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# Automotive Emotions: An Investigation of Their Natures, Frequencies of Occurrence and Causes

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***Abstract*—**Technological and sociological developments in the automotive sector are shifting the focus of design towards developing a better understanding of driver needs, desires and emotions. Human centred design methods are being more frequently applied to automotive research, including the use of systems to detect human emotions in real-time. One method for a non-contact measurement of emotion with low intrusiveness is Facial-Expression Analysis (FEA). This paper describes a research study investigating emotional responses of 22 participants in a naturalistic driving environment by applying a multi-method approach. The research explored the possibility to investigate emotional responses and their frequencies during naturalistic driving through real-time FEA. Observational analysis was conducted to assign causes to the collected emotional responses. In total, 730 emotional responses were measured in the collective study time of 440 minutes. Causes were assigned to 92% of the measured emotional responses. 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.

***Keywords*—**Affective computing, case study, emotion recognition, human computer interaction.

## I. Introduction

THE automotive industry is currently undergoing rapid change, in which disruptive new developments such as autonomous driving, electrification, and telematics are becoming market realities [1], [2]. These developments are anticipated to lead to a 30% increase in automotive revenues by 2030 and lead to changes in customer needs, desires and behaviours [1], as well as shifts in the emotional relationship between owner and automobile [3]. In order to respond to these challenges, the concept of an automotive habitat laboratory [4] has emerged, which utilizes real-time application of human centred design methods on the road during actual driving [4], [5]. Real-time emotion detection and estimation is a crucial component of any such approach due to the need to understand how the human occupants react to their environment and feel about their automobile.

The influence of emotions on the driving experience can be inferred from the role of human emotion during activities such as goal generation, decision making, focus and attention, motivation, performance [6]. A better understanding of the drivers' and passengers' emotions is therefore crucial, not only to improve the driving experience but also to investigate behaviour indirectly influenced by emotions [7].

Past research [8]-[10] has investigated the use of affective computing in driving environments due to the fundamental influence of emotional states on driving reactions and opinions [11]. Previous research has focused mostly on road rage, aggressive driving and accident prevention [10], [12], [13], but 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. More recently, affective computing has been applied to automotive research to improve human-machine interaction [11], [14], develop affective intelligent car interfaces [15] and create a richer interaction between automobile and driver [9]. While multiple researchers conducted studies investigating drivers' emotions, research systematically analysing natures, frequencies and causes of emotions during driving is limited [16], [17].

One concept of improving the driving experience and the creation of a better human-machine interaction is personalisation [1]. With in-depth knowledge about drivers' emotional states and their causes, datasets for machine learning could be created for the prediction of emotional responses to a given stimulus. The diving experience could then be personalised based on the knowledge collected about the user's emotional behaviour. For this to happen, and automobiles to become affective and respond to their occupants, a model of emotional states is required as a baseline for comparison. A first step towards the creation of such a model is the establishment and validation of a methodology for the investigation of emotions and their causes in the driving environment and the creation of a database.

In this research, FEA was applied as a non-contract, low-intrusiveness tool for emotion capture with the aim of investigating natures and frequencies of emotions during driving. The assignment of causes to the measured emotional responses through observational analysis was explored. The six basic emotions and a selection of six action units (contractions or relaxations of one or more facial muscles) were measured. Their frequencies were defined as the number of emotional responses per minute. Causes were emotion triggers such as *high traffic density* or *music*.

The research hypothesis was defined as: FEA can be successfully applied as a real-time tool for the investigation of natures and frequencies of occurrence of emotional responses under naturalistic driving conditions. Causes of the measured emotional responses can be assigned through observational analysis.

### A. Investigation of Emotional States during Driving

Past research has explored various technologies for the

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detection of one or more human emotional states in the automotive habitat [9], [10], [18]. The studies have noted difficulties attributed to the use of sensors which require direct contact with the participant. Technologies such as Electromyography (EMG) and Galvanic Skin Response (GSR) have been found to be difficult to deploy during driving [8], as have techniques characterized by a high degree of intrusiveness such as vocal-expression-analysis [9]. As a result, the research focus in recent years has shifted to FEA, owing to its low intrusiveness and non-contact nature [19].

