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Transportation Research Interdisciplinary Perspectives 10 (2021) 100383

Contents lists available at ScienceDirect

Transportation Research Interdisciplinary Perspectives

journal homepage: www.elsevier.com/locate/trip

# Capable and considerate: Exploring the assigned attributes of an automated vehicle

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ARTICLE INFO

*Keywords:*
Automated vehicle
Acceptance
Driving behaviour
Tangible attributes
Intangible attributes
Attribution of meaning

ABSTRACT

Users' acceptance, and subsequent adoption, of automated vehicles is likely affected by the understanding they develop of the vehicle based on its driving style properties. This paper explores how driving style properties – as a type of tangible attribute – are perceived by users, and how they affect users' interpretations of AVs. 18 participants experienced a seemingly fully automated vehicle on a test track and were interviewed regarding the experience, both during and after. The findings show that the participants noticed most driving style properties but to different degrees, and that participants assigned four groups of intangible attributes: functionality attributes, ability, awareness, and character, where the last three represent higher-order attributes. These intangible attributes were directly affected by the driving style properties but was also formed by a chain of assigned intangible attributes. The findings also indicate two major themes of attributes which users perceive when experiencing an AV: the vehicle's capability and the consideration it shows towards its occupants and other road users. Because users assign attributes regarding capability and consideration, it is important to take into account that the vehicle is perceived in both these respects already in the early development stages, including in the vehicle's control algorithm development.

## 1. Introduction

Automated vehicles (AVs) are considered to have potential to greatly improve several aspects related to driving. Some of the argued improvements include reduced stress and improved productivity for commuters, increased traffic safety through reduction of 'human errors', and reduced congestion and fuel consumption (Fagnant and Kockelman, 2015; Litman, 2018). However, for AVs to become widely adopted there are technical as well as user-related issues that need to be resolved. One of the latter issues concerns user acceptance, a precondition for use of AVs (Najm et al., 2006), which is strongly influenced by how AVs are perceived and understood. Previous research has shown that the understanding of system functionality affects users' acceptance of the AV (e.g. Blömacher et al., 2020), as well as users' trust in the AV (Khastgir et al., 2019), the latter argued to be an important prerequisite for acceptance of automated systems (Choi and Ji, 2015; Ghazizadeh et al., 2012; Molnar et al., 2018). It is therefore essential to gain more knowledge about how users of AVs develop their understanding of the AV, in order to in turn better understand how acceptance can be achieved and the benefits described above realised.

One major source of information for the user of an AV to build their understanding on is the vehicle's driving style. For instance, a study by Hartwich et al. (2018) showed that familiarity with the AV's driving style affected users' level of acceptance. Other studies have seen the effect of AV driving styles on factors influencing acceptance such as trust (Baltodano et al., 2015; Ekman et al., 2019; Sonoda and Wada, 2016), perceived safety (Yusof et al., 2016), and comfort (Bellem et al., 2018; Scherer et al., 2015). However, little is known about what in the driving style that helps users form their understanding. If we know which properties of the style that are noticed and thus (probably) influence understanding, those can be exploited to convey the workings of the AV to the user. Therefore, *this paper investigates which driving style properties (out of all driving style properties) a user notices or does not notice when using an AV.*

Driving style properties are an example of so called (product) "attributes" as described by Hirschman (1980). Attributes can be dichotomised into tangible and intangible product features. A vehicle can for example be described as black, large, and luxurious where black and large are examples of tangible attributes (since they describe physical properties of the car) whereas luxurious is fundamentally an intangible attribute (Lefkoff-Hagius and Mason, 1990). Hirschman (1980) noted

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https://doi.org/10.1016/j.trip.2021.100383
Received 7 September 2020; Revised 29 March 2021; Accepted 29 April 2021

that a user's comprehension of a product is a mixture of perceptions of objective properties (i.e. tangible attributes) and subjective associations (i.e intangible attributes) and that both play a role in how a user perceives and understands a product such as an AV. Consumers use both types of attributes as their basis for evaluating a product in terms of what is important to them and the benefits they may provide (e.g. Aaker et al., 1992; Mackenzie, 1986). Furthermore, in particular intangible attributes are believed to be a substantial part of the user's experience with the product and have been noted to greatly motivate consumer preferences (Creusen and Schoormans, 2005). So, to be able to increase the knowledge of how users understand AVs and in turn accept and use AVs, it is crucial to investigate how they assign both tangible and intangible attributes. Therefore, *this paper also investigates how driving style properties affect users' interpretations of AVs.*

Thus, the research presented in the paper contributes to knowledge on how users of AVs develop their understanding of the AV, by investigating which driving style properties that are noticed by users and how they affect users' interpretation of the AV. This knowledge can contribute to the design of AVs that users will accept and adopt.

The remainder of this paper is structured as follows. The following section presents the framework, including the concepts of tangible and intangible attributes. Section 3 then presents the method employed in the experimental study to investigate users' understanding of AVs. Section 4 presents findings from the study relating to the driving style properties and how they affect participants' interpretation of the AV. Section 5 discusses the findings and section 6 closes with a conclusion.

## 2. Framework

As established in the introduction, both tangible and intangible attributes are important for users' understanding of and how users evaluate a product. The following section offers further explanation of both attribute types in relation to AVs and the study at hand.

### 2.1. Tangible attributes

Tangible attributes are objective product characteristics that are detected by an individual through one or more of the human senses (Hirschman, 1980). In this paper, the tangible attributes of the AV that will be considered are *driving style properties, properties of the vehicle's movement that can be meaningfully used to distinguish different* driving styles from each other. Driving style is one of two parts that make up someone's driving behaviour, and refers to the habitual or chosen way of driving (Elander et al., 1993). (The second part of driving behaviour is *driving skill*: the ability to perform certain elements of the driving task.)

In literature, driving styles are often categorized on a scale from aggressive to defensive. An aggressive driving style is most often described as holding a faster speed, more powerful acceleration, and with short headway maintenance (Murphey et al., 2009; Yan et al., 2019). On the other side of the spectrum is the defensive driving style which can be described as driving carefully, longer deceleration and anticipating upcoming traffic situations – longer headway (e.g. Spolander (1983). In these short descriptions we can discern several different driving style properties that can be used to characterize and determine driving styles. "The power of" acceleration and deceleration are probably the most common (e.g. Johnson and Trivedi, 2011) but also jerk, that is to say the derivate of acceleration, has been used (Doshi and Trivedi, 2010; Murphey et al., 2009). Other commonly used properties relate to the vehicle's interaction with the environment. Some studies have looked at distance to other vehicles (e.g. Canale and Malan, 2002), while others (e.g. Doshi and Trivedi, 2010) found that lateral placement constantly differed between driving styles, drivers with an aggressive driving style tended to start their lane change later prior to intersections compared to non-aggressive drivers. Similarly, Bellem et al. (2016) used parameters such as headway and lane deviation when identifying differences between driving styles. All in all, six categories of driving style properties were identified from literature: acceleration, frequency of velocity shift, lateral placement, frequency of lateral placement, distance to objects and frequency of change in distance to objects (see summary in Table 1). These categories were used to develop two distinct, but equally safe, driving styles for the experimental study described in section 3, one on the aggressive part of the scale and one on the defensive (but neither of them on the extreme end).

