basic emotion events was, according to the t-test results, not significantly different.

Inspecting the t-test results for the AUs it became apparent that while the comparison of all individual AUs between the two studies showed no significant difference, the comparison of the sum of all AUs was statistically different between both studies. This phenomenon can be explained through the Simpson's paradox.

8.3.2 Simpson's Paradox

The Simpson's Paradox is a situation in statistics that can arise during the analysis of two or more variables. The paradox is characterised as a reversal of a trend, which appears in multiple groups of data, when those groups of data are combined, and is also called the reversal paradox. The first person to address the paradox in a publication was Edward H. Simpson in 1951 but the phenomenon was mentioned earlier by Pearson et al. (1899) and Udny Yule (1903). The effect was first named "paradox" by Cohen and Nagel (1934), presumably due to the fact that its contradictory conclusions seemed somewhat paradoxical (Pearl, 2014). The phenomenon often occurs in social science (Wijayatunga, 2014). A popular example of the Simpson's Paradox is a study at the University of California, Berkeley (1973) concerning gender bias for the admission of men and women applying to the school. While the summarised results showed that men were much more likely to be admitted, the majority of individual departmental results showed a small but significant bias in favour of women. The same phenomena can be seen in other situations (Pearl, 2003; Wijayatunga, 2014).

When considering the phenomena, the question arises as to whether the aggregated or partitioned data should be consulted in choosing an action. Pearl states that it is often the aggregated data which leads to the correct choice of action, but the choice which data should be prioritised depends on "the story behind the data" (Pearl, 2003, p.2). Therefore, depending on the research methodology and approach, every researcher must make the decision which data to base the conclusion on himself/herself after carefully considering the study, which was stated to be the real paradox behind the phenomena (Pearl, 2003).

In the case of this research the paradox could not be solved. To do so requires detailed knowledge on which factors were a deeper, underlying cause of the individual results collected. While suggestions for potential causes of individual results were made, the significance of the influence is unclear due to the real-world environment. While it might be possible to solve the Simpson's Paradox in future research by designing studies with only one major difference between each study (e.g. identical studies where only the type of automobile is changed), certain parameters cannot be controlled in on-road studies e.g. light conditions. Since it will be difficult to isolate a specific factor potentially contributing to the paradox, solving the Simpson's Paradox will present a challenge that requires significant further work.

This is a classic limitation of studies in the wild. While data collected in naturalistic settings is more suitable for the investigations of people's feelings and behaviours, and results are more revealing about what occurs in the real world (Marshall et al., 2011; Rogers et al., 2007), limitations include lack of control and uncertainty about results. Due to the nature of studies in the wild it is difficult to identify what causes particular effects and how participants might react to those. Rogers and Marshall state that non-significant findings can be most informative for studies run in the wild, as their purpose is often the exploration of the unexpected rather than confirmation of previous theories (Rogers and Marshall, 2017).

8.4 Discussion and Conclusion

In this chapter, the setting and approaches as well as qualitative and quantitative results of the two on-road studies *Chapter 6 Study 2: On-Road Study for Observation of Emotional States in a Natural Setting* and *Chapter 7 Study 3: On-Road Study for Observation of Emotional States in a Partially Controlled Setting* were compared. In a first step, major differences of the settings between both studies were discussed, including study time, research automobile and driving environment. Next, natures and frequencies of emotional events and assigned trigger events were compared. Results were then interpreted based on the collected qualitative and quantitative data, and inferences were made which explained different frequencies of emotions through specific causes and different settings. In order to statistically determine whether these assumptions might be valid an independent samples t-test was conducted. Finally, results of the statistical analysis were explained.

The comparison of the two studies delivered important insights into potential causes for emotions during automobile driving. While, due to the nature of the study (Marshall et al., 2011; Rogers et al., 2007), most findings were not significantly different and the null hypothesis was accepted in most cases, important deductions about causes were made. Future studies should be conducted with the goal of altering a single parameter, e.g. length of the study, while keeping all other parameters constant. Building a database of results from a set of such studies will allow for a precise determination of the factors that contribute to different results, as well as the significance of their effects.

Statistically valid results comparing different driving studies can be extended to future research. While the FEA methodology used for the two studies compared here can be used to give an impression of the direction that automotive design should take and inform key decisions, statistical comparison of studies can be used to verify causalities and confirm significance of contributing factors. Thus, future automotive design can be guided to produce optimal decisions in a rigorous and scientific fashion.

While not statistically validated, the main findings of the comparison of both on-road studies are the following:

- *Interaction with another person, music/radio* and *enjoying driving the car* may have triggered positive emotions during automobile driving in this research.
- *Poor road conditions* and *navigation alerts* may have triggered negative emotions during automobile driving in this research.

While the main findings might have been influenced by the specific environment and the experimental settings, the fact that the findings occurred in different circumstances indicates that they may be repeatable on other roads and in different automobiles. In order to confirm that the main findings are valid for the automotive environment in general, further studies should specifically investigate the effects of road conditions, the navigation system, interaction with other vehicle occupants/drivers/pedestrians and the radio or listening to music. If the applicability of the research results to the general automotive environment is confirmed, the identified causes for negative and positive emotions can be avoided or enhanced in future automotive design. For example, the knowledge that the navigation system might cause negative emotion could hint at the need to alter existing navigation systems. Poor road conditions could be flagged and avoided in future route planning to avoid their negative influence. Positive emotions may be enhanced through a human-like personal assistant, or triggered through the use of radio or personalised music choices in order to improve the driver's mood.

The influence of the type of automobile on positive emotions should be investigated through repeated testing in the same setting where only the type of automobile is varied. Through in-depth investigation the component of the an automobile that causes positive emotions could be identified. Results could be used to improve automotive design and the driving experience and trigger positive emotions during driving through the improvement of specific vehicle components and characteristics.

The alteration of current automobiles and their system components to avoid negative and enhance positive emotions could be a major step towards an improved driving experience. In the future, the introduced method can be used to not only improve but also personalise the driving experience and help the occupants cope with future developments in the automotive industry.

9. Conclusions and Future Development

9.1 Introduction

Technological growth in the modern age has a significant impact on many facets of human life, and challenges us to constantly adapt. One industry greatly influenced by technological developments is the automotive industry (Manyika et al., 2013). The automobile is known to be the habitat of multiple human emotions (Sheller, 2004) but is also branded by its emotional history and its connection to important social values, such as personification, identification and personal image (Edensor, 2004). The historical stages of the research in the automotive industry have seen the main focus progress from transportation to safety, to comfort, to experience. According to future predictions, the focus will shift towards human emotion (Chapter 1.1 Developments in the Automotive Industry). This is not merely a possibility but a requirement and an inevitability when considering current developments in the automotive industry (e.g. the sophistication of in-car technologies, further automation, self-driving automobiles) and the impact those will have on humans. For humans to cope with recent and potential future developments the automotive industry and the traditional design process will have to change (Giuliano, Germak and Giacomin, 2017). The growing role of emotion in automobile driving calls for emotion research to respond to human requirements, and studies of human behaviour and emotional states in the driving context are a necessity to improve future automotive design.

While investigations of negative emotional states (e.g. aggressiveness and anger, road rage) have been widely conducted (Deffenbacher et al., 2002; Parkinson, 2001) the focus is slowly shifting towards a wider investigation of multiple emotional states. Recent research studies, however, are often limited through the choice of emotion measurement method, the research methodology or application (Chapter 3.2.5 Limitations). Therefore, this research takes the view that more in-depth investigations are required in order to gain an advanced understanding of human emotions and needs in the automotive habitat and take the first steps towards a modern approach of automotive design.

9.2 Addressing the Research Question and Hypotheses

The aim of this work was to investigate human emotions and their importance in the automotive environment and explore how a better understanding can be reached through comprehensive investigations. The research questions this thesis addressed are:

- How can human emotional responses be measured in an automotive environment?
- Can emotional responses be triggered and measured in a simulated driving environment? What are the major challenges?
- What are the typical natures, frequencies and causes of emotional events in a natural real driving environment?
- What are the typical natures, frequencies and causes of emotional events in a partially controlled real driving environment?
- How can the typical natures, frequencies and causes of emotional events between two studies in different settings be compared?

In order to address the research questions a literature review was conducted and the following hypotheses have been formulated:

- Emotion elicitation can be successfully achieved in a standard driving simulator, and the emotions themselves can be successfully detected by means of Facial-Expression Analysis (FEA).

- High numbers of emotion events can be automatically measured in a natural setting during an average driving study length of 20 minutes per participant, and observational analysis permits the detection of the causes of the emotions in the vast majority of cases.

- High numbers of emotion events can be automatically measured in a partially controlled setting during an average driving study length of 40 minutes per participant, and observational analysis permits the detection of the causes of the emotions in the vast majority of cases. Natures, frequencies and causes of emotional states can be assigned to different road types.

The research methodology applied to address the research questions and hypotheses was introduced in Chapter 4 (Table 6, Figure 14). In the following, the approach, method and results of each hypothesis are explained.

Hypothesis 1: Emotion elicitation can be successfully achieved in a standard driving simulator and the emotions themselves can be successfully detected by means of FEA.

Hypothesis 1 was addressed through a case study in a driving simulator, described in Chapter 5. Simulator based tests were performed with 21 participants in a driver study (n=11) and a passenger study (n=10). Due to limitations of simulated environments and consequent difficulties in the investigation of emotional states, emotion elicitation, a method frequently used in psychology, was applied. For this purpose, a set of potential emotion triggers was identified from literature and implemented into the driving simulator environment as driver and passenger scenarios. The applicability and usefulness of FEA to measure the triggered emotional states was investigated. Results confirmed the hypothesis that emotion elicitation could be successfully achieved in a driving simulator and that emotions could be detected through FEA. While limitations of the simulated environment and the applied research methodology were identified, the results of Study 1 delivered insights on emotional states in the automotive environment. Furthermore, results gave indicators of influences of emotional states of both driver and passenger.

Hypothesis 2: High numbers of emotion events can be automatically measured in a natural setting during an average driving study length of 20 minutes per participant, and observational analysis permits the detection of the causes of the emotions in the vast majority of cases.

Hypothesis 2 was addressed through an on-road case study, observing 22 participants driving their own cars on familiar routes (e.g. their daily commute) in a natural driving environment. To get a better understanding of emotional states in the driving environment, the natures, frequencies of occurrence and causes of emotional events were investigated through FEA. Quantitative results were evaluated and triggers were assigned in a qualitative manner. Results of the study showed high frequencies of emotion events during driving, and event triggers were successfully assigned in the majority of cases. The most frequent emotional expressions and emotion triggers were identified for an automobile in a natural driving environment.

Hypothesis 3: High numbers of emotion events can be automatically measured in a partially controlled setting during an average driving study length of 40 minutes per participant, and observational analysis permits the detection of the causes of the emotions in the vast majority of cases. Natures, frequencies and causes of emotional states can be assigned to different road types.

Hypothesis 3 was addressed in Chapter 8 through an on-road study, observing 21 participants in a partially controlled setting on a planned road circuit in a research automobile. The study adopted a very similar methodology and approach to that of Study 2, and aimed for a more standardised approach through the inclusion of a greater variety of driving situations and the planning of a road circuit. Additionally, the influence of different road types and their specific events triggers on natures and frequencies of emotion events during driving was explored. The assignment of event triggers was validated through the combination of thematic coding and an inter-observer reliability test.