Research studies investigating the frequencies and causes of emotions during driving are limited [17], [20]-[22] and not directly comparable since applied methods and chosen emotion taxonomies vary significantly. Three research studies investigated the frequencies of anger during driving using self-assessment tools [20]-[22]. Limitations of the research were noted previously due to the reliance on self-assessment as the main estimate for emotions and the possibility that the chosen methodologies have influenced the participants' perception of their own emotional states [17]. A further study combined physiological measures with observational analysis of facial expressions and self-report to investigate three emotional states and their causes. Anxiety, anger and happiness were reported to occur five times in an average driving time of 50 minutes per participant. Causes were assigned to those, and most frequently occurring causes were *other drivers*, *lack of safety,* and *other people* [17].

Due to the lack of existing studies and their methodologies varying greatly no framework for the measurement of emotions, and investigations of their natures, frequencies and causes could be identified. Therefore, the current study focused on a thorough investigation of emotions and their causes, and the creation of a methodology for the study of natures, frequencies and causes of emotions through which systems and factors causing positive and negative emotional effects can be identified.

## II. Driving Study

### A. Choice of Emotion Taxonomy

For the current study, the choice was made to investigate the six basic emotions (joy, anger, surprise, fear, disgust, sadness) and a selection of action units (AUs) which are part of the Facial Action Coding System (FACS) [23]. The choice to include AUs into the emotion taxonomy was made based on criticism of previous research relying only on the six basic emotions due to their often scarce occurrence and significant variations between participants [24], [25]. Research instead suggests modification of existing emotion taxonomies by including AUs, combining the investigation of both major and minor changes in emotional responses [26]-[29].

AUs around the eyes and mouth, known to suggest certain affective states, were chosen as they have been found to be strong indicators of human emotion [29]. The chosen AUs included lip press and lip pucker, indicating anger and concentration/annoyance respectively [30], [31], inner brow raise and brow raise indicating surprise [32], brow furrow indicating displeasure and lip corner pull indicating pleasure [33].

### B. Measurement Equipment

In order of priority, the criteria for the choice of the measurement equipment were the following:

1) Real-time FEA measurement
2) Ease and robustness of multi-channel application
3) Data collection synchronised with multiple video recordings
4) Field portability
5) Low cost
6) Technical support

The data acquisition and data integration platform chosen for the research was the iMotions AttentionTool [34], providing a single system which can accommodate many of the currently available emotion sensors, which integrates Affdex Affectiva as the main FEA tool. The real-time tool provides scores from 0-100 (absent to fully present) for each basic emotion and AU. Research suggests a threshold of 50-70 [34].

To adapt the usage of the FEA tool to the automotive environment, any basic emotion and AU had to reach the chosen threshold of 70 to be added to the database. After preliminary evaluation, it was noted that emotional responses below the chosen threshold would be unreliable in the automotive setting. To minimise the effect of noise and anomalies an immediate median correction of the last 3 samples was applied.

### C. Study Parameters

Naturalistic driving studies are conducted to provide insights on the behaviour of participants driving in instrumented automobiles (usually their own), often for long periods of time (6-12 months) [35], [36]. The main advantage of naturalistic driving research is that studies provide insights into the actual real-world behaviour of drivers, unaffected by experimental conditions and associated biases [36].

While frameworks for the planning of large-scale naturalistic driving studies over long periods of time have been created in past research [35], no framework for small-scale naturalistic studies exists. To plan a small-scale study, appropriate automobile types, driving conditions and driving routes representative of naturalistic driving had to be defined.

The following table introduces naturalistic study parameters and their inclusion and exclusion criteria, based on literature and automotive sector practice. Table I was used as a basis for the inclusion and exclusion of entirety of sections of studies, determined through an assessment of how representative those were to naturalistic automobile driving (e.g. exclusion of highly improbable driving situations).