### 2.2. Intangible attributes

Intangible attributes are derived from different sources, including experiences with the product as well as market communication (e.g. Krishnan, 1996). In this paper intangible attributes refer to the attributes that are the result of interpretations of the driving style of AVs and triggered by users' experience of the AV's driving style properties.

Whereas tangible attributes are derived from sensory perception, *intangible attributes* exist only in the mind of the individual (Hirschman, 1980). They are subjective, abstract constructions, at different levels of abstraction, mentally associated with or assigned to the product by the individual. It has been suggested that these intangible attributes are derived from different processes. Johnson (1989) describes the relationship between more or less concrete attributes as instrumental, reflective, and vicarious relationships. An instrumental relationship implies a concrete attribute having a direct effect on the perception of a more abstract one; reflective relationships are the result of one or more instrumental relationships, whereas vicarious relationships describe a relationship that is not direct or functional but merely perceived. Allen (2000) suggests that tangible attributes may well be evaluated one at a time whereas intangible attributes arise in a holistic judgement from a cluster of tangible attributes, and further that intangible attributes are more than the sum of tangible ones.

Even though tangible attributes are important for users' comprehension and evaluation products, it has been advocated that intangible attributes play an equally important, or in some cases even more important, role (Allen, 2000; Creusen and Schoormans, 2005; Hirschman, 1980). This importance of intangible attributes in how users perceive, comprehend, and evaluate products is why they are assumed by the authors to potentially be an important factor influencing user acceptance of AVs.

In summary, both tangible attributes, i.e. objective product characteristics (in this case driving style properties), and intangible attributes, i.e. subjective abstract constructions assigned to the product, are important to consider in order to comprehend how users understand and evaluate an AV.

## 3. Method

In order to investigate which driving style properties a user notices and how they affect users' interpretations of the AV, an experimental study was conducted on a test course.

### 3.1. Participants

The study involved 18 participants, 10 male and 8 female, between 20 and 50 years old (M = 37, SD = 11). Two additional participants were excluded from the analysis, one because of technical issues and one because the participant suspected that it was a human driving the test vehicle. For studies which rely on qualitative data, there is no general agreement on the required minimum number of participants. Based on recommendations by e.g. Patton (2015), Robinson (2014), Francis et al. (2010) and Braun and Clarke (2013), and a focused scope (cf. Morse, 2000) the sample size is considered sufficient to find patterns and elicit sufficiently rich information regarding the phenomena of interest.

**Table 1**
Driving style properties with respective descriptor and differences between the Aggressive and Defensive driving style. The driving style properties Frequency of acceleration, Frequency of lateral placement and Frequency of change in distance to objects were not part of the test setup but were included for the purpose of the analysis.

| Category of driving style properties | Driving style properties | Descriptor | Driving Style | |
|---|---|---|---|---|
| | | | Aggressive | Defensive |
| Longitudinal movement | Acceleration | Powerful | More powerful acceleration; start & stop (comes to full stop) | Slower acceleration; keeps the vehicle rolling (avoids standstill) |
| | | Slow | | |
| | Frequency of velocity shift | Smooth | No difference between driving styles | |
| | | Jerky | | |
| Placement in lane | Lateral placement | Centred | Late indication of right or left turn (through positioning in lane) | Early indication of right or left turn (through positioning in lane) |
| | | Uncentred | | |
| | Frequency of lateral placement | Stable | No difference between driving styles | |
| | | Wobbly | | |
| Distance to objects | Distance to objects | Close | Closer distance to objects | Longer distance to objects |
| | | Long | | |
| | Frequency of change in distance to objects | Consistent | No difference between driving styles | |
| | | Fluctuating | | |

The participants were recruited via a newspaper advertisement and were compensated for travel expenses. The only inclusion criterion was that the participants had to have a valid driver's license. The participants had a mixed level of driving experience, ranging from 3 to 35 years. As for driving frequency, half the participants (n = 9) drove almost every day and the other half (n = 9) drove from a couple of times a week to a couple of times per year. All except one participant had previous experience with advanced driver assistance systems. Most of them (n = 9) had previous experience with cruise control systems, some (n = 3) with adaptive cruise control, and some (n = 5) with adaptive cruise control plus steering assist. Informed consent was obtained from all participants.

### 3.2. Study setup and procedure

In order to let the participants experience an fully automated vehicle (Level 5 (SAE, 2018)) in an as natural and varied a setting as possible, the study was conducted on a closed test course (https://www.astazero.com) using a Wizard of Oz-approach, i.e. a human driver simulating the AV functionality. The selected route on the test course consisted of both a rural road, with normal road standard for bi-directional traffic, and a small city area with buildings and intersections. The Wizard of Oz-approach utilised a modified Volvo XC90, with a hidden driver who simulated the autonomous system (see setup in Fig. 1) and drove with two distinctly different driving styles (but with equal skill), here referred to as 'Aggressive' and 'Defensive' (explained in Table 1).

Each participant experienced two test runs, one with each driving style – the study was run with a within-subject design and with a counterbalanced test order. Each test run, consisting of three laps on the course, took approximately 15 min during which the participants first experienced a test lap to get acquainted with the AV and then had two more laps in which they encountered seven predefined traffic situations: 1) stopping at a red light in an intersection, 2) overtaking a moving car, 3) driving through a roundabout, 4) stopping for a pedestrian at a pedestrian crossing, 5) making a U-turn, 6) passing a cyclist, and 7) meeting an oncoming moving car. Depending on the driving style of the vehicle used for the test run, the vehicle handled these situations in predefined, distinct ways.