Finally a comparison of Study 2 and 3 was conducted in Chapter 8 to identify differences in natures, frequencies and causes of emotion events of the two studies. This aimed to identify what differences were present between the results for individual emotions, and suggest possible causes of the discrepancy. Statistical analysis was applied to the data for the basic emotion and AU event frequencies to identify what differences were statistically significant.

9.3 Contributions to the Field

The major contribution to the field provided by this body of work was an improved understanding of the role of human emotion in the automotive habitat. Contributions made through this research include the following:

- Successful application of quantitative and qualitative research methods to identify both emotions and triggers to be assigned to given emotions, allowing the cause of emotion to be identified. Verification of the qualitative observational analysis results.
- Demonstration that a partially controlled study with controlled parameters such as route, duration and car type can be used to provide an environment in which emotion data can be successfully collected and analysed, allowing the determination of triggers while remaining highly comparable between individual participants.
- Application of FEA in an on-road study in people's own cars on familiar routes, successfully collecting emotion data and demonstrating the versatility of the method.

- Demonstration that a combination of pre-planned studies and varying parameters allows exact factors to be pinpointed and their effects gauged.
- Demonstration that qualitative and quantitative study results can be statistically analysed to determine contributing factors and the significance of their effects.

- Application of emotion elicitation to a simulated driving study in order to trigger emotions in a laboratory environment, demonstrating its effectiveness and assessing the optimal setup for studies in a real-driving environment. Identification of potential problems with the application of FEA likely to be encountered and solutions to them.
- Identification of Facial-Expression Analysis (FEA) as a suitable tool for the investigation of emotional states during driving due to its non-contact application and low intrusiveness.
- An in-depth review of information on emotions relevant to the driving environment in order to develop a basic model of emotions in the driving environment.
- Discussion of methods of emotion detection e.g. GSR, FEA and their suitability for application in automotive research.

9.4 Further Findings of the Research

In Study 1, confusion and frustration were identified as being of significant importance in the driving environment. Study 2 and 3 confirmed the importance of action units identified through previous research. Results of this research therefore showed that while the basic emotions seem to be of high value, the emotion taxonomy chosen for automotive research should be extended to include not only basic emotions, but also other emotional or affective states. The inclusion of secondary emotional or affective states and/or action units can provide additional insights into emotional experiences during driving which are valuable to consider. In fact, the investigation of the addition to the emotion taxonomy (action units and/or secondary emotional/affective states) might be more valuable in automotive research than results gained focusing on the investigation of basic emotions.

This research recommends that only early-stage testing is conducted in a simulated driving environment (e.g. to explore the applicability of a measurement technique). The studies confirmed that disadvantages of driving simulators (limited physical, behavioural and perceptual fidelity) may cause unrealistic driving behaviour and introduce unrealistic influences on emotional expressions, potentially impacting the outcome of the research (De Winter, Van Leuween and Happee, 2012). While simulators have many advantages when used in early-stage testing (3.2.4 Study Environment) it is advised to apply emotion elicitation to trigger realistic emotional responses.

FEA was identified as a suitable measurement tool for emotional responses in automotive research due to its non-contact application and low intrusiveness. Multiple cameras should be used to increase the versatility of the measurement tool and limit the impact on the visual field caused by the need for a centrally-placed single camera. Intolerance of head movement and lighting changes were identified as limitations of FEA; for instance, the data stream might be interrupted when driving through a tunnel. Different measurement techniques should therefore be combined to reach reliable results and add another layer of investigation through the measurement of intensity of emotions (e.g. through Galvanic Skin Response).

In automotive emotion research, the inclusion of different road types and road situations delivers important insights into emotional responses. Rural roads should be included in road circuits planned for emotion testing as results showed higher frequencies of emotion expressions on those. On the other hand, researchers should be aware of the potential impact on emotions the road situation might have, and system components should therefore be tested on a variety of different road types. For optimum results, the ratio of road types recommended in Chapter 7.2.4 Road Circuit Selection should be adhered to.

Results could be used to create certain situations and scenarios which might be beneficial for the test of specific system components. A navigation system could be tested with the aim of avoiding poor road conditions, which has been identified as a cause of negative emotions in this research. A specific personalised music selection could be applied to improve the driver's mood when a higher than average frequency of negative emotions is detected.

The results suggested a significant negative impact of the navigation system on the emotional driving experience. This should be further investigated, and navigation systems improved to alleviate the negative effects. Since results showed that *interaction with another person* often caused positive emotions, one approach might be to investigate how to emulate *interaction with another person* through the navigation system, a feature already ubiquitous in electronic appliances, e.g. Alexa, Siri etc. An improved, affective human-machine interaction between the driver and the navigation system could even result in a positive effect on emotions, instead of a negative one. To alleviate the negative impact of *poor road conditions*, a system could be developed through which affected sections of road are flagged by automobiles as they pass, and communicated via V2V communication or to a centralised database in order to be avoided in future route planning. Music and radio were identified as causing positive emotions which could be used for the personalisation of the driving experience. Moreover, the type of automobile seems to have a significant influence on the positive driving experience. This should be further investigated and could be used to identify which specific vehicle components have the most significant influence. Results could aid to create an improved driving experience.

9.5 Research Limitations

Limitations of this research were determined, and in future research may be avoided or mitigated through the following proposals:

Bias Through the Research Automobile

To avoid potential bias through the research automobile, studies are suggested to be conducted in a variety of different automobile models.

Focus on Only One Measurement Tool

A more reliable and robust result could be achieved, and impact of the limitations of FEA (e.g. interrupted data collection due to head movement) avoided if the tool is combined with other measurement techniques.

Lack of Intensity Indication

Since the used software applications (*Emotient Facet* and *Affectiva Affdex*) do not provide a definitive intensity measurement, it has been recommended that FEA be combined with a physiological measurement tool which can be used for the measurement of arousal/intensity of emotion (e.g. Galvanic Skin Response). Results could then not only indicate which emotion is experienced but also give information on the intensity of the emotional state. Research on the possibility of using the length of an emotional expression as an indicator of its intensity is limited.

The Researcher's Presence in the Automobile

To avoid potential influences caused by the presence of the researcher in the study automobile, a real-time connection between the automobile and a control room is suggested. Emotion data could be streamed to the control room and directly assessed without the intrusion of the automotive habitat through the researcher.

More research is required to produce highly reliable results. For this purpose, studies should be conducted which use a greater participant sample size. Similarly, more road types and driving situations should be included in future tests. Assessing not only the driver but also the passenger could provide significant knowledge for a more holistic understanding of emotion in the automotive habitat. A potential extension of the range of emotions should be explored in further research. Finally, a deeper investigation should be conducted into the use of action units to construct emotional expressions and improve the effectiveness of emotion detection in automotive research. To explore the impact of a driving situation on the emotional experience, future studies should be conducted with only one differentiated factor (e.g. the type of automobile or the length of study), allowing the significance of the factor to be gauged statistically.

9.6 Suggested Applications and Future Work

Table 1 in Chapter 1 introduced the most popular technological current and future developments in the automotive industry. Table 49 below revisits the developments introduced in Table 1, names potential problems they may cause for the occupants and introduces suggestions on how to apply occupants' emotion data to remedy the situation. While some of the suggestions are already applied in automotive car concepts (e.g. Honda's automated network assistant HANA; Toyota's personal assistant Yui), others may be applied to avoid problems caused by technological developments and improve the driving experience in the future.

Development	Potential problems for occupants	Suggestions for potential solutions using emotion data
• Connected cars, • V2V communication • Real-time internet of things (IoT) connectivity (Karlsson, Ahn and Choi, 2017; Kalogianni, 2016, 2017; Intland, 2016)	Information overload	• Regulation of information stream to the driver based on emotional states • Transmission of behavioural information to other vehicles and IoT to predict responses and increase situational awareness
• Electrification • Increasing number of sensors • Sophistication of in-car technologies • Disruptive technologies (Intland, 2016; Manyika et al., 2013)	Confusion due to number of electrical systems	• Improved affective human-machine interaction • Driver assistance to enable/disable certain electrical systems/components
• Gesture control systems • Voice recognition (Ropert, 2014)	Attention sharing, confusion, frustration	• Affective personal assistance

• Car sharing • Shared mobility (Harris, 2017; Manyika et al., 2013)	Loss of the feeling of personal freedom and adaptability	• Personalisation of shared cars through emotion data (e.g. driver style)
• In-car connectivity • Internet connection • Integration of social media • Integration of mobile devices (Brauer, 2015; Kalogianni, 2016; Karlsson, Ahn and Choi, 2017)	Information overload, attention sharing	• Regulation of information stream to the driver based on emotional states • Affective personal assistance
• Augmented reality included into the automobile interface (Ropert 2014)	Attention sharing	• Regulation of information stream to the driver based on emotional states • Affective personal assistance
• Partially autonomous driving • Driver assistance features (Kalogianni, 2016)	Difficulties with control handover	• Improved affective human-machine interaction • Communication based on emotion data
• Fully autonomous driving (Karlsson, Ahn and Choi, 2017)	Lack of trust, feeling of loss of independence and freedom of decision	• Personalisation through emotion data (e.g. driver style) • Improved affective human-machine interaction

Table 49 Potential impact of current and future technological developments in the automotive industry and potential solutions using the occupants' emotion data

This research clearly demonstrates the significance of emotion in the automotive environment and provides knowledge on the causes and influences of emotional states and their effect on driving and the driving experience. The methodology developed for the in-depth investigation of emotional responses during driving can be applied to a research or industry environment to assess causes of both negative and positive emotions in a rigorous fashion, and aid in developing solutions to many of the issues raised in Chapter 1. Different system components and their applications could be tested in different driving situations and on different roads by applying the knowledge produced through this research. Results can be used to inform design decisions and lead to an improved human-machine interaction, enriched car design and a more pleasant driving experience.

The driving experience could be adjusted (e.g. regulation of the information flow) according to information on causes for emotional responses, with the intention of avoiding negative effects and emphasising the positive. Applying machine learning to large sets of emotion data could lead to a fully personalised driving experience (e.g. adapting the driving style) and the possibility to predict emotional reactions to upcoming driving situations and responding accordingly. The methodology developed in this research could be applied in future automobile design (e.g. autonomous vehicles) to enable an affective communication between the automobile and the customer. An improved human-machine interaction in the automotive habitat and the personalisation of the automobile could help with the adoption of future technologies. Potential implications of this line of research are improvements both to trust in autonomous automobiles and the capacity of humans to engage with and benefit from increasingly sophisticated automotive environments and technologies.

Machine learning will be essential for implementing many of the suggested applications of this research. For machine learning to function, large data sets are required. Jeff Dean, the head of the Google Brain team, states that deep learning needs at least 100,000 data examples to function effectively (Frank, 2017). While machine learning is based on a self-trained network, data is needed to start the training. The collection of this data can take time, and requires significant human input. Supplementary human activities include adding human labels to examples (such an in this case event triggers to emotions), and the creation of the large data sets which may then be used for machine learning processes. This research takes a first step towards the creation of a framework which can be used to produce the large data sets of emotions and their causes, ready for application to machine learning processes. Initial efforts to apply machine learning to the resultant data sets could be used to improve the data collection and processing framework, to improve the effectiveness of future machine learning projects within the field of automotive emotions.