Participants were asked to ignore the presence of the researcher on the back-seat of the vehicle as far as possible. The starting point of the study was Brunel University London. All participants drove on a familiar route of their choosing, not exceeding a 15-minute driving time from the starting point. All potential roads included are presented in Fig. 1. All studies took place between 11am and 4pm on Mondays-Fridays, therefore traffic was primarily medium, with infrequent instances of high traffic (in Uxbridge City Centre).

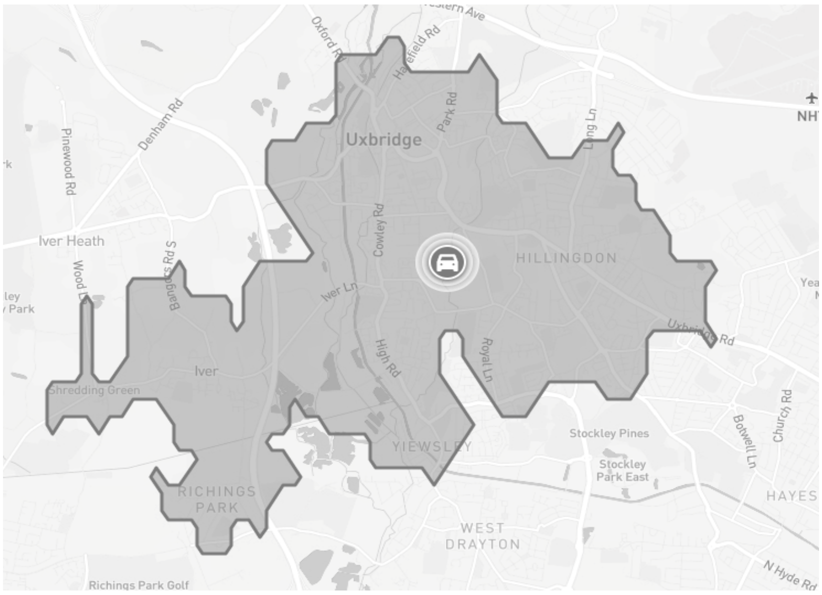


Fig. 1 Map around starting point (Brunel University) with an indication of a 15-minute driving time in all possible directions [40]

TABLE I
NATURALISTIC STUDY PARAMETERS AND THEIR INCLUSION AND EXCLUSION CRITERIA FOR SMALL-SCALE STUDIES

| Study Parameter | Inclusion criteria | Exclusion criteria | Source |
|---|---|---|---|
| Automobile Type | Participants' own cars: Passenger cars (e.g. sedans, coupes, hatchbacks, station wagons and sport utility vehicles) | Highly unusual vehicles, other vehicle types (e.g. trucks) | [35], [37] |
| Driving condition | Medium to high traffic | Very low traffic, extreme weather conditions (e.g. heavy fog), extreme driving situations (e.g. broken down vehicle) | [38], [22] |
| Driving route | Daily commute including rural roads, major roads and urban roads | Private roads, off-road driving | [37]-[39] |

Two cameras (Logitech C920 HD), one for FEA and to capture the driver's face (face camera), the other one to capture the driving environment (scene camera) were fixed in the car. The face camera was attached to the windshield of the automobile with a flexible arm to tailor the placement to the automobile and participant. The scene camera was fixed to the passenger seat' headrest to capture parts of the interior and the driving environment. All emotion data and the video data were collated on a laptop (Lenovo Thinkpad) by the researcher, seated in the back of the car.

*D. Participant Selection and Recruitment*

The primary sampling criteria, driving style, gender and age-group, were chosen following a purposive sampling strategy. The choice of sampling criteria was based on the knowledge that they might influence driving attitude and behaviour [41]. An even distribution of all sampling criteria was therefore aimed for. When following a purposive sampling strategy in mixed method studies, 20-30 participants has been suggested as an appropriate sampling size [42] therefore a total 22 participants was recruited.

Participant selection, recruitment and all phases of the study were performed in accordance with the University's ethics policy.