### 3.3. Driving style

The two distinctly different driving styles of the vehicle, named Aggressive and Defensive, were developed based on the previous identification of categories of driving style properties (Section 2.1). The two styles were designed to be experienced as competent and skilled but

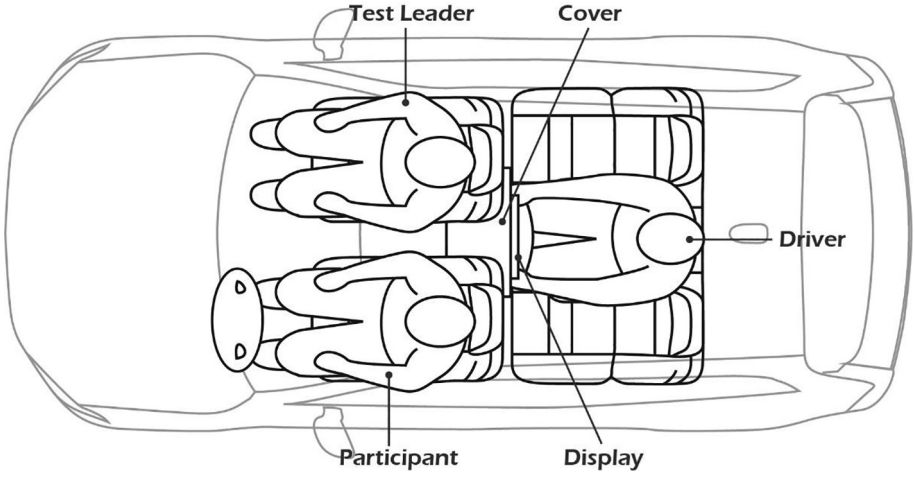


**Fig. 1.** Wizard of Oz-setup.

also to specifically differ in regard to the power of acceleration/deceleration, starting/stopping behaviour, distance kept to objects, and lane positioning (see Table 1 for detailed information).

The two driving styles were developed together with the professional test driver who acted as "wizard" throughout the study. To develop the driving styles and ensure that the wizard driver was able to drive as consistently as possible, several practice runs were performed before the actual test. During these practice runs, the driving styles were developed and the driver was able to establish the consistency of his performance using elements in the environment (e.g. road marker posts) to cue actions and an accelerometer that measured longitudinal and lateral acceleration and deceleration (Defensive measured to be within 0.06–0.09 g (accel.), 0.1–0.13 g (decel.) and Aggressive within 0.11–0.23 g (accel.), 0.17–0.32 g (decel.)). During the actual test runs, feedback was only provided to the driver from a normal instrument cluster display (speedometer and tachometer).

### 3.4. Data collection and analysis

Data from participants was gathered both during and after the test runs in order to obtain information about their experiences with the AV. They were encouraged to think aloud at the seven predefined situations during the test runs, they were interviewed after each run, and in addition, a longer interview was held after both runs were completed.

Sound was recorded throughout. The recordings were later transcribed, the material reviewed in full and statements containing any reference to driving style properties and/or interpretation were selected for further analysis, which was divided into two parts.

In the first part of the analysis, a deductive approach was used, where statements mentioning driving style properties were sorted in accordance with the categorization of driving style properties in Table 1, as well as which driving style was mentioned in relation to the statement. For example, statements like "…*it drove a bit into the opposite lane*" was categorized as 'uncentered' and statements like "*it stopped well ahead*…" was categorized as 'long distance'. The number of mentions was quantified and summarized to find which driving style properties stood out for the participants, and whether driving style had an impact on how often each property was mentioned.

In the second part of the analysis, an inductive approach was used, without any pre-defined categories. Here, statements which were considered to contain any form of assignment of intangible attributes were further analysed using Affinity diagramming (cf. Lucero, 2015). In a **first step** of the affinity diagramming, statements were coded and each code was noted down on a paper (e.g. *"it felt like the car knew that there would be a traffic light far in advance"* was coded as 'awareness of upcoming events'). Next, in a **second step**, the statements and notes were organized together with other similar codes and statements, forming clusters that were iteratively rearranged and labelled. In a **third step**, the resulting clusters were compared to find relationships and differences between them. The analysis process identified and distinguished between two major groups of clusters.

One group was labelled 'functionality attributes'– attributes that explained how the AV was able carry out driving actions, e.g. sensing or planning. The other group consisted of higher-order interpretations, – attributes that concerned why the AV drove as it did, e.g. the AV's more general ability or level of awareness, and was labelled 'higher-order attributes'. Within the higher-order attributes group, four different sub-groups were identified: functionality, ability, awareness, and character (explained and exemplified in sections 4.2.2–4.2.4).

Lastly, both clusters were further analysed by making explicit connections between tangible attributes and intangible attributes to find possible connections between intangible attributes and driving style. Statements which contained intangible attributes and tangible attributes were identified as well as if the assigned intangible attributes were talked about in positive or negative terms in connection to the tangible attribute. The outcome was summarized into a table and further analysed.

All analyses were performed by two researchers (1st and 3rd author) and any discrepancies in categorization were discussed until full agreement was reached.

## 4. Findings

In their statements during test runs and interviews, the participants referenced driving style properties belonging to all categories listed in Table 1. The analysis shows that they also assigned numerous intangible attributes to the AV, building chains of interpretation both directly from the driving style properties and from other intangible attributes. In the following, the results of the analysis of the tangible attributes are first presented, and then the results of the analysis of the intangible attributes.

### 4.1. Prominent driving style properties

As mentioned, participants referred to driving style properties belonging to all categories in Table 1 when describing the vehicle and its actions. The most frequently mentioned were 'Acceleration', 'Frequency of velocity shift', 'Lateral placement' and 'Distance to object' (see Fig. 2), indicating that these four were the most prominently noticeable, forming part of the basis for the users' interpretation of an AV.

The distinct way in which participants referred to the driving style properties of the two driving styles shows that they clearly noticed a difference between the styles. For example, acceleration was almost only assessed as 'slow' in relation to the defensive driving and 'powerful' in relation to the aggressive driving; distance to objects was mostly assessed as 'long' in relation to the defensive and 'close' in relation to the aggressive driving. Fig. 2 shows the difference between which descriptor was used for which driving style, with the largest differences in relation to both properties in the 'Movement' category, and regarding 'Distance to object'. The 'Placement' category shows a different pattern. The results show a more equal distribution of the descriptors 'centred' and 'uncentred' for the two driving styles but at the same time there is a considerable difference in the number of statements concerning the character of the vehicle's lateral placement: 'uncentred' is mentioned more frequently. Uncentred placement was mostly mentioned when the participants perceived the AV to choose an improper lane position, indicating that to the drivers there was a "wrong" and a "right" way of driving in relation to lateral placement, more connected to driving skill than driving style. The aforementioned properties of acceleration, velocity shift and distance to object were not associated in the same way with "right" or "wrong", but instead seen more as characteristics of the specific style (e.g. powerful acceleration being part of an aggressive driving style).

The "Frequency of change in distance to objects" property was not mentioned at all by the participants. Here, the probable explanation is the study setup. The setup only included a brief section where the participant vehicle followed another road user (during the overtaking situation), which was probably too short a period of time for the participants to be able to notice a shift in the distance to the object.