10. Bibliography

Abdu, R., Shinar, D. and Meiran, N., 2012. Situational (state) anger and driving. Transportation research part F: traffic psychology and behaviour, 15(5), pp.575-580.

Aguirre, G.K., Detre, J.A., Zarahn, E. and Alsop, D.C., 2002. Experimental design and the relative sensitivity of BOLD and perfusion fMRI. Neuroimage, 15(3), pp.488-500.

Akamatsu, M., Green, P. and Bengler, K., 2013. Automotive technology and human factors research: Past, present, and future. International journal of vehicular technology, 2013.

Amodio, D.M., Zinner, L.R. and Harmon-Jones, E., 2007. Social psychological methods of emotion elicitation. Handbook of emotion elicitation and assessment, p.91.

Anonymisation: managing data protection risk code of practice, 2012. ICO. Available at: https://ico.org.uk/media/1061/anonymisation-code.pdf (Accessed: 21 June 2017)

Armstrong, D., Gosling, A., Weinman, J. and Marteau, T., 1997. The place of inter-rater reliability in qualitative research: an empirical study. Sociology, 31(3), pp.597-606.

Baches, M., 2016. Heirarchy of Needs: Application in urban design and community-building. Available at: http://mallorybaches.com/discuss/2016/1/26/hierarchy-of-needs (Accessed: 10 September 2017)

Bänziger, T., Tran, V. and Scherer, K.R., 2005. The Geneva Emotion Wheel: A tool for the verbal report of emotional reactions. Poster presented at ISRE, 149, pp.271-294.

Ball, K. and Rebok, G., 1994. Evaluating the driving ability of older adults. Journal of Applied Gerontology, 13(1), pp.20-38.

Bard, P., 1928. A diencephalic mechanism for the expression of rage with special reference to the sympathetic nervous system. American Journal of Physiology--Legacy Content, 84(3), pp.490-515.

Bartlett, M.S., Littlewort, G., Fasel, I. and Movellan, J.R., 2003, June. Real Time Face Detection and Facial Expression Recognition: Development and Applications to Human Computer Interaction. In Computer Vision and Pattern Recognition Workshop, 2003. CVPRW'03. Conference on (Vol. 5, pp. 53-53). IEEE.

Bella, F., 2014. Driver perception hypothesis: driving simulator study. Transportation research part F: traffic psychology and behaviour, 24, pp.183-196.

Bentley, T., Johnston, L. and von Baggo, K., 2005, November. Evaluation using cued-recall debrief to elicit information about a user's affective experiences. In Proceedings of the 17th Australia conference on Computer-Human Interaction: Citizens Online: Considerations for Today and the Future (pp. 1-10). Computer-Human Interaction Special Interest Group (CHISIG) of Australia.

Biswas, P. and Prabhakar, G., 2018. Detecting drivers' cognitive load from saccadic intrusion. *Transportation research part F: traffic psychology and behaviour*, *54*, pp.63-78.

Blaikie, D., 2010. Hypergoods: diagnosis, not ontology (Doctoral dissertation, Concordia University).

Blana, E., 1996. Driving Simulator Validation Studies: A Literature Review.Institute of Transport Studies, University of Leeds, Working Paper 480. White Rose Consortium ePrints Repository eprints@whiterose.

Blanckenberg, L., 2009. Joy is BMW. Available at: https://www.press.bmwgroup.com/middle-east/article/detail/T0049254EN/joy-is-bmw?language=en (Accessed 31 October 2017)

Boutellier, R. and Heinzen, M., 2014. Growth Through Innovation: Managing the Technology-Driven Enterprise. Springer Science & Business Media.

Boril, H., Omid Sadjadi, S., Kleinschmidt, T. and Hansen, J.H., 2010. Analysis and detection of cognitive load and frustration in drivers' speech. Proceedings of INTERSPEECH 2010, pp.502-505.

Boril, H., Sadjadi, S.O. and Hansen, J.H., 2011, September. UTDrive: Emotion and cognitive load classification for in-vehicle scenarios. In 5th Biennial Workshop on DSP for In-Vehicle Systems.

Boyatzis, R.E., 1998. Transforming qualitative information: Thematic analysis and code development. sage.

Bradley, M.M. and Lang, P.J., 1994. Measuring emotion: the self-assessment manikin and the semantic differential. Journal of behavior therapy and experimental psychiatry, 25(1), pp.49-59.

Bradley, M.M. and Lang, P.J., 2000. Emotion and motivation. Handbook of psychophysiology, 2, pp.602-642.

Brake report on safe driving, 2012. Available at: http://www.brake.org.uk/assets/docs/dl_reports/DLreport3-DISTRACTION-pt1-Dec11.pdf (Accessed on 28 November 2017)

Brandt, T., Stemmer, R. and Rakotonirainy, A., 2004, October. Affordable visual driver monitoring system for fatigue and monotony. In Systems, Man and Cybernetics, 2004 IEEE International Conference on (Vol. 7, pp. 6451-6456). IEEE.

Brauer, K. 2015. Top 10 Advanced Car Technologies by 2020. Available at: https://www.forbes.com/sites/kbrauer/2015/01/19/top-10-advanced-car-technologies-by-2020/#307df7526705 (Accessed: 12 October 2017)

Braun, V. and Clarke, V., 2006. Using thematic analysis in psychology. Qualitative research in psychology, 3(2), pp.77-101.

Brooks, J.O., Goodenough, R.R., Crisler, M.C., Klein, N.D., Alley, R.L., Koon, B.L., Logan, W.C., Ogle, J.H., Tyrrell, R.A. and Wills, R.F., 2010. Simulator sickness during driving simulation studies. Accident Analysis & Prevention, 42(3), pp.788-796.

Bullis, K., 2011. How vehicle automation will cut fuel consumption. MIT's Technology Review. October, 24.

Burnard, P., 1991. A method of analysing interview transcripts in qualitative research. Nurse education today, 11(6), pp.461-466.

Business Wire, 2014. Study Finds 88 Percent Of Adults Would Be Worried About Riding In A Driverless Car. Available at: https://www.thestreet.com/story/12300610/1/study-finds-88-percent-of-adults-would-be-worried-about-riding-in-a-driverless-car.html (Accessed: 2 November 2017)

Busso, C., Deng, Z., Yildirim, S., Bulut, M., Lee, C.M., Kazemzadeh, A., Lee, S., Neumann, U. and Narayanan, S., 2004, October. Analysis of emotion recognition using facial expressions, speech and multimodal information. In Proceedings of the 6th international conference on Multimodal interfaces (pp. 205-211). ACM.

Butler, E.A. and Strayer, J., 1998. The many faces of empathy. In *Poster presented at the annual meeting of the Canadian Psychological Association, Edmonton, Alberta, Canada*.

Bryman, A., 1988. Quality and Quantity in Social Research in Bulmer (ed). Contemporary Social Research: 18.

Caicedo, D.G. and Van Beuzekom, M., 2006. How do you feel? An assessment of existing tools for the measurement of emotions and their application in consumer product research. Delft University of Technology, Department of Industrial Design.

Calvo, R.A. and D'Mello, S., 2010. Affect detection: An interdisciplinary review of models, methods, and their applications. IEEE Transactions on affective computing, 1(1), pp.18-37.

Cannon, W.B., 1931. Again the James-Lange and the thalamic theories of emotion. Psychological Review, 38(4), p.281.

Capps, 2015. The Science of Road Rage. Available at: https://www.citylab.com/equity/2015/02/the-end-of-road-rage/385395/ (Accessed on 28 November 2017)

Carberry, S. and de Rosis, F., 2008. Introduction to special Issue on ‘Affective modeling and adaptation’. User Modeling and User-Adapted Interaction, 18(1-2), pp.1-9.

Clarion, A., Ramon, C., Petit, C., Dittmar, A., Bourgeay, J.P., Guillot, A., Gehin, C., McAdams, E. and Collet, C., 2009. An integrated device to evaluate a driver’s functional state. Behavior research methods, 41(3), pp.882-888.

Carrabine, E. and Longhurst, B., 2002. Consuming the car: anticipation, use and meaning in contemporary youth culture. The sociological review, 50(2), pp.181-196.

Cerin, E., Szabo, A. and Williams, C., 2001. Is the experience sampling method (ESM) appropriate for studying pre-competitive emotions?. Psychology of Sport and Exercise, 2(1), pp.27-45.

Chen, L., Yoon, S.Y., Leong, C.W., Martin, M. and Ma, M., 2014, November. An initial analysis of structured video interviews by using multimodal emotion detection. In *Proceedings of the 2014 workshop on Emotion Representation and Modelling in Human-Computer-Interaction-Systems* (pp. 1-6). ACM.

Cienki, A. and Mittelberg, I., 2013. Creativity in the forms and functions of spontaneous gestures with speech. The Agile Mind: A Multidisciplinary Study of a Multifaceted Phenomenon. Berlin, Germany: De Gruyter Mouton, pp.231-252.

Cisco, 2013. Cisco customer experience research, Automotive industry, Global data. Available at: https://www.cisco.com/c/dam/en_us/about/ac79/docs/ccer_report_manufacturing.pdf (Accessed: 2 August 2017)

Coan, J.A. and Allen, J.J. eds., 2007. Handbook of emotion elicitation and assessment. Oxford university press.

Cohen, A.O., Dellarco, D.V., Breiner, K., Helion, C., Heller, A.S., Rahdar, A., Pedersen, G., Chein, J., Dyke, J.P., Galvan, A. and Casey, B.J., 2016. The impact of emotional states on cognitive control circuitry and function. Journal of cognitive neuroscience.

Cohen, M.R. and Nagel, E., An Introduction to Logic and Scientific Method, 1939. George Routledge and Sons, London.

Collet, C., Vernet-Maury, E., Delhomme, G. and Dittmar, A., 1997. Autonomic nervous system response patterns specificity to basic emotions. Journal of the autonomic nervous system, 62(1), pp.45-57.

Coombes, S.A., Cauraugh, J.H. and Janelle, C.M., 2007. Dissociating motivational direction and affective valence: specific emotions alter central motor processes. Psychological Science, 18(11), pp.938-942.

Cornet, A. and Krieger, A., 2005. Customer-Driven Innovation Management.

Creswell, J.W. and Zhang, W., 2009. The application of mixed methods designs to trauma research. Journal of traumatic stress, 22(6), pp.612-621.

Creswell, J.W. and Poth, C.N., 2017. Qualitative inquiry and research design: Choosing among five approaches. Sage publications.

Crotty, M., 1998. The foundations of social research: Meaning and perspective in the research process. Sage.

Dahl, S. and Friberg, A., 2007. Visual Perception of Expressiveness in Musicians9 Body Movements. Music Perception: An Interdisciplinary Journal, 24(5), pp.433-454.

Damasio, A.R., Tranel, D. and Damasio, H., 1990. Face agnosia and the neural substrates of memory. Annual review of neuroscience, 13(1), pp.89-109.