*E. Data Analysis Approach*

Quantitative and qualitative data analyses were combined following a mixed method approach.

The quantitative data analysis included the collation of all emotional responses of all passengers and the calculation of the frequencies per minute/second of both basic emotions and AUs. The emotional responses were then divided into the individual basic emotions and AUs to investigate their frequencies individually. All individual frequencies were expressed as percentages of the total of basic emotions and AUs.

In the qualitative data analysis, observational analysis was performed with the aim of assigning causes to the identified emotional responses. The observational analysis was performed during the on-road study by the researcher seated in the back-seat of the participant's automobile. All emotional responses and their assigned causes were then reviewed by the researcher by examining the video material after the studies. If the researcher was not able to assign an obvious cause to the emotional responses, the emotional response was categorized as *no cause assigned* (NCA). Finally, all assigned causes and their corresponding emotional responses were collated.

## III. Results

### A. Natures, Frequencies and Causes of Emotional Responses

In total, 730 emotional responses were measured in the collective study time of 440 minutes with 22 participants. The total number of emotional responses was divided into 218 basic emotions and 512 AUs. On average, one basic emotion was detected every 2 minutes, and one AU every 51 seconds. The natures and frequencies of all individual basic emotions and AUs are shown in Tables II and III.

TABLE II
Natures and Frequencies of All Individual Basic Emotions

| Basic emotion | N | % of all basic emotions (total=218) |
|---|---|---|
| JOY | 77 | 35 |
| ANGER | 13 | 6 |
| SURPRISE | 59 | 27 |
| FEAR | 0 | 0 |
| DISGUST | 62 | 28 |
| SADNESS | 7 | 3 |

TABLE III
Natures and Frequencies of All Individual Action Units

| Action unit (AU) | N | % of all AUs (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 IV
Most Frequently Assigned Causes for Joy, Anger and Surprise

| Basic emotion | JOY | | ANGER | | SURPRISE | |
|---|---|---|---|---|---|---|
| | N | Cause | N | Cause | N | Cause |
| Causes | 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 | NCA | 2 | Long wait at traffic light | 5 | Cut off by another driver |
| | 3 | Spotting friend | 2 | NCA | 5 | Traffic light changing |

TABLE V
Most Frequently Assigned Causes for Disgust and Sadness

| Basic emotion | DISGUST | | SADNESS | |
|---|---|---|---|---|
| | N | Cause | N | Cause |
| Causes | 8 | Sun/light blinding | 2 | Sun/light blinding |
| | 7 | Long wait at traffic light | 2 | NCA |
| | 4 | High traffic density | | |
| | 2 | NCA | | |

All causes assigned to the individual emotional responses were then collected. Causes were assigned to 672 of the total of 730 (92%) emotional responses. The most frequently assigned causes are shown in Tables IV-VII.

TABLE VI
Most Frequently Assigned Causes for Lip Cress, Lip Corner Cull and Brow Raise

| Action units | LIP PUCKER | | INNER BROW RAISE | | BROW FURROW | |
|---|---|---|---|---|---|---|
| | N | Cause | N | Cause | N | Cause |
| Causes | 14 | High traffic density | 9 | High traffic density | 27 | Checking mirror |
| | 13 | Tight road passage | 4 | Roundabout | 20 | NCA |
| | 9 | Long wait at traffic light | 4 | NCA | 9 | High traffic density |
| | 7 | NCA | | | 5 | Speedbump |

TABLE VII
Most Frequently Assigned Causes for Lip Pucker, Inner Brow Raise and Brow Furrow

| Action units | LIP PRESS | | LIP CORNER PULL | | BROW RAISE | |
|---|---|---|---|---|---|---|
| | N | Causes | N | Causes | N | Causes |
| Causes | 8 | High traffic density | 10 | Checking mirror | 10 | High traffic density |
| | 7 | NCA | 10 | Long wait at traffic light | 9 | NCA |
| | 5 | Sun/light blinding | 9 | Roundabout | 9 | Sun/light blinding |
| | | | 9 | Slow driver ahead | 7 | Infotainment change |

## IV. Discussion

Sociological and technological changes are transforming the automotive industry [1], calling for an improved understanding of driver's emotions, desires and needs [4]. The aim of the current study was to thoroughly investigate the drivers' emotional responses and their causes in order to take the first steps towards an improved, affective human-machine interaction and a more human centred approach towards automotive design.