### 4.2. From tangible to intangible

Beyond noticing specific driving style properties and describing them, the participants also appear to have assigned a number of intangible attributes to the vehicle on the basis of their experience of these driving style properties. It is possible to discern a thought process from the participants' statements where intangible attributes were often directly interpreted based on the driving style properties of the AV: *"I believe it is driving quite smoothly and carefully since it is so much more*

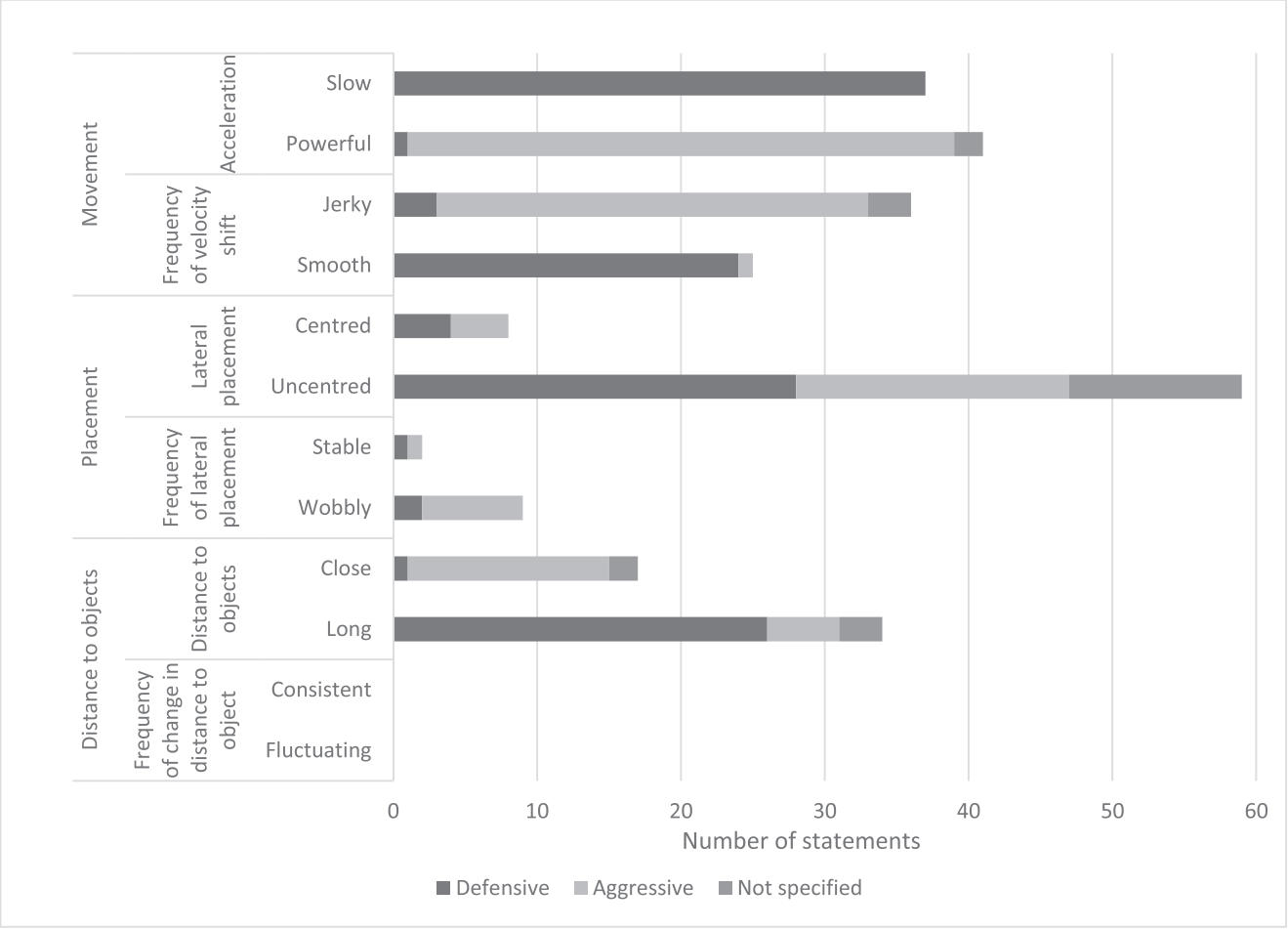


**Fig. 2.** Number of mentions of driving style properties in each category, and in reference to which driving style.

*aware of where it is"* (P12), in other words the intangible attribute 'awareness' was interpreted based on the change in frequency of velocity shift being perceived as 'smooth'.

In addition to these direct interpretations of driving style properties, it was also possible to discern a longer chain of interpretation from the driving style properties to several intangible attributes, where attributes appear to have been assigned based on other assigned intangible attributes. For example, one participant assigned the AV with several intangible attributes based on the same one driving style property: "*My interpretation is that it [the AV] has not noticed it [the roundabout] early enough and therefore did not have enough foresight. That is why it [the manoeuvre] becomes a bit jerky*" (P10), i.e. the jerkiness evoked the intangible attributes of noticing and being aware of upcoming events.

Among the intangible attributes, patterns emerged leading to categorization into four groups: labelled assigned functionality, ability, awareness, and character (further explained and exemplified in sections 4.2.1–4.2.4). One part of this interpretation consisted of test participants assigning functionality attributes to the vehicle in order to explain how it was able to carry out driving actions (further explained in 4.2.1). However, different levels of a higher-order interpretation were also evident from the analysis. Compared to assigned functionality, which is an interpretation of how the AV is able to perform the driving task, the higher-order attributes concern why it drives as it does. These higher-order attributes spoke of the vehicle's more general ability, its level of awareness and its overall character. These levels in turn differ in the temporal aspect, where 'Ability' often contains statements that refer to single actions, while 'Character' often describes more long-term situations or behaviours. The levels also differ in the level of agency that is assigned to the AV, where most agency is assigned 'Character'.

Furthermore, the higher-order attributes also relate to an evaluation of the driving behaviour which reveals which attributes the participants consider important for an AV – or a driver – to have. Depending on the action performed by the AV, it was for example considered as having more or less awareness of the situation, indicating that the participants had a notion of what was for them an ideal driving behaviour against which they compared the AV's behaviour.