Damasio, A.R., 1994. Descartes' Error: Emotion, Reason and the Human Brain. New York: Putnam.———. 1999. The Feeling of What Happens: Body and Emotion in the Making of Consciousness.

Damasio, A.R., 2003. Looking for Spinoza: Joy, sorrow, and the feeling brain. Houghton Mifflin Harcourt.

Dant, T., 2004. The driver-car. Theory, Culture & Society, 21(4-5), pp.61-79.

Darwin, C. and Prodger, P., 1998. The expression of the emotions in man and animals. Oxford University Press, USA.

Data Protection Act, 1998. Available at: http://www.legislation.gov.uk/ukpga/1998/29/contents (Accessed: 16 June 2017)

Davidson, J.W., 1994. What type of information is conveyed in the body movements of solo musician performers. Journal of Human Movement Studies, 6, pp.279-301.

Davidson, R.J., 1992. Anterior cerebral asymmetry and the nature of emotion. Brain and cognition, 20(1), pp.125-151.

Deffenbacher, J.L., Lynch, R.S., Oetting, E.R. and Swaim, R.C., 2002. The Driving Anger Expression Inventory: A measure of how people express their anger on the road. Behaviour research and therapy, 40(6), pp.717-737.

Deffenbacher, J.L., Deffenbacher, D.M., Lynch, R.S. and Richards, T.L., 2003. Anger, aggression, and risky behavior: a comparison of high and low anger drivers. Behaviour research and therapy, 41(6), pp.701-718.

Dement, W.C., 1997. The perils of drowsy driving.

Denscombe, M., 2008. Communities of practice: A research paradigm for the mixed methods approach. Journal of mixed methods research, 2(3), pp.270-283.

Denzin, N.K., 1973. The research act: A theoretical introduction to sociological methods. Transaction publishers.

Denzin, N.K. and Lincoln, Y.S. eds., 2011. The Sage handbook of qualitative research. Sage.

Desmet, P., 2002. Designing emotions. Delft University of Technology. Department of Industrial Design.

Desmet, P., 2003. Measuring emotion: Development and application of an instrument to measure emotional responses to products. In Funology (pp. 111-123). Springer Netherlands.

Detre, J.A. and Wang, J., 2002. Technical aspects and utility of fMRI using BOLD and ASL. Clinical Neurophysiology, 113(5), pp.621-634.

De Winter, J., Van Leuween, P. and Happee, P., 2012, August. Advantages and disadvantages of driving simulators: a discussion. In Proceedings of Measuring Behavior (pp. 47-50).

Dehzangi, O. and Williams, C., 2015, June. Towards multi-modal wearable driver monitoring: impact of road condition on driver distraction. In *Wearable and Implantable Body Sensor Networks (BSN), 2015 IEEE 12th International Conference on*(pp. 1-6). IEEE.

DFT (Department of Transport), 2017. Road length notes definitions. Available at: http://www.englandhighways.co.uk/wp-content/uploads/2017/03/road-length-notes-definitions.pdf (Accessed: 26 June 2017)

Dibley, L., 2012. Analysing narrative data using McCormack's Lenses Nurse Researcher 18(3), 13-19. Available at: http://nurseresearcher.rcnpublishing.co.uk/newsandopinion/commentary/analysing-qualitative-data (Accessed: 01 August 2016)

Di Stasi, L.L., Contreras, D., Canas, J.J., Candido, A., Maldonado, A. and Catena, A., 2010. The consequences of unexpected emotional sounds on driving behaviour in risky situations. Safety science, 48(10), pp.1463-1468.

Duenwald, M., 2005. The physiology of facial expressions. Retrieved September, 19, p.2007.

Dula, C.S. and Geller, E.S., 2003. Risky, aggressive, or emotional driving: Addressing the need for consistent communication in research. Journal of safety research, 34(5), pp.559-566.

Dumaine, B., 2012. The driverless revolution rolls on. Availabe at http://fortune.com/2012/11/12/the-driverless-revolution-rolls-on/ (Accessed: 3 September 2017)

Edensor, T., 2004. Automobility and national identity: Representation, geography and driving practice. Theory, Culture & Society, 21(4-5), pp.101-120.

Ekkekakis, P., Hall, E.E., VanLanduyt, L.M. and Petruzzello, S.J., 2000. Walking in (affective) circles: can short walks enhance affect?. Journal of Behavioral Medicine, 23(3), pp.245-275.

Ekkekakis, P., 2013. The measurement of affect, mood, and emotion: A guide for health-behavioral research. Cambridge University Press.

Ekman, P. and Friesen, W.V., 1971. Constants across cultures in the face and emotion. Journal of personality and social psychology, 17(2), p.124.

Ekman, P., Levenson, R.W. and Friesen, W.V., 1983, September. Autonomic nervous system activity distinguishes among emotions. American Association for the Advancement of Science.

Ekman, P., Friesen, W.V. and Ellsworth, P., 2013. Emotion in the human face: Guidelines for research and an integration of findings. Elsevier.

El Kaliouby, R. and Robinson, P., 2005. Real-time inference of complex mental states from facial expressions and head gestures. In Real-time vision for human-computer interaction (pp. 181-200). Springer US.

Elliott, E.A. and Jacobs, A.M., 2013. Facial expressions, emotions, and sign languages. Frontiers in psychology, 4.

Elliot, H., 2009. Fifty years of mini love. Available at: https://www.forbes.com/2009/07/29/bmw-mini-cooper-lifestyle-vehicles-mini-car-50.html (Accessed: 10 September 2017)

Eyben, F., Wöllmer, M., Poitschke, T., Schuller, B., Blaschke, C., Färber, B. and Nguyen-Thien, N., 2010. Emotion on the road—necessity, acceptance, and feasibility of affective computing in the car. Advances in human-computer interaction, 2010.

Feagin, J.R., Orum, A.M. and Sjoberg, G. eds., 1991. A case for the case study. UNC Press Books.

Forgas, J.P., 1992. Affect in social judgments and decisions: A multiprocess model. Advances in experimental social psychology, 25, pp.227-275.

Fox, E., 2008. Emotion science cognitive and neuroscientific approaches to understanding human emotions. Palgrave Macmillan.

Frank, B. H., 2017. Google Brain chief: Deep learning takes at least 100,000 examples. Available at: https://venturebeat.com/2017/10/23/google-brain-chief-says-100000-examples-is-enough-data-for-deep-learning/ (Accessed: 20 October 2017)

Fusch, P.I. and Ness, L.R., 2015. Are we there yet? Data saturation in qualitative research. The Qualitative Report, 20(9), p.1408.

Gao, H., Yüce, A. and Thiran, J.P., 2014, October. Detecting emotional stress from facial expressions for driving safety. In Image Processing (ICIP), 2014 IEEE International Conference on(pp. 5961-5965). IEEE.

Gao, P.,Kaas, H., Mohr, D., Wee, D., 2016. Automotive revolution: perspective towards 2030: how the convergence of disruptive technology-driven trends could transform the auto industry. Available at: http://www.mckinsey.com/industries/high-tech/our-insights/disruptive-trends-that-will-transform-the-auto-industry (Accessed: 05 January 2017)

Gendron, M. and Feldman Barrett, L., 2009. Reconstructing the past: A century of ideas about emotion in psychology. Emotion review, 1(4), pp.316-339.

Giacomin, J. and Bracco, R., 1995. An experimental approach for the vibration optimisation of automotive seats. ATA Third International, 7.

Giuliano, L., Germak, C. and Giacomin, J., 2017. Effect of Driving Context On Design Dialogue.

Gkatzidou, V., Giacomin, J. and Skrypchuk, L., 2016. Automotive Habitat Laboratory: a facility for automotive co-design.Proceedings of the 7th International Conference on Applied Human Factors and Ergonomics, Orlando, Florida, USA. July 27-31.

Gkouskos, D., Normark, C.J. and Lundgren, S., 2014. What drivers really want: Investigating dimensions in automobile user needs. International Journal of Design, 8(1).

Goeleven, E., De Raedt, R., Leyman, L. and Verschuere, B., 2008. The Karolinska directed emotional faces: a validation study. *Cognition and emotion*, *22*(6), pp.1094-1118.

Gott, P., 2014. The impact of New Urban Mobility on Automotive Markets and Industry. Available at: https://www.ihs.com/pdf/Auto_New-Urban-Mobility_ExecSumm-ToC_147546110913052132.pdf (Accessed 4 June 2016)

Graham, F.K., 1992. Attention and information processing in infants and adults: perspectives from human and animal research. Attention: the heartbeat, the blink, and the brain. Hillsdale, NJ: Lawrence Erlbaum Associates, pp.3-29.

Gratton, C. and Jones, I., 2010. Research methods for sports studies. Taylor & Francis.

Gray, D.E., 2013. Doing research in the real world. Sage.

Grimm, M., Kroschel, K., Harris, H., Nass, C., Schuller, B., Rigoll, G. and Moosmayr, T., 2007. On the necessity and feasibility of detecting a driver's emotional state while driving. Affective computing and intelligent interaction, pp.126-138.

Gross, J.J. and Levenson, R.W., 1995. Emotion elicitation using films. Cognition & emotion, 9(1), pp.87-108.

Guba, E.G. (1990). The alternative paradigm dialogue. In E.G. Guba (Ed.), The paradigm dialogue (pp. 17-27).

Guo, Y., Logan, H.L., Glueck, D.H. and Muller, K.E., 2013. Selecting a sample size for studies with repeated measures. BMC medical research methodology, 13(1), p.100.

Gupta, P., 2011. Humanity in medicine. Journal of medical ethics and history of medicine, 4.

Gwyther, H. and Holland, C., 2012. The effect of age, gender and attitudes on self-regulation in driving. Accident Analysis & Prevention, 45, pp.19-28.

Hagel, J., Vitale, J., 2017. How technology is moving the automotive industry from products to relationships. Available at: https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-mfg-how-technology-is-moving-the-automotive-industry-from-products-to-relationships.pdf (Accessed: 15 July 2017)

Hagman, O., 2010. Driving pleasure: A key concept in Swedish car culture. Mobilities, 5(1), pp.25-39.

Hall, R.A., Premont, R.T., Chow, C.W., Blitzer, J.T., Pitcher, J.A., Claing, A., Stoffel, R.H., Barak, L.S., Shenolikar, S., Weinman, E.J. and Grinstein, S., 1998. The β2-adrenergic receptor interacts with the Na+/H+-exchanger regulatory factor to control Na+/H+ exchange. Nature, 392(6676), pp.626-630.

Hansen, J.H., Boyraz, P., Takeda, K. and Abut, H. eds., 2012. Digital signal processing for in-vehicle systems and safety. Springer, pp.149, 221.

Harrigan, J.A., 2005. Proxemics, kinesics, and gaze. The new handbook of methods in nonverbal behavior research, pp.137-198.

Harris, H. and Nass, C., 2011, May. Emotion regulation for frustrating driving contexts. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 749-752). ACM.