The driving study investigated the natures, frequencies and causes of emotional responses of 22 participants in a total driving time of 440 minutes.

High numbers of both, basic emotions and AUs (total=730), as well as high frequencies with one basic emotion every 2 minutes and one AU every 51 seconds, confirmed the hypothesis that FEA can be successfully applied for affective driving research.

While other studies investigating frequencies and causes of emotions during driving [17], [20]-[22] noted considerably less frequent emotional responses, it is important to note that both methodologies and emotion taxonomies differed significantly. The significantly higher frequencies of emotions in the current study may be explained by a wider emotion taxonomy, a different method of emotion capture and a different study approach. Furthermore, comparable studies mainly relied on self-assessment as an emotion measurement technique which has been criticized in previous research [17].

The majority of causes assigned to emotional responses were directly related to the driving task (e.g. *high traffic density*, *tight road passage*). This result indicates that the suggested methodology and results can be directly applied for the development of an improved, affective human-machine interaction by avoiding causes triggering negative emotions, enhancing causes triggering positive emotions and mitigate emotional responses as required when they occur. Moreover, results may be used for the formulation of automotive design criteria to improve future automotive design [43].

The emotional response most frequently measured in the total study time was joy, followed by disgust and surprise (35%, 28% and 27% of all basic emotions respectively). Less frequently measured were anger and sadness (6% and 3%), while fear was not measured at all. Since fear is an emotion that may be expected during driving [44], no measures of fear during the total study time were rather surprising. The fact that participants were asked to drive in their own automobiles on familiar routes, and therefore may have experienced the comfort associated with a familiar environment, might have contributed to the absence of recorded instances of fear. Nevertheless, the lack of fear should be investigated in future research. The AUs most frequently measured were inner brow raise and brow raise (24%, 22% of all AUs respectively), followed by lip press, brow furrow, lip pucker and lip corner pull (19%, 14%, 14% and 7% respectively). In decreasing frequency, these are known to indicate surprise, anger or concentration, displeasure, anger or annoyance and pleasure as the least frequent [30]-[33].

When comparing occurrences of basic emotion and AUs it is striking that inner brow raise and brow raise, which are known to indicate surprise, occurred more frequently than the basic emotion surprise. This indicates that surprise may be more likely to be communicated through the individual corresponding AUs than the full basic emotion surprise. This hypothesis should be investigated in future research. Also noteworthy is the difference in frequencies of occurrence of joy and lip corner pull (indicating pleasure). The relationship and differences of joy and lip corner pull should be investigated in future research. Frequencies of anger compared to lip press and lip pucker, indicating anger or concentration and annoyance respectively, show significantly higher frequencies for both AUs than the emotion anger. This may be caused by the ambiguity of both emotional responses, indicating anger and a secondary emotion. Nevertheless, it can be hypothesized that anger as an isolated emotion is less likely to occur in a driving environment than a combination of anger and a secondary emotion (concentration/annoyance). The AU brow furrow, which indicates displeasure, is included in most negative basic emotions (anger, fear, sadness). When comparing frequencies, brow furrow occurred significantly more often than those basic emotions which include the AU. It may be concluded that brow furrow is a better indicator of negative emotions during driving but further investigation is necessary. When comparing the natures and frequencies of occurrence of basic emotions and AUs it can be inferred that AUs may play an important role for the investigation of emotions while driving and that it may be necessary to include AUs in emotion taxonomies for automotive research. The findings and hypotheses should be investigated in future research.

In total causes were assigned to 92% (672 out of the total 730) emotional responses. This confirmed the hypothesis that the assignment of causes to the collected emotional responses can be successfully achieved.