It is evident from these evaluations that the different driving style properties influenced the way the participants talked about the assigned intangible attributes in positive and/or negative terms (Table 2). For example, slow driving style properties seem to positively affect how aware the AV is perceived to be while jerky and uncentred driving style properties seem to negatively affect the perceived awareness of the AV. The 'slow acceleration', 'smooth change in frequency of velocity shift', and 'long distance to objects' driving style properties seem to have the most positive associations while 'powerful acceleration', 'jerky change in frequency of velocity shift', and 'uncentred lane placement' seem to result in more negative associations. Several of the properties that had positive associations (e.g. slow acceleration and long distance to objects) were part of the defensive driving style while some of the properties that had more negative associations (e.g. powerful acceleration) were part of the aggressive driving style. Thus, in general the defensive driving style evoked more positive evaluations

**Table 2**
Driving style properties' effect on the evaluation of intangible attributes. The number indicates the number of times the assigned intangible attributes were talked about in positive or negative terms in connection to each driving style property (negative numbers indicated with -).

| | | Slow | | Powerful | | Jerky | | Smooth | | Centred | | Uncentred | | Stable | | Wobbly | | Close | | Long | | Consistent | | Fluctuating | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Positive | Negative | Positive | Negative | Positive | Negative | Positive | Negative | Positive | Negative | Positive | Negative | Positive | Negative | Positive | Negative | Positive | Negative | Positive | Negative | Positive | Negative | Positive | Negative |
| Higher-order attributes | Functionality | 5 | −1 | 1 | −2 | | −2 | 2 | | 1 | | | −1 | 1 | | | −1 | | | 1 | | | | | |
| | Ability | 6 | | 0 | −2 | | −2 | 3 | | | | 1 | | | | | −1 | | | 2 | | | | | |
| | Awareness | 4 | −1 | 1 | −1 | | −3 | | | 1 | | | −4 | | | | −1 | | | 3 | | | | | |
| | Character | 2 | −1 | 0 | −2 | | −2 | 2 | | 1 | | | −1 | | | | | | | 2 | | | | | |

of the intangible attributes but not for all participants and not in all situations.

#### 4.2.1. Assigned functionality

The first type of intangible attribute that can be discerned from the participants' statements is attributes connected to the interpreted inner workings of the vehicle; participants appear to have assigned certain functionality to the vehicle to explain how it was able to perform the driving task. These interpretations were often directly linked to specific driving actions in specific situations and included functionality such as 'seeing', 'thinking' and 'evaluating'. For instance, one participant said: *"I got the feeling that the car had seen the pedestrian*" (P8) while another concluded "*it could have slowed down and evaluated the situation better"* (P11).

When describing how the vehicle worked, participants spoke in either human or machine terms, using human-related words like 'see' and 'evaluate' as in the quotes above, or referring to the vehicle using more of machine-related words such as 'sensing' or 'making calculations' in certain situations: *"I believe that the technology is so good that it can calculate the trajectory for the roundabout without having to make sudden adjustments" (P10)*.

#### 4.2.2. Assigned ability

The second type of intangible attribute that can be discerned consists of attributes connected to the AV's ability to perform driving actions properly, its *assigned ability*.

Participants appear to have interpreted that the vehicle had a more general ability to handle driving, particularly an ability to perform driving actions in a controlled way, handle situations and signal its actions in advance. These interpretations were sometimes connected directly to tangible driving style properties (such as interpreting the AV's braking as signalling intent), but sometimes they were judgments based on the functionality that the participants had assigned to the vehicle. The assigned ability was also often based on single driving style properties or driving actions in specific situations. For example, the assignment of the ability to perform controlled driving appears to be mainly connected directly to driving style properties. Some participants associated the frequency of velocity shift with perceived control of an action, and most of them regarded smoother acceleration as more controlled: "*I believe that you perceive it as having more traffic control if it drives more smoothly"* (P6). Others associated control with lateral placement: *"Most of the time it had control except in lane placement where it drifted a little to the right and left"* (P9). The ability to handle situations involves controlled driving but adds the vehicle's consideration to the context and other road users. Participants assigned this ability for example when they perceived the vehicle to time its actions well: *The slow one [Defensive] handled the pedestrian crossing better because it felt like it considered the situation a bit in advance, since it released the throttle earlier and drove slower towards it*" (P11). Another important indicator of this ability appears to be the AV not exposing itself to risky consequences, such as lateral placement in a wide turn: *"I was unsure how it would have handled the situation if there had been a vehicle in the opposite lane"* (P3 referring to Aggressive).

Another important ability was the ability to signal its intended actions to the participant inside the vehicle or to other road users outside it. One participant described how a combination of different driving style properties together communicated the vehicle's intentions to a pedestrian at an intersection: *"The car slowed down early and took action … I perceived that we signalled because we kept close to the sidewalk and also positioned the car at an angle and gently rolled around the corner. Thus, the vehicle communicated to (the pedestrian) that 'I am going to turn right'"* (P19 referring to Defensive). Other participants inferred the AV's ability to communicate internally with them, for instance how deceleration signalled the intention of the AV with one driving style but not the other: *"It was a distinct deceleration which suggested that*

*the system had detected something and braked. It was smoother last time, so there was no signal that the car had seen the person walking across the street and the vehicle could just as well have continued driving"* (P8). The ability to signal (both internally and externally) was deemed an important part of overall driving ability of the AV, the vehicle had to both perform capably and inform about its actions, which was made clear by one participant's reaction when passing the cyclist: *"It did not warn me that it was planning to do that. It probably reacted in a correct way but could have informed me a bit earlier so I would be prepared that something would happen"* (P2 when overtaking a cyclist with the Aggressive driving style).

#### 4.2.3. Assigned awareness

A third type of intangible attribute the participants assigned to the vehicle concerns its awareness. Four different kinds of awareness can be discerned from the participants' statements: awareness of itself, of the situation, of upcoming events, and of formal and informal traffic rules. Compared to ability (which was assigned in specific situations), the assignment of awareness to the vehicle appears to relate to a more comprehensive evaluation of the experience across several situations.

*Awareness of itself* and *awareness of the situation* both connect to the vehicle's physical presence in the world, where the former included being aware of its own position, size and own actions, and the latter awareness of the elements of the environment and the position of other road users. Some participants interpreted this awareness based on the vehicle's movements, for example *"the pedestrian crossing felt very calm and safe in the first lap [defensive], it really felt like it was aware of the person's position and where it was supposed to stop"*(P16 when stopping at the pedestrian crossing). Another participant described how they perceived control being linked to awareness*: "It feels like the car has better control when it drives gently and calmly, it becomes a bit stressful when there is a lot of steering movement… I think it was the first time when we entered the highway from the on-ramp, it felt quite calm and that it was aware of what it was doing"* (P12 referring to Defensive).

Furthermore, the participants appeared to assign the vehicle an *awareness of upcoming events*, a certain level of foresight, and in this case referred to some specific situations but also to the test run as a whole. One participant explained that the AV, independent of driving style, had this awareness: *"In both situations [test runs], it felt like the car knew that there would be a traffic light far in advance" (P4)*. Others perceived a difference between the two driving styles: *"On the highway both runs felt equally good, but the other situations, curves, intersections, and the roundabout felt a lot better the second time [Defensive] since it showed more foresight"*. (P2)

The final type of assigned awareness, *awareness of traffic rules and unwritten rules*, relates to the vehicle's demonstration of common sense in traffic. This concerned knowledge about how other road users should act as well as how the vehicle itself should behave in relation to other road users. Several participants talked about whether the vehicle was aware that other road users are more or less predictable. One participant discussed, at an intersection with another car, if the vehicle considered the intention of the other vehicle, stating: *"I did not know if it [the AV] took it [other car] into consideration or not, or if it [the AV] only assumed that the car would follow the traffic rules*" (P3).