Harris, J., 2017.Owning a car will soon be a thing of the future. Available at: https://www.theguardian.com/commentisfree/2017/oct/23/owning-car-thing-of-the-past-cities-utopian-vision (Accessed: 24 October 2017)

Healey, J.A., 2000. Wearable and automotive systems for affect recognition from physiology (Doctoral dissertation, Massachusetts Institute of Technology).

Healey, J.A. and Picard, R.W., 2005. Detecting stress during real-world driving tasks using physiological sensors. IEEE Transactions on intelligent transportation systems, 6(2), pp.156-166.

Heppard, C., 2015.Maslow's Hierarchy of Marketing Needs. Available at: https://www.linkedin.com/pulse/maslows-hierarchy-marketing-needs-cheryl-heppard (Accessed: 9 June 2017)

How To Deal With Fear Of Driving In Bad Weather, 2015. Available at: http://overcomefearofdriving.org/92/fear-of-driving-in-bad-weather/ (Accessed on 28 November 2017)

Höök, K., Isbister, K. and Laaksolahti, J., 2006. Sensual evaluation instrument. In Proc CHI ‘06.

Hoch, S., Althoff, F., McGlaun, G. and Rigoll, G., 2005, March. Bimodal fusion of emotional data in an automotive environment. In Acoustics, Speech, and Signal Processing, 2005. Proceedings.(ICASSP'05). IEEE International Conference on (Vol. 2, pp. ii-1085). IEEE.

Horrell, P., 2014. Autopilot for cars – are we nearly there yet? Available at: http://360.here.com/2014/03/07/autopilot-for-cars-are-we-nearly-there-yet/ (Accessed: 2 June 2016)

Hsu, W.Y., Lu, Y.N. and Ho, C.H., 2013. Using Pupillary Response for Evaluating Users' Emotion Elicited by Cars. National Science Council of the Republic of China

Hughes, C. 2006. Quantitative and qualitative approaches. Available at: http://www2.warwick.ac.uk/fac/soc/sociology/staff/academicstaff/chughes/hu ghesc_index/teaching researchprocess/quantitativequalitative/quantitativequalitative/ (Accessed 31 July 2016)

Huguenin, R.D. and Rumar, K., 2001. Models in traffic psychology. In Traffic psychology today (pp. 31-59). Springer US.

iMotions, 2013. Attention Tool Guide. Available at: http://imotionsglobal.com/wpcontent/uploads/2013/08/Guide.pdf (Accessed 25 September 2015)

Intland, 2016. Webinar: Preparing for Automotive Embedded Development Trends in 2017. Available at: https://intland.com/blog/automotive/automotive-industry-development-trends-2017/ (Accessed 29 September 2017)

Isbister, K., Höök, K., Laaksolahti, J., Sharp, M. (2007). The sensual evaluation instrument: Developing a trans-cultural self-report measure of affect. International journal of human-computer studies 65 (4): 315–328.

Jick, T.D., 1979. Mixing qualitative and quantitative methods: Triangulation in action. Administrative science quarterly, 24(4), pp.602-611.

Karlsson, P-H., Ahn, H. K., Choi, B. 2017. Connected Car, a new Ecosystem. Ipsos BC Analysis. Available at: http://www.ipsosconsulting.com/pdf/connected-car-a-new-ecosystem.pdf (Accessed 27 October 2017)

Isen, A.M., 2001. An influence of positive affect on decision making in complex situations: Theoretical issues with practical implications. Journal of consumer psychology, 11(2), pp.75-85.

Isomursu, M., Tähti, M., Väinämö, S. and Kuutti, K., 2007. Experimental evaluation of five methods for collecting emotions in field settings with mobile applications. International Journal of Human-Computer Studies, 65(4), pp.404-418.

Izquierdo-Reyes, J., Ramirez-Mendoza, R.A., Bustamante-Bello, M.R., Navarro-Tuch, S. and Avila-Vazquez, R., 2018. Advanced driver monitoring for assistance system (ADMAS). *International Journal on Interactive Design and Manufacturing (IJIDeM)*, *12*(1), pp.187-197.

Jacques, C., 2014. Self-driving Cars an $87 Billion Opportunity in 2030, Though None Reach Full Autonomy. Lux Research. Available at: http://www.luxresearchinc.com/news-and-events/press-releases/read/self-driving-cars-87-billion-opportunity-2030-though-none-reach (Accessed 31 October 2017)

James, W.T., 1932. A study of the expression of bodily posture. The Journal of General Psychology, 7(2), pp.405-437.

James, L., 2000. Road rage and aggressive driving: Steering clear of highway warfare. Prometheus Books.

Jeon, M., Walker, B.N. and Yim, J.B., 2014. Effects of specific emotions on subjective judgment, driving performance, and perceived workload. Transportation research part F: traffic psychology and behaviour, 24, pp.197-209.

Jeon, M., Yim, J.B. and Walker, B.N., 2011, November. An angry driver is not the same as a fearful driver: effects of specific negative emotions on risk perception, driving performance, and workload. In Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications(pp. 137-142). ACM.

Jeon, M. 2015a. Lessons from Emotional Driving Research. Proceedings 19th Triennial Congress of the IEA, Melbourne

Jeon, M., 2015b. Towards affect-integrated driving behaviour research. Theoretical Issues in Ergonomics Science, 16(6), pp.553-585.
Jeon, M., Walker, B.N. and Gable, T.M., 2015. The effects of social interactions with in-vehicle agents on a driver's anger level, driving performance, situation awareness, and perceived workload. Applied ergonomics, 50, pp.185-199.

Ji, Q. and Yang, X., 2002. Real-time eye, gaze, and face pose tracking for monitoring driver vigilance. Real-Time Imaging, 8(5), pp.357-377.

Ji, Q., Zhu, Z. and Lan, P., 2004. Real-time nonintrusive monitoring and prediction of driver fatigue. *IEEE transactions on vehicular technology*, *53*(4), pp.1052-1068.

Jones, C.M. and Jonsson, I.M., 2005, November. Automatic recognition of affective cues in the speech of car drivers to allow appropriate responses. In Proceedings of the 17th Australia conference on Computer-Human

Interaction: Citizens Online: Considerations for Today and the Future (pp. 1-10). Computer-Human Interaction Special Interest Group (CHISIG) of Australia.

Jones, C.M. and Jonsson, I.M., 2007. Performance analysis of acoustic emotion recognition for in-automobile conversational interfaces, in Universal Access in Human-Computer Interaction. Ambient Interaction, Part II, vol. 4555 of Lecture Notes in Computer Science, pp. 411–420

Jones, C. and Jonsson, I.M., 2008. Using paralinguistic cues in speech to recognise emotions in older car drivers. Affect and Emotion in Human-Computer Interaction, 4868, pp.229-240.

Jonsson, I.M., Zajicek, M., Harris, H. and Nass, C., 2005, April. Thank you, I did not see that: in-car speech based information systems for older adults. In CHI'05 Extended Abstracts on Human Factors in Computing Systems (pp. 1953-1956). ACM.

Kalogianni, A., 2016. The next 10 years in car tech will make the last 30 look just like a warm-up. Available at: https://www.digitaltrends.com/cars/the-future-of-car-tech-a-10-year-timeline/ (Accessed 1 October 2017)

Kanske, P., Heissler, J., Schönfelder, S., Bongers, A. and Wessa, M., 2010. How to regulate emotion? Neural networks for reappraisal and distraction. Cerebral Cortex, 21(6), pp.1379-1388.

Kaplan, B. and Duchon, D., 1988. Combining qualitative and quantitative methods in information systems research: a case study. MIS quarterly, pp.571-586.

Kapoor, A., Qi, Y. and Picard, R.W., 2003, October. Fully automatic upper facial action recognition. In Analysis and Modeling of Faces and Gestures, 2003. AMFG 2003. IEEE International Workshop on (pp. 195-202). IEEE.

Katz, J., 2001. How emotions work. University of Chicago Press.

Kennington, R., 1980. The Philosophy of Baruch Spinoza.

Kim, K.H., Bang, S.W. and Kim, S.R., 2004. Emotion recognition system using short-term monitoring of physiological signals. Medical and biological engineering and computing, 42(3), pp.419-427.

Kim, S., Georgiou, P.G., Lee, S. and Narayanan, S., 2007, October. Real-time emotion detection system using speech: Multi-modal fusion of different timescale features. In Multimedia Signal Processing, 2007. MMSP 2007. IEEE 9th Workshop on (pp. 48-51). IEEE.

Kleinginna, P.R. and Kleinginna, A.M., 1981. A categorized list of emotion definitions, with suggestions for a consensual definition. Motivation and emotion, 5(4), pp.345-379.

Ko, B.C., 2018. A Brief Review of Facial Emotion Recognition Based on Visual Information. *sensors*, *18*(2), p.401.

Koo, J., Kwac, J., Ju, W., Steinert, M., Leifer, L. and Nass, C., 2015. Why did my car just do that? Explaining semi-autonomous driving actions to improve driver understanding, trust, and performance. International Journal on Interactive Design and Manufacturing (IJIDeM), 9(4), pp.269-275.

Kreibig, S.D., Wilhelm, F.H., Roth, W.T. and Gross, J.J., 2007. Cardiovascular, electrodermal, and respiratory response patterns to fear-and sadness-inducing films. Psychophysiology, 44(5), pp.787-806.

Kuhn, T.S., 1962. The Structure of Scientific Revolutions, 1st enl. ed. University of Chicago Press.

Landrum, B. and Garza, G., 2015. Mending fences: Defining the domains and approaches of quantitative and qualitative research. Qualitative psychology, 2(2), p.199.

Lang, P.J., 1980. Self-assessment manikin. Gainesville, FL: The Center for Research in Psychophysiology, University of Florida.

Lang, P.J., Greenwald, M.K., Bradley, M.M. and Hamm, A.O., 1993. Looking at pictures: Affective, facial, visceral, and behavioral reactions. Psychophysiology, 30(3), pp.261-273.

Lardinois, F., 2012. Google's Self-Driving Automobiles Complete 300K Miles Without Accident. Available at: https://techcrunch.com/2012/08/07/google-cars-300000-miles-without-accident/ (Accessed 31 October 2017)

Larsen, R.J. and Diener, E., 1992. Promises and problems with the circumplex model of emotion.

Lazar, J., Feng, J.H. and Hochheiser, H., 2017. Research methods in human-computer interaction. Morgan Kaufmann.

Lee, Y.C., 2010, September. Measuring drivers' frustration in a driving simulator. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 54, No. 19, pp. 1531-1535). Sage CA: Los Angeles, CA: Sage Publications.

Lee, K.W., Yoon, H.S., Song, J.M. and Park, K.R., 2018. Convolutional Neural Network-Based Classification of Driver's Emotion during Aggressive and Smooth Driving Using Multi-Modal Camera Sensors. *Sensors*, *18*(4), p.957.

Levelt, P.B.M., 2003. Praktijkstudie naar emoties in het verkeer. S WOV Report R-2003-08. Leidschendam: SWOV.

Lewis, M., Haviland-Jones, J.M. and Barrett, L.F. eds., 2010. Handbook of emotions. Guilford Press.

Li, X. and Ji, Q., 2005. Active affective state detection and user assistance with dynamic Bayesian networks. IEEE transactions on systems, man, and cybernetics-part a: systems and humans, 35(1), pp.93-105.