In comparable research [17], causes could only be assigned to 60% of emotions. The fact that in the current study the observational analysis took place during driving may have given the researcher more information about the environment in and around the car, the additional information may have led to a higher rate of successful assignment of causes.

The most frequently assigned causes of both, the basic emotions and AUs were the following, the number of occurrences is indicated in brackets:

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

The most frequently assigned cause of joy was *interaction with another person*, at 38% of occurrences. While participants were asked to ignore the presence of the researcher as far as possible, some interaction could not be prevented. The comfort of driving in a familiar environment may have also increased the likelihood of friendly interactions with other road users and people known to the driver causing joy.

The most frequently assigned causes in this dataset indicated some of the main causes of both positive and negative emotions during driving. Knowledge of these could be applied for the development of affective human-machine interaction to avoid potential causes of negative emotions as well as enhance those for positive emotions to improve the driving experience. The most frequently assigned causes which triggered any of the basic emotions included *interaction with another person*, *high traffic density*, *sun/light blinding* and *checking mirror*. *Interaction with another person* as one of the most frequent causes was not surprising considering the highly interactive nature of the automotive environment. *High traffic density*, *sun/light blinding* and *checking mirror* are causes of emotional responses closely connected to the driving task and therefore a logical result. In this dataset the most frequently occurring causes of 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 causes, 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 assigned causes. 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 emotions were compared for this dataset, it became evident that the three out of four of the most frequently assigned causes 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, causes of joy and lip corner pull were not comparable. In fact, causes of lip corner pull matched those of negative emotions. Similarly, assigned causes were not shared for surprise, inner brow raise and brow raise. Correlations between the causes of both basic emotional responses 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 causes of negative emotions during driving. This knowledge could be used for future design ideas, e.g. improved/personalized 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 caused by *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 of occurrence and causes of emotions during driving, 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.

## V. Threats to Validity

In the following, threats to validity are listed and explained, including the researcher’s presence in the automobile, bias in the observational analysis/assignment of causes, the experimental setting and the choice of technology.

### 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 responses. To avoid the negative effects of the researcher’s presence in the automobile 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.

### Observational Analysis/ Assignment of Causes

The assignment of causes to the emotional responses during the study was conducted only by the researcher. Experimenter bias may have influenced the study results. In future studies the researcher’s assignment should be validated by multiple researchers repeating the assignment exercise.

### 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 wider variety of routes, road types and driving situations should be tested in the future.

### Choice of Technology

Limitations of software and hardware may have impacted the results. For FEA only a single camera was used, which restricted the range of head movement allowing successful FEA and therefore limited results. Furthermore, the use of one camera required a central camera placement which had an impact on the participant’s field of view. In future research FEA should be combined with another measurement tool for the investigation of emotional states to achieve more reliable results.

## VI. Conclusions

In this research, 22 participants’ emotional responses and their causes were explored in a real-driving environment under naturalistic circumstances. High frequencies of emotional responses 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 of occurrence and causes of emotions during driving. The study explored which emotional responses occurred most frequently and which causes had the most significant influence on the emotional experience in the automobile. The successful assignment of causes to the emotional responses delivered insights which can be directly applied to future automotive design.

In this dataset, joy was the most frequently occurring emotional response, caused primarily by interaction with other people. The rare occurrence of anger and sadness, and complete lack of measurements of fear, was 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) emphasized the need to include AUs in emotion taxonomies for emotion research in the automotive environment. The most frequently assigned causes in the study were *interaction with another person* and *music/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 [43]. 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 drivers' emotions and their causes 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 application in both current and future design decisions.

In future research studies, more road types and driving situations will be included in the study. The investigation of emotions on a wider variety of roads and in different situations could deliver further insights on the drivers' responses. Additionally, tests should take place in only one research automobile, traveling along the same road circuit for each participant, in order to standardize the experimental methodology and make emotional responses more comparable between participants. The impact of specific road types on the emotional experience should be further investigated.

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