The participants also discussed how considerate they perceived the vehicle to be towards others, by having common sense and following the unwritten rules. Some participants talked about how the vehicle's actions affected other car users: *"It [the AV] accelerated pretty hard but that did not bother me. If you consider other motorists around you, it would be irritating if you ended up behind a self-driving car that accelerated really slowly*" (P10 referring to Aggressive). Many participants also emphasized the need for common sense and consideration toward vulnerable road users. One participant focused on the unpredictability of certain road users by explaining that *"It felt good, since it kept the wobble distance that you say cyclists should have*" (P5 referring to Defensive). Participants found it important for the AV to have an awareness that enabled good handling but also that the AV understood that it needs to consider other road users by understanding unwritten rules.

#### 4.2.4. Assigned character

The last type of intangible attribute, character, involved attributes relating to how the AV acts over time, an assessment of the vehicle as a whole. These attributes were often assigned to the driving style as a whole or to larger segments of the ride. The assigned character consists of two categories, 'competent' and 'respectful'.

Regarding competence, the vehicle was described as being more or less 'competent', 'intelligent' and 'professional'. One participant characterized the two different driving styles, describing the overall impression of one of them as competent: *"It felt just like being a passenger. First [Defensive] like a passenger with a competent driver and then [Aggressive] like a passenger with a less safe driver who took more risks"* (P8). Another participant reflected on the difference between the overall perceptions of the separate driving styles, referring to one of them as more professional than the other: *"I think it [Aggressive] was a bit sloppy when overtaking the cyclist, I reckon the overtaking could have been smoother as in the first round. I think it acted more professionally in the first round in this situation [Defensive]"* (P10).

In addition to being competent, being 'respectful' emerged as an important aspect. Participants described the vehicle as being more or less respectful, doing what was expected of it. One participant elaborated on the respectfulness of the driving style by stating: *"I think the other one [Defensive] felt almost too kind. It was a nice drive and felt like very respectful driving"* (P4). Some participants also discussed that the AV did not feel respectful even if it was safe, one elaborating on professionality by saying *"It [Aggressive] cut corners and I do not like that. I do not think it is a professional way of driving even if it is 100 percent safe"* (P20).

## 5. Discussion

The two-fold aim of this study was firstly to describe which tangible attributes a person notices when using an AV, in this case the driving style properties, and secondly to investigate which intangible attributes users assign to an AV. The purpose was to better understand how tangible attributes influence the perception of intangible attributes and how these, in turn, influence the way users understand and evaluate AVs.

With regard to the first aim, the findings show that the participants noticed all the driving style properties that were analysed except for 'Frequency of change in distance to objects', as described in 4.1 Prominent driving style properties. However, the participants noticed the other properties to different degrees and differently depending on driving style. Similarly, Bellem et al. (2016) also noted that the difference between different driving styles (comfortable, everyday and

**Table 3**
Summary of intangible attributes.

| Assigned functionality | Assignedability | Assigned awareness | Assigned character |
|---|---|---|---|
| Functionality allowing the AV to see, think, calculate etc. | Ability to perform controlled driving | Awareness of itself | A competent character (personality) |
| | Ability to handle situations | Awareness of situations | A respectful character (personality) |
| | Ability to signal intended actions | Awareness of upcoming events | |
| | | Awareness of traffic rules, formal and informal | |

dynamic) depended on several different driving style properties (e.g. acceleration, deceleration and following distance). Indicating that perception of the driving style is not based on a single driving style property but a combination of several.

With regard to the second aim, the results show that the participants assigned a range of intangible attributes to the AV (see Table 3 for a summary). In the paper these have been organized in functionality attributes and higher-order attributes.

While the assignment of intangible attributes was expected to result from the participants experiencing the AV, following the ideas of Hirschman (Hirschman, 1980), the richness of the picture painted by the participants and the different types of intangible attributes that could be discerned from the participants' descriptions was not. The findings show that the participants created very elaborate interpretations about AV functionality and capability, based on quite limited information of the AV's driving behaviour and previous understanding. They also assigned intangible attributes to the AV with much agency similar to that of a person's character or personality. Previous research has shown that the perceived personality of the AV may be a very strong factor in users' trust in AVs (Baltodano et al., 2015), making intangible attributes crucial in users' acceptance of AVs and therefore important to investigate.

### 5.1. The relationship between tangible and intangible attributes

Investigating the relationship between the participants' perceptions of the tangible driving style properties and the intangible attributes that they assigned to the AV, the intangible attributes were often shaped directly by the driving style properties, such as the attributes in the 'Assigned Ability' category, a conclusion partly supported by Allen (2000) who states that intangible attributes are tied to a cluster of tangible attributes. In other cases, intangible attributes appear to have been constructed based on other assigned intangible attributes. For some participants, it was possible to discern a chain of interpretation from the driving style properties to the assignment of functionality attributes and further to the assignment of the higher-order attributes of 'ability', 'understanding' and 'character'. This chain of assigning new intangible attributes based on previously assigned intangible attributes explains how participants managed to create such an elaborate image of the AV and its agency based on very limited information about the AV's actual intentions and capabilities. However, given this long association chain there is an increased risk that a user may develop an incorrect understanding, a flawed mental model of the AV and its limitations.

Furthermore, the assignment of intangible attributes seems to develop through an interpretation chain from tangible attributes to higher-order attributes, in other words as a bottom-up process. However, this sequence is uncertain as it is also possible that the chain develops in the opposite direction, that is to say a top-down process where the user's usage experience triggers the assignment of higher-order attributes such as character attributes, which in turn trigger a chain of attributes to be assigned to functionality attributes. For example, the participants may experience the AV as highly capable, from that infer that it has to be intelligent and therefore needs to be aware of itself and the situation, and that it needs to be able to sense and interpret the environment. Thus, while this study points to the existence of a chain of attribute assignment, how this chain works (e.g. what triggers what) needs to be further investigated: firstly in order to gain a clear understanding of how users build their interpretation, and secondly in order to be able to influence this process. Nevertheless, it is probable that this process of assigning attributes to other attributes is considerably impacted by the user's preconceptions about the AV's functionalities, which may be a result of their conceptual model of AVs. Since AV technology is fairly new and not widely available, users' conceptual models may be based on very little information, formed from experiences with similar technology and/or news media. It is therefore important to understand more in-depth users' conceptual models of AVs in order to better understand how they will be interpreted.