Lima, M., Silva, K., Magalhães, A., Amaral, I., Pestana, H. and de Sousa, L., 2012. Can you know me better? An exploratory study combining behavioural and physiological measurements for an objective assessment of sensory responsiveness in a child with profound intellectual and multiple disabilities. Journal of Applied Research in Intellectual Disabilities, 25(6), pp.522-530.

Lincoln, Y.S. and Guba, E.G., 1985. Naturalistic inquiry (Vol. 75). Sage.

Lisetti, C.L. and Nasoz, F., 2005, July. Affective intelligent car interfaces with emotion recognition. In Proceedings of 11th International Conference on Human Computer Interaction, Las Vegas, NV, USA.

Loveridge, P., 1990. The strategic management of technological innovation. Somerset, England: Wiley.

Lucey, P., Cohn, J.F., Kanade, T., Saragih, J., Ambadar, Z. and Matthews, I., 2010, June. The extended cohn-kanade dataset (ck+): A complete dataset for action unit and emotion-specified expression. In *Computer Vision and Pattern Recognition Workshops (CVPRW), 2010 IEEE Computer Society Conference on* (pp. 94-101). IEEE.

Lyons, W., 1999. The philosophy of cognition and emotion. Handbook of cognition and emotion, pp.21-44.

Lyznicki, J.M., Doege, T.C., Davis, R.M. and Williams, M.A., 1998. Sleepiness, driving, and motor vehicle crashes. Jama, 279(23), pp.1908-1913.

Mack, N., Woodsong, C., MacQueen, K.M., Guest, G. and Namey, E., 2005. Qualitative research methods: a data collectors field guide.

Malta, L., Miyajima, C., Kitaoka, N. and Takeda, K., 2011. Analysis of real-world driver's frustration. IEEE Transactions on Intelligent Transportation Systems, 12(1), pp.109-118.

Marques, J.F. and McCall, C., 2005. The application of interrater reliability as a solidification instrument in a phenomenological study. The Qualitative Report, 10(3), pp.439-462.

Marshall, P., Morris, R., Rogers, Y., Kreitmayer, S. and Davies, M., 2011, May. Rethinking'multi-user': an in-the-wild study of how groups approach a walk-up-and-use tabletop interface. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 3033-3042). ACM.

Martin, M., 1990. On the induction of mood. Clinical Psychology Review, 10(6), pp.669-697.

Maslow, A.H., 1943. A theory of human motivation. Psychological review, 50(4), p.370.

Matthews, G., Dorn, L., Hoyes, T.W., Davies, D.R., Glendon, A.I. and Taylor, R.G., 1998. Driver stress and performance on a driving simulator. Human Factors, 40(1), pp.136-149.

Matthews, R., McDonald, N.J., Anumula, H. and Trejo, L.J., 2006. Novel hybrid sensors for unobtrusive recording of human biopotentials. Foundations of Augmented Cognition, 2006, pp.91-101.

Mauss, I.B. and Robinson, M.D., 2009. Measures of emotion: A review. Cognition and emotion, 23(2), pp.209-237.

May, T. and Williams, M., 2002. An introduction to the philosophy of social research. Routledge.

McDuff, D., Mahmoud, A., Mavadati, M., Amr, M., Turcot, J. and Kaliouby, R.E., 2016, May. AFFDEX SDK: a cross-platform real-time multi-face expression recognition toolkit. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (pp. 3723-3726). ACM.

Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P. and Marrs, A., 2013. Disruptive technologies: Advances that will transform life, business, and the global economy (Vol. 180). San Francisco, CA: McKinsey Global Institute.

Meeder, M., Bosina, E. and Weidmann, U., 2017. Autonomous vehicles: Pedestrian heaven or pedes-trian hell?.

Meehan, M., 2000, March. An objective surrogate for presence: Physiological response. In 3rd International Workshop on Presence.

Meehan, M., 2001. Physiological reaction as an objective measure of presence in virtual environments (Doctoral dissertation, University of North Carolina at Chapel Hill).

Mesken, J., 2006. Determinants and consequences of drivers' emotions. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV.

Mesken, J., Hagenzieker, M.P., Rothengatter, T. and de Waard, D., 2007. Frequency, determinants, and consequences of different drivers' emotions: An on-the-road study using self-reports,(observed) behaviour, and physiology. Transportation research part F: traffic psychology and behaviour, 10(6), pp.458-475.

Michael, M., 2001. The invisible car: the cultural purification of road rage. Car cultures, pp.59-80.

Miller, D., 2001. Driven societies. in D. Miller (ed.) Automobile Cultures. Oxford: Berg.

Miller, E.E., 2013. Effects of Roadway on Driver Stress: An On-Road Study using Physiological Measures (Doctoral dissertation).

Minhad, K.N., Ali, S.H.M. and Reaz, M.B.I., 2017. Happy-anger emotions classifications from electrocardiogram signal for automobile driving safety and awareness. *Journal of Transport & Health*, *7*, pp.75-89.

Moore-Ede, M., Campbell, S. and Baker, T., 1988, November. Falling asleep behind the wheel: research priorities to improve driver alertness and highway safety. In Proceedings of Federal Highway Administration Symposium on Truck and Bus Driver Fatigue. Washington, DC.

Morris, J.D., 1995. Observations: SAM: the Self-Assessment Manikin; an efficient cross-cultural measurement of emotional response. Journal of advertising research, 35(6), pp.63-68.

Morse, J.M. ed., 1994. Critical issues in qualitative research methods. Sage, pp. 281–297.

Mota, S. and Picard, R.W., 2003, June. Automated posture analysis for detecting learner's interest level. In *Computer Vision and Pattern Recognition Workshop, 2003. CVPRW'03. Conference on* (Vol. 5, pp. 49-49). IEEE.

Motavalli, J., 2014. Forward Drive: The Race to Build the Clean Car of the Future. Routledge.

Murphy, F.C., Nimmo-Smith, I.A.N. and Lawrence, A.D., 2003. Functional neuroanatomy of emotions: a meta-analysis. Cognitive, Affective, & Behavioral Neuroscience, 3(3), pp.207-233.

Murray, I.R. and Arnott, J.L., 1993. Toward the simulation of emotion in synthetic speech: A review of the literature on human vocal emotion. The Journal of the Acoustical Society of America, 93(2), pp.1097-1108.

Namba, S., Kabir, R.S., Miyatani, M. and Nakao, T., 2017. Spontaneous Facial Actions Map onto Emotional Experiences in a Non-social Context: Toward a Component-Based Approach. Frontiers in Psychology, 8.

Nancarrow, C. and Brace, I., 2000. Saying the “right thing”: Coping with social desirability bias in marketing research. Bristol Business School Teaching and Research Review, 3(11).

Nass, C., Jonsson, I.M., Harris, H., Reaves, B., Endo, J., Brave, S. and Takayama, L., 2005, April. Improving automotive safety by pairing driver emotion and car voice emotion. In CHI'05 Extended Abstracts on Human Factors in Computing Systems (pp. 1973-1976). ACM.

National Highway Traffic Safety Administration, 2008. National motor vehicle crash causation survey: Report to congress. National Highway Traffic Safety Administration Technical Report DOT HS, 811, p.059.

Newbury, S., 2002. Car Design Yearbook 1: The Definitive Guide to New Concept and Production Cars Worldwide. Merrell.

Normark, C.J. and Gkouskos, D., 2012. Exploring user needs in automobiles. In International Design Conference: 21/05/2012-24/05/2012 (pp. 1369-1376). Design Research Society.

Norman, D.A., 1990. The'problem'with automation: inappropriate feedback and interaction, not'over-automation'. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 327(1241), pp.585-593.

Norman, D.A., 2007. The design of future things: author of the design of everyday things.

Panksepp J. Affective neuroscience: The foundations of human and animal emotions. New York: Oxford University Press; 1998.

Panksepp, J., 2007. Neuroevolutionary sources of laughter and social joy: Modeling primal human laughter in laboratory rats. Behavioural brain research, 182(2), pp.231-244.

Pantic, M. and Rothkrantz, L.J.M., 2000. Automatic analysis of facial expressions: The state of the art. IEEE Transactions on pattern analysis and machine intelligence, 22(12), pp.1424-1445.

Parkinson, B., 2001. Anger on and off the road. British journal of Psychology, 92(3), pp.507-526.

Parrott, W.G. ed., 2001. Emotions in social psychology: Essential readings. Psychology Press.

Pearl, J., 2003. Causality: models, reasoning and inference. Econometric Theory, 19(675-685), p.46.

Pearl, J., 2014. Comment: understanding simpson's paradox. The American Statistician, 68(1), pp.8-13.

Pelly, C., 1996. Creative consciousness: Designing the driving experience. Design Management Review, 7(4), pp.51-54.

Peugeot Motion & Emotion, 2010, Fleeteurope. Available at: https://www.fleeteurope.com/en/news/peugeot-motion-emotion (Accessed 31 October 2017)

Picard, R.W., Vyzas, E. and Healey, J., 2001. Toward machine emotional intelligence: Analysis of affective physiological state. IEEE transactions on pattern analysis and machine intelligence, 23(10), pp.1175-1191.

Picard, R.W., 2003. Affective computing: challenges. International Journal of Human-Computer Studies, 59(1), pp.55-64.

Pittam, J. and Scherer, K.R., 1993. Vocal expression and communication of emotion. Guilford Press.

Pollick, F.E., Paterson, H.M., Bruderlin, A. and Sanford, A.J., 2001. Perceiving affect from arm movement. Cognition, 82(2), pp.B51-B61.

Pope, B., 2010. Recession Affects Automotive Design in Variety of Ways. WardsAuto. Available at: http://wardsauto.com/news-analysis/recession-affects-automotive-design-variety-ways (Accessed: 2 November 2017)

Popper, K.R., 1968. Epistemology without a knowing subject. Studies in Logic and the Foundations of Mathematics, 52, pp.333-373.

Posner, J., Russell, J.A. and Peterson, B.S., 2005. The circumplex model of affect: An integrative approach to affective neuroscience, cognitive development, and psychopathology. Development and psychopathology, 17(3), pp.715-734.

Puri, C., Olson, L., Pavlidis, I., Levine, J. and Starren, J., 2005, April. StressCam: non-contact measurement of users' emotional states through thermal imaging. In CHI'05 extended abstracts on Human factors in computing systems (pp. 1725-1728). ACM.

Punch, M., 1994. Politics and ethics in qualitative research. Handbook of qualitative research, 2, pp.83-98.

Rakauskas, M.E., Gugerty, L.J. and Ward, N.J., 2004. Effects of naturalistic cell phone conversations on driving performance. Journal of safety research, 35(4), pp.453-464.

Rand Report, 2014. Available at: https://www.rand.org/content/dam/rand/pubs/corporate_pubs/CP000/CP1-2014/RAND_CP1-2014.pdf (Accessed: 2 November 2017)

Rau, P.S., 2005, June. Drowsy driver detection and warning system for commercial vehicle drivers: field operational test design, data analyses, and progress. In 19th International Conference on Enhanced Safety of Vehicles (pp. 6-9).

Ray, R.D., 2007. Emotion elicitation using films. Handbook of emotion elicitation and assessment, pp.9-28.

Rebolledo-Mendez, G., Reyes, A., Paszkowicz, S., Domingo, M.C. and Skrypchuk, L., 2014. Developing a body sensor network to detect emotions during driving. IEEE transactions on intelligent transportation systems, 15(4), pp.1850-1854.

Regan, M.A., 2004. New technologies in automobiles: Human factors and safety issues. Ergonomics Australia, 18 (3). Review.

Reis, H.T. and Patrick, B.C., 1996. Attachment and intimacy: Component processes.

Revelle, W. and Loftus, D.A., 1992. The implications of arousal effects for the study of affect and memory. The handbook of emotion and memory

Riener, A., Ferscha, A. and Aly, M., 2009, September. Heart on the road: HRV analysis for monitoring a driver's affective state. In Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 99-106). ACM.

Riva, G., Wiederhold, B.K. and Molinari, E. eds., 1998. Virtual environments in clinical psychology and neuroscience: Methods and techniques in advanced patient-therapist interaction (Vol. 58). IOS press.

Riva, G., Davide, F. and IJsselsteijn, W.A., 2003. Being there: Concepts, effects and measurements of user presence in synthetic environments. Ios Press.

Roberts, K.M., 1980. FHWA HIGHWAY DRIVING SIMULATOR. Public Roads, 44(HS-031 069).

Robinson, C., 2002. Real world research: a resource for social scientists and practitioner-researchers.

Rogers, Y., and Marshall, P. 2017. Research in the wild. Synthesis Lectures on Human-Centred Informatics, #37

Rogers, Y., Connelly, K., Tedesco, L., Hazlewood, W., Kurtz, A., Hall, R., Hursey, J. and Toscos, T., 2007. Why it's worth the hassle: The value of in-situ studies when designing ubicomp. UbiComp 2007: Ubiquitous Computing, pp.336-353.

Ropert, S., 2014. Connected Cars Overview and trends. Communications & Strategies, (96), p.153.

Russell, J.A. and Fernández-Dols, J.M. eds., 1997. The psychology of facial expression. Cambridge university press.

Sat-Nav Rage of British Motorits, 2011. Available at: http://www.telegraph.co.uk/motoring/news/8806607/Sat-nav-rage-of-British-motorists.html (Accessed on 28 November 2017)

Saunders, M.N., 2011. Research methods for business students, 5/e. Pearson Education India.

Schmitter, A., 2006. Hume on the Emotions. Stanford Encyclopedia of Philosophy

Schoettle, B. and Sivak, M., 2014. A survey of public opinion about autonomous and self-driving vehicles in the US, the UK, and Australia.

Schuller, B., Lang, M. and Rigoll, G., 2006. Recognition of spontaneous emotions by speech within automotive environment. Fortschritte der Akustik, 32(1), p.57.

Schwandt, T.A., 2014. The Sage dictionary of qualitative inquiry. Sage Publications.

Schweitzer, J. and Green, P.E., 2007. Task acceptability and workload of driving city streets, rural roads, and expressways: Ratings from video clips.

Shah, F., 2010. Discrete wavelet transforms and artificial neural networks for speech emotion recognition. International Journal of Computer Theory and Engineering, 2(3), p.319.

Shah, M., Cooper, D.G., Cao, H., Gur, R.C., Nenkova, A. and Verma, R., 2013, September. Action unit models of facial expression of emotion in the presence of speech. In Affective Computing and Intelligent Interaction (ACII), 2013 Humaine Association Conference on (pp. 49-54). IEEE.

Shaikh, S. and Krishnan, P., 2013. A framework for analysing driver interactions with semi-autonomous vehicles. arXiv preprint arXiv:1301.0043.

Sheller, M., 2004. Automotive emotions: feeling the car. Theory, culture & society, 21(4-5), pp.221-242.

Sheridan, T.B., Meyer, J.E., Roy, S.H., Decker, K.S., Yanagishima, T. and Kishi, Y., 1991. Physiological and psychological evaluations of driver fatigue during long term driving (No. 910116). SAE Technical Paper.

Silberg, G., Manassa, M., Everhart, K., Subramanian, D., Corley, M., Fraser, H. and Sinha, V., 2013. Self-Driving Cars: Are We Ready?. KPMG LLP.

Smith, J.C., O'Connor, P.J., Crabbe, J.B. and Dishman, R.K., 2002. Emotional responsiveness after low-and moderate-intensity exercise and seated rest. Medicine & Science in Sports & Exercise.

Solomon, R.C., 1976. The passions: Emotions and the meaning of life. Hackett Publishing.

Stanley, B., Gyimesi, K., 2015. Automotive 2025: Industry without borders. Available at: https://www-935.ibm.com/services/multimedia/GBE03640USEN.pdf (Accessed 10 July 2016)

Sterkenburg, J., 2015. Impacts of distraction on driving: An analysis of physical, cognitive, and emotional distraction(Doctoral dissertation, Michigan Technological University).

Storbeck, J. and Clore, G.L., 2005. With sadness comes accuracy; with happiness, false memory: Mood and the false memory effect. Psychological Science, 16(10), pp.785-791.

Storbeck, J., Robinson, M.D. and McCourt, M.E., 2006. Semantic processing precedes affect retrieval: The neurological case for cognitive primacy in visual processing. Review of general psychology, 10(1), p.41.

Strayer, D.L. and Drew, F.A., 2004. Profiles in driver distraction: Effects of cell phone conversations on younger and older drivers. Human factors, 46(4), pp.640-649.

Strongman, K.T., 1996. The Psychology of Emotions: theories of emotions in perspective. Chichester, Willey and Sons, 40.

Takeda, K., Erdogan, H., Hansen, J. and Abut, H. eds., 2009. In-vehicle corpus and signal processing for driver behavior. Springer Science & Business Media.

Taubman-Ben-Ari, O., Mikulincer, M. and Gillath, O., 2004. The multidimensional driving style inventory—scale construct and validation. Accident Analysis & Prevention, 36(3), pp.323-332.

Teddlie, C. and Yu, F., 2007. Mixed methods sampling: A typology with examples. Journal of mixed methods research, 1(1), pp.77-100.

Terre Blanche, M. and Durrheim, K., 1999. Histories of the present: Social science research in context. Research in practice: Applied methods for the social sciences, 2, pp.1-17.

The Guardian view of the car industry: an electric future, 2017. Available at: https://www.theguardian.com/commentisfree/2017/mar/06/the-guardian-view-of-the-car-industry-an-electric-future (Accessed 10 October 2017)

Thrift, N., 2004. Driving in the City. Theory, Culture & Society, 21(4-5), pp.41-59.

Thrun, S., 2010. Toward robotic cars. Communications of the ACM, 53(4), pp.99-106.

Tian, Y.I., Kanade, T. and Cohn, J.F., 2001. Recognizing action units for facial expression analysis. IEEE Transactions on pattern analysis and machine intelligence, 23(2), pp.97-115.
Tischler, M.A., Peter, C., Wimmer, M. and Voskamp, J., 2007, September. Application of emotion recognition methods in automotive research. In Proceedings of the 2nd Workshop on Emotion and Computing—Current Research and Future Impact(Vol. 1, pp. 55-60).

Turner, C. and McClure, R., 2003. Age and gender differences in risk-taking behaviour as an explanation for high incidence of motor vehicle crashes as a driver in young males. Injury control and safety promotion, 10(3), pp.123-130.

Uchiyama, Y., Kojima, S.I., Hongo, T., Terashima, R. and Wakita, T., 2002, September. Voice information system adapted to driver's mental workload. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 46, No. 22, pp. 1871-1875). Sage CA: Los Angeles, CA: SAGE Publications.

UK Clinical Ethics Network, 2011. Ethical Issues. Available at: http://www.ukcen.net/ethical_issues (Accessed: 12 June 2017)

Underwood, G., Chapman, P., Wright, S. and Crundall, D., 1999. Anger while driving. Transportation Research Part F: Traffic Psychology and Behaviour, 2(1), pp.55-68.

Urry, J., 2004. The ‘system’of automobility. Theory, Culture & Society, 21(4-5), pp.25-39.

Vaida, S. and Ormenişan, M.C., 2013. From Plato to Ellis. A Short Investigation of the Concept of Emotions. Procedia-Social and Behavioral Sciences, 78, pp.571-575.

VanVoorhis, CR Wilson, and Betsy L. Morgan. "Understanding power and rules of thumb for determining sample sizes." Tutorials in Quantitative Methods for Psychology 3, no. 2 (2007): 43-50.

Velusamy, S., Kannan, H., Anand, B., Sharma, A. and Navathe, B., 2011, May. A method to infer emotions from facial action units. In Acoustics, Speech and

Signal Processing (ICASSP), 2011 IEEE International Conference on (pp. 2028-2031). IEEE.

Wang, J.S., Knipling, R.R. and Goodman, M.J., 1996, October. The role of driver inattention in crashes: New statistics from the 1995 Crashworthiness Data System. In 40th annual proceedings of the Association for the Advancement of Automotive Medicine (Vol. 377, p. 392).

Warell, A., 2008. Multi-modal visual experience of brand-specific automobile design. The TQM Journal, 20(4), pp.356-371.

Wegrzyn, M., Vogt, M., Kireclioglu, B., Schneider, J. and Kissler, J., 2017. Mapping the emotional face. How individual face parts contribute to successful emotion recognition. PloS one, 12(5), p.e0177239.

Wells-Parker, E., Ceminsky, J., Hallberg, V., Snow, R.W., Dunaway, G., Guiling, S., Williams, M. and Anderson, B., 2002. An exploratory study of the relationship between road rage and crash experience in a representative sample of US drivers. Accident Analysis & Prevention, 34(3), pp.271-278.

Wijayatunga, P., 2014. Viewing Simpson's paradox. Statistica & Applicazioni, 12(2), pp.225-235.

Wildemuth, B.M., 1993. Post-positivist research: two examples of methodological pluralism. The Library Quarterly, 63(4), pp.450-468.

Windhager, S., Slice, D.E., Schaefer, K., Oberzaucher, E., Thorstensen, T. and Grammer, K., 2008. Face to face. Human Nature, 19(4), pp.331-346.

Wolff, C., 2015. The hand in psychological diagnosis (Vol. 3). Routledge.

Wöllmer, M., Metallinou, A., Eyben, F., Schuller, B. and Narayanan, S.S., 2010. Context-sensitive multimodal emotion recognition from speech and facial expression using bidirectional lstm modeling. In Eleventh Annual Conference of the International Speech Communication Association.

Yaremko, R.M., Blair, M.W. and Leckart, B.T., 1970. The orienting reflex to changes in a conceptual stimulus dimension. Psychonomic Science, 21(2), pp.115-116.

Yerkes, R.M. and Dodson, J.D., 1908. The relation of strength of stimulus to rapidity of habit-formation. Journal of comparative neurology, 18(5), pp.459-482.

Yin, R.K., 1981. The case study crisis: Some answers. Administrative science quarterly, 26(1), pp.58-65.

Yu, J., Tseng, P., Muggleton, N.G. and Juan, C.H., 2015. Being watched by others eliminates the effect of emotional arousal on inhibitory control. Frontiers in psychology, 6.