### 5.2. Two major themes among the attributes

When looking closer at the higher-order attributes, two themes emerge among the attributes across all three levels: 'Capability' and 'Consideration'. These themes indicate two overarching evaluation criteria.

The attributes within the 'Capability' theme concern interpretations of how capable the AV is at performing the driving task and range from the vehicle having control of its movements, and having awareness of itself, to being competent. This is expected from the evaluation of the AV's driving behaviour since it partly reflects the vehicle's driving skill, that is to say the vehicle's ability to perform elements of the most crucial task, the driving. The 'Consideration' theme, on the other hand, comprises attributes that do not involve the AV's capability, but instead relate to how considerate the AV is perceived to be. The importance of consideration as a property of AVs has also been highlighted by Domeyer et al. (2020) who argue that AVs must be able to communicate, through the vehicle's behaviour, with other road users in a way that not only facilitates efficiency but also signals politeness and fairness. Interestingly, in this study the participants took into account both the consideration shown by the AV towards the occupants of the vehicle, i.e. themselves, and the consideration shown towards other road users. Attributes related to 'Consideration' range from signalling intentions to the user to understanding official and unwritten traffic rules.

The findings imply that the participants put a lot of emphasis on how considerate the AV is perceived to be. Therefore, it appears to be an important aspect in users' evaluation of the AV's performance, which is crucial in relation to acceptance. However, most research and development has so far focused on the capabilities of the system (the development of AVs is largely a case of technology push). Having said that, since driving style properties can be designed, and since these can affect how considerate the AV is perceived to be, it is important to focus on both aspects early in the development phase in order to develop AVs that users will accept and adopt.

The intention of this study was never to draw conclusions about which the best driving style is for AVs. The two styles used in the study were simply means to investigate whether style impacted user understanding in the first place, and if so, which properties of the style that would be relevant to investigate further in the future – if one then wanted to create the best style. What we can see is that the properties identified contribute to the formation of the users' understanding of AVs. However, they are not the sole factor that determine which style is the best/optimal AV driving style overall. Previous studies have indicated some other influences, such as how similar the style is to your own (Bellem et al., 2018) and the complex interaction of the style and the situational context (Ekman et al., 2021). Therefore, much research remains regarding how to develop an AV driving style that will contribute to user acceptance, or even enjoyment, and how the style could intentionally be used to communicate the vehicle's capability and consideration to the user.

### 5.3. Limitations and further work

The study was designed as a Wizard of Oz (WOz) study. The WOz-approach, that is being in a real car and experiencing different traffic situations, seems to have been a fruitful way of approaching the research questions. Even if traffic was sparse and not all possible driving style properties were incorporated in the test, the study triggered the participants' attribution of many intangible properties. It is probable that the inclusion of other driving style properties, situations, or participants or indeed a real traffic context would have resulted in a longer list of intangible attributes than those identified in the present

study, but not necessarily in completely different types of attributes. In addition, the vehicle in the test did not offer an in-vehicle interface providing information on parameters such as what the system senses or system status. Therefore, participants only received information from the AV's driving behaviour and the environment. However, this was also the intention.

Moreover, the participants had a mixed level of previous experience with AV systems, ranging from participants who had no experience to participants who had used vehicles with steering assist in addition to advance cruise control. The differences in experience with AV systems will probably have shaped their preconception and in turn their interpretation and experience of the AV in the study. Thus, it is likely that the interpretation of the AV differed between the participants. However, since the aim of the study was to explore how the driving style affect users' interpretation of the AV in general the study did not investigate these individual differences. Therefore, further studies should investigate how the previous experience of AV systems affects users' understanding of AVs.

## 6. Conclusion

This study aimed to investigate which driving style properties are most prominent to users when riding in an AV and, further, to explore if and how driving style properties affect the understanding of the AV. The most prominent driving style properties of the AV relate to the movement category and were 'Acceleration' and 'Frequency of velocity shift'. The findings further show that based on a very short usage experience and limited information from the vehicle, users of AVs build a mental representation of the vehicle, its functions, and its character. This representation was directly affected by the driving style properties, that is to say tangible attributes of the AV, but was also formed by a chain of assigned intangible attributes. This assignment of attributes indicates that the users' perception of the AV is not only affected by what the AV objectively is but also subjective interpretations of it and that the users' understanding of the AV is an aggregation of the two. The implication for this could be that faulty mental models can quickly build up, possibly leading to an incorrect perception of the AV. The findings also indicate that there are two major themes of attributes which users perceive when experiencing an AV: the vehicle's capability and the consideration it shows towards its occupants and other road users. Because users assign attributes regarding capability and consideration, it is important to take into consideration that it is experienced and understood as both. Therefore, it is important to have a user experience approach early in the process, at the stage of the vehicle's control algorithm development.

## CRediT authorship contribution statement

**Mikael Johansson:** Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft. **Fredrick Ekman:** Conceptualization, Methodology, Investigation, Formal analysis, Writing - review & editing. **Helena Strömberg:** Conceptualization, Formal analysis, Writing - review & editing, Supervision. **MariAnne Karlsson:** Conceptualization, Writing - review & editing, Supervision. **Lars-Ola Bligård:** Conceptualization, Writing - review & editing, Supervision.

## Acknowledgements

This work was supported by Vinnova, Sweden's Innovation Agency, under grant number 2014-01411. The study was also able to use the facilities and expertise of the AstaZero full-scale test environment through the open research grant, application number A-0025. The authors would also like to acknowledge Volvo Car Corporation for use of the Wizard-of-Oz vehicle.

## References

Aaker, D.A., Batra, R., Myers, J.G., 1992. Advertising management. Prentice Hall, Englewood Cliffs, N.J..

Allen, M.W., 2000. The attribute-mediation and product meaning approaches to the influences of human values on consumer choices. Adv. Psychol. Res. 1, 31–76.

Baltodano, S., Sibi, S., Martelaro, N., Gowda, N., & Ju, W. (2015). The RRADS platform: a real road autonomous driving simulator. Paper presented at the Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Nottingham, United Kingdom.

Bellem, H., Schönenberg, T., Krems, J.F., Schrauf, M., 2016. Objective metrics of comfort: developing a driving style for highly automated vehicles. Transp. Res. Part F Psychol. Behav. 41, 45–54. https://doi.org/10.1016/j.trf.2016.05.005.

Bellem, H., Thiel, B., Schrauf, M., Krems, J.F., 2018. Comfort in automated driving: an analysis of preferences for different automated driving styles and their dependence on personality traits. Transp. Res. Part F Psychol. Behav. 55, 90–100. https://doi.org/10.1016/j.trf.2018.02.036.