Zeng, Z., Pantic, M., Roisman, G.I. and Huang, T.S., 2009. A survey of affect recognition methods: Audio, visual, and spontaneous expressions. IEEE transactions on pattern analysis and machine intelligence, 31(1), pp.39-58.

11. Appendix

Appendix A: Model Consent Form

Appendix B: Information Sheet for Research Participants

Appendix C: Health Form for Research Participants

Appendix D: Simulator Sickness Questionnaire

Appendix E: Ethics Approval Study 1

Appendix F: Ethics Approval Study 2

Appendix G: Ethics Approval Study 3

Appendix H: Screening Questions and Set-up Study 2

Appendix I: Screening Questions and Set-up Study 3

Appendix J: Multidimensional Driving Style Inventory

Appendix K: Research Ethics Risk Assessment (Study 2)

Appendix A: Model Consent Form

Consent Form for Research Participants

Please complete this form after you have read the Information Sheet.

A driving simulator study to inform the design of an Automotive Habitat Lab.

This study has been approved by the Brunel University Research Ethics Committee.

Thank you for your interest in taking part in this research. Before you agree to take part, the person organising the research must explain the project to you. If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you to decide whether to join in.

Participant's Statement

Please tick the appropriate box

- Have you read the Research Participant Information Sheet? YES ☐ NO ☐
- Do you understand that you will not be referred to by name in any report concerning the study? YES ☐ NO ☐
- Do you understand that you are free to withdraw from the study before the results are published without having to give a reason for withdrawing? YES ☐ NO ☐
- I agree to the study being recorded and I consent to the use of this material by the research team, as part of the study. YES ☐ NO ☐
- I agree to the use of non- attributable direct quotes when the study is written up or published. YES ☐ NO ☐
- I agree that the research project named above has explained to my satisfaction and I agree to take part in this study. YES ☐ NO ☐
- I understand that the information I have submitted will be published as a report and that I can contact the researchers to get a copy. YES ☐ NO ☐

Participant Name: ……………………………… **Date:** ………………..……

Signed: ………………………………………………..

Appendix B: Information Sheet for Research Participants

Information Sheet for Research Participants

You will be given a copy of this information sheet.

A driving simulator study to inform the design of an Automotive Habitat Lab.

We would like to invite you to participate in this research project. It involves a driving simulation study where you can help us design the future in-car technology.

What is the study about?

We are investigating emotions in the Automotive Habitat in order to improve the future driving experience.

What do the researchers want to find out?

Do I have to take part? No. It is completely up to you whether you take part or not.

What happens to my information? All information, including what is being discussed during the focus groups, is kept confidential (private) within the research team. No one outside the research team will have access to information which could be used to identify you. The researchers will remove any information, which could identify you (like your name) so that the data we keep is anonymous. Once this has been done, it will not be possible to withdraw your data. When we write our study report, we will not mention any names or other identifying information.

Can I find out the results of the study?

Yes. If you would like to be sent a copy of the study report, please contact the researcher using the email or phone number above.

Can I keep this information sheet?

Yes, this information sheet is for you to keep.

All data will be collected and stored in accordance with the Data Protection Act 1998.

Appendix C: Health Form for Research Participants

Health Form for Research Participants

Please complete this form after you have read the Information Sheet.

A driving simulator study to inform the design of an Automotive Habitat Lab.

This study has been approved by the Brunel University Research Ethics Committee.

Thank you for your interest in taking part in this research.

Participant's Statement

Please tick the appropriate box

Do you suffer from any of the following:

Migraines	YES ☐	NO ☐
Epilepsy	YES ☐	NO ☐
Motion Sickness	YES ☐	NO ☐
Vertigo	YES ☐	NO ☐
Postural Instability	YES ☐	NO ☐
Blurred vision	YES ☐	NO ☐
Fatigue	YES ☐	NO ☐
Blurred vision	YES ☐	NO ☐
Ear blockages	YES ☐	NO ☐
Upper respiratory illness	YES ☐	NO ☐

Have you recently (in the last 12 hours) taken medications or alcohol?

YES ☐ NO ☐

Are you or could you be pregnant?

YES ☐ NO ☐

Signed: ……………………………………………………..

Participant Name: ………………………… **Date**:

Appendix D: Simulator Sickness Questionnaire

Simulator Sickness Questionnaire

Instructions: Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.
** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of
nausea.

Appendix E: Ethics Approval Study 1

College of Engineering, Design and Physical Sciences Research Ethics Committee
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

4 March 2016

LETTER OF APPROVAL

Applicant: Miss Marlene Weber

Project Title: Simulator Study

Reference: 2754-LR-Mrz/2016-2574

Dear Miss Marlene Weber

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.
- Approval granted if the inclusion/exclusion criteria is followed as per your previous application number 0582.
- Approval granted if how you intend to recruit your participants is as per your previous application number 0582.
- Approval granted if the scenarios you use are as per your previous application number 0582.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- **[delete for staff applications]** You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Hua Zhao

Chair

College of Engineering, Design and Physical Sciences Research Ethics Committee
Brunel University London

Appendix F: Ethics Approval Study 2

College of Engineering, Design and Physical Sciences Research Ethics Committee
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

17 November 2016

LETTER OF CONDITIONAL APPROVAL

Applicant: Miss Marlene Weber

Project Title: Real-driving Study

Reference: 4404-LR-Nov/2016- 4476-1

Dear Miss Marlene Weber

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- **The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.**
- **Do not use a generic email address to recruit your participants as this is in violation of the Brunel Acceptable use policy. You can submit a research participation invitation through Intrabrunel.**
- **Please ensure that a risk assessment form is completed before any testing and that this has been checked for approval by your supervisor.**
- **Please ensure that the number of participants is reasonable for the time period.**

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- **[delete for staff applications]** You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Hua Zhao

Chair

College of Engineering, Design and Physical Sciences Research Ethics Committee
Brunel University London

Appendix G: Ethics Approval Study 3

College of Engineering, Design and Physical Sciences Research Ethics Committee
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

29 March 2017

LETTER OF APPROVAL

Applicant: Miss Marlene Weber

Project Title: Real-driving Study

Reference: 4404-A-Mar/2017- 6951-1

Dear Miss Marlene Weber

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Hua Zhao

Chair

College of Engineering, Design and Physical Sciences Research Ethics Committee
Brunel University London

Screening Questions and Set-up

An explorative real-driving study including facial expression analysis to inform the design of an Automotive Habitat Lab.

Thank you for your interest in taking part in this research. Before you agree to take part, please answer the following screening questions, if you have any questions arising from this document, please ask the researcher before you to decide whether to join in.

- ☐ **Do you have a full and clean driver's license?**

- ☐ **Do you have a valid insurance and MOT for your car?**

If you decide to take part in the study, please send in advance or bring to the study copies/photographs of your license, proof of identify, proof of your insurance and MOT.

Set-up:

2 cameras will be fixed in your car, one with a suction cup on the windshield, the second one with a clam to the driver seat's headrest (see image below). The set-up will take only a maximum of 5 minutes and will not leave any traces in your car.

Screening Questions and Set-Up

An explorative real-driving study including facial expression analysis to inform the design of an Automotive Habitat Lab.

Thank you for your interest in taking part in this research. Before you agree to take part, please answer the following screening questions, if you have any questions arising from this document, please ask the researcher before you to decide whether to join in.

☐ **Do you have a full and clean driver's license?**

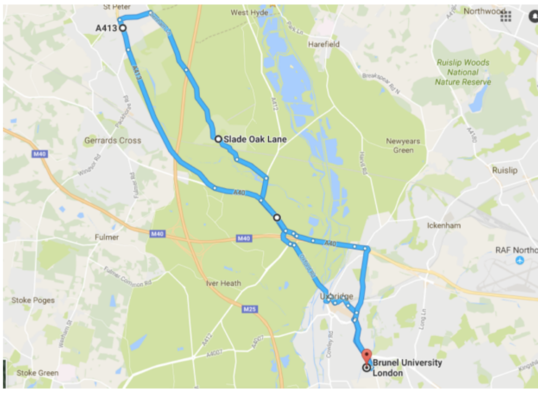
☐ **Are you an experienced, confident driver?**

☐ **Are you an Brunel student or staff member?**

If you decide to take part in the study, please send in advance copies/photographs of your license and Brunel card/proof of identify.

Set-up and Route:

The car for the study is a Land Rover Discovery Sport kitted out with the following equipment:
3 cameras will be fixed in the car, one with a suction cup on the windshield, the second and third owe one with a clam to the seat's headrest (see image below). A navigation system will send the participant along a route (see map below).



Appendix J: Multidimensional Driving Style Inventory

Multidimensional Driving Style Inventory

Please fill in the following demographic questions (your data will be treated confidentially) and the shortened Multidimensional Driving Style Inventory (van Huysduynen et al. 2016).

Name		
Age Group	18-24	
	25-34	
	35-44	
	45-54	
	55-64	
	>64	
Gender	Male	
	Female	
	I'd rather not say	

Please answer the questions by choosing on the 6-point-scale from 1 "not at all" to 6 "very much" (your answers will not influence the study) Thank you!

Not at all very much

Number	Question	1	2	3	4	5	6
1	When someone does something on the road that annoys me, I flash them with high beam						
2	Intend to switch on the windscreen wipers, but switch on the lights instead						
3	Feel nervous while driving						
4	Feel I have control over driving						
5	Drive cautiously						
6	Like to take risks while driving						
7	Do relaxing activities while driving						
8	Use muscle relaxation techniques while driving						
9	Honk my horn at others						
10	Plan my route badly, so that I hit traffic that I could have avoided						
11	Driving makes me feel frustrated						
12	Feel distressed while driving						
13	Blow my horn or "flash" the car in front as a way of expressing frustrations						
14	Meditate while driving						
15	Attempt to drive away from traffic lights in third gear (or on the neutral mode in automatic cars)						
16	Tend to drive cautiously						
17	Enjoy the sensation of driving on the limit						
18	Nearly hit something due to misjudging my gap in a parking lot						
19	Feel comfortable while driving						
20	Enjoy the excitement of dangerous driving						
21	Forget that my lights are on full beam until flashed by another motorist						
22	Swear at other drivers						
23	It worries me when driving in bad weather						
24	Like the thrill of flirting with death or disaster						

Appendix K: Research Ethics Risk Assessment (Study 2)

RESEARCH ETHICS RISK ASSESSMENT

Identified Risks	**Likelihood**	**Potential Impact/Outcome**	**Risk Management/Mitigating Factors**
Identify the risks/hazards presents	*High/Medium/Low*	*Who might be harmed and how?*	*Evaluate the risks and decide on the precautions, e.g. Health & Safety*
Travel Risks, Accident	Medium	Researcher/Participant: Physical Injury/ Psychological harm	Risk Assessment of Driving Ability (5 minute drive in parking lot) Only drivers with clean license
Travel from unknown location back, risk of getting lost	Low	Psychological harm	Timetable and locations shared with other researchers
Abuse of researcher	Low	Psychological harm	Timetable and locations shared with other researchers
Impact on visual field of driver	Medium	Distraction/Accident	Minimum impact ensured Discussed with driver in advance