Blömacher, K., Nöcker, G., Huff, M., 2020. The evolution of mental models in relation to initial information while driving automated. Transp. Res. Part F Psychol. Behav. 68, 198–217. https://doi.org/10.1016/j.trf.2019.11.003.

Braun, V., Clarke, V., 2013. Successful Qualitative Research: A Practical Guide for Beginners. Sage Publications, London, UK.

Canale, M., Malan, S., 2002. Analysis and classification of human driving behaviour in an urban environment. Cogn. Technol. Work 4 (3), 197–206.

Choi, J.K., Ji, Y.G., 2015. Investigating the importance of trust on adopting an autonomous vehicle. Int. J. Human-Computer Interact. 31 (10), 692–702. https://doi.org/10.1080/10447318.2015.1070549.

Creusen, M.E.H., Schoormans, J.P.L., 2005. The different roles of product appearance in consumer choice. J. Prod. Innov. Manage 22 (1), 63–81. https://doi.org/10.1111/j.0737-6782.2005.00103.x.

Domeyer, J.E., Lee, J.D., Toyoda, H., 2020. Vehicle automation-other road user communication and coordination: theory and mechanisms. IEEE Access 8, 19860–19872. https://doi.org/10.1109/ACCESS.2020.2969233.

Doshi, A., Trivedi, M. M. (2010). Examining the impact of driving style on the predictability and responsiveness of the driver: Real-world and simulator analysis. Paper presented at the Intelligent Vehicles Symposium (IV), 2010 IEEE.

Ekman, F., Johansson, M., Bligård, L.-O., Karlsson, M., Strömberg, H., 2019. Exploring automated vehicle driving styles as a source of trust information. Transp. Res. Part F Psychol. Behav. 65, 268–279. https://doi.org/10.1016/j.trf.2019.07.026.

Ekman, F., Johansson, M., Karlsson, M., Strömberg, H., Bligård, L.-O., 2021. Trust in what? Exploring the interdependency between an automated vehicle's driving style and traffic situations. Transp. Res. Part F Psychol. Behav. 76, 59–71. https://doi.org/10.1016/j.trf.2020.10.012.

Elander, J., West, R., French, D., 1993. Behavioral correlates of individual differences in road-traffic crash risk: an examination of methods and findings. Psychol. Bull. 113 (2), 279–294.

Fagnant, D.J., Kockelman, K., 2015. Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. Transp. Res. Part A Policy Pract. 77, 167–181. https://doi.org/10.1016/j.tra.2015.04.003.

Francis, J.J., Johnston, M., Robertson, C., Glidewell, L., Entwistle, V., Eccles, M.P., Grimshaw, J.M., 2010. What is an adequate sample size? Operationalising data saturation for theory-based interview studies. Psychol. Health 25 (10), 1229–1245. https://doi.org/10.1080/08870440903194015.

Ghazizadeh, M., Lee, J.D., Boyle, L.N., 2012. Extending the technology acceptance model to assess automation. Cogn. Technol. Work 14 (1), 39–49. https://doi.org/10.1007/s10111-011-0194-3.

Hartwich, F., Beggiato, M., Krems, J.F., 2018. Driving comfort, enjoyment and acceptance of automated driving–effects of drivers' age and driving style familiarity. Ergonomics 61 (8), 1017–1032.

Hirschman, E.C., 1980. Attributes of attributes and layers of meaning. ACR North Am. Adv..

Johnson, D. A., Trivedi, M. M. (2011). Driving style recognition using a smartphone as a sensor platform. Paper presented at the Intelligent Transportation Systems (ITSC), 2011 14th International IEEE Conference on.

Johnson, M.D., 1989. On the nature of product attributes and attribute relationships Retrieved from NA – Adv. Consumer Res. 16, 598–604 https://www.acrwebsite.org/volumes/6969/volumes/v16/NA-16.

Khastgir, S., Birrell, S., Dhadyalla, G., Jennings, P., 2019. Effect of Knowledge of Automation Capability on Trust and Workload in an Automated Vehicle: A Driving Simulator Study. Cham.

Krishnan, H.S., 1996. Characteristics of memory associations: a consumer-based brand equity perspective. Int. J. Res. Mark. 13 (4), 389–405. https://doi.org/10.1016/S0167-8116(96)00021-3.

Lefkoff-Hagius, R., Mason, C.H., 1990. The role of tangible and intangible attributes in similarity and preference judgments Retrieved from Adv. Consum. Res. 17 (1), 135–143 http://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=buh&AN=6431057&site=eds-live&scope=site&custid=s3911979&authtype=sso&group=main&profile=eds.

Litman, T. (2018). Autonomous vehicle implementation predictions: Victoria Transport Policy Institute Victoria, Canada.

Lucero, A. (2015). Using Affinity Diagrams to Evaluate Interactive Prototypes, Cham.

Mackenzie, S.B., 1986. The role of attention in mediating the effect of advertising on attribute importance. J. Consumer Res. 13 (2), 174–195. https://doi.org/10.1086/209059.

Molnar, L.J., Ryan, L.H., Pradhan, A.K., Eby, D.W., St. Louis, R.M., Zakrajsek, J.S., 2018. Understanding trust and acceptance of automated vehicles: an exploratory simulator study of transfer of control between automated and manual driving. Transp. Res. Part F Psychol. Behav. 58, 319–328.

Morse, J.M., 2000. Determining sample size. Qual. Health Res. 10 (1), 3–5. https://doi.org/10.1177/104973200129118183.

Murphey, Y. L., Milton, R., Kiliaris, L. (2009). Driver's style classification using jerk analysis. Paper Presented at the Computational Intelligence in Vehicles and Vehicular Systems, 2009. CIVVS'09. IEEE Workshop on.

Najm, W., Stearns, M., Howarth, H., Koopmann, J., & Hitz, J. S. (2006). Evaluation of an automotive rear-end collision avoidance system.

Patton, M.Q. (2015). Qualitative research and methods: Integrating theory and practice (4th ed.).

Robinson, O.C., 2014. Sampling in interview-based qualitative research: a theoretical and practical guide. Qualitative Res. Psychol. 11 (1), 25–41. https://doi.org/10.1080/14780887.2013.801543.

SAE. (2018). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. In: SAE International.

Scherer, S., Dettmann, A., Hartwich, F., Pech, T., Bullinger, A. C., & Wanielik, G. (2015). How the driver wants to be driven-modelling driving styles in highly automated driving. Paper presented at the 7. Tagung Fahrerassistenzsysteme.

Sonoda, K., Wada, T. (2016, 9-12 Oct. 2016). Driver's trust in automated driving when sharing of spatial awareness. Paper presented at the 2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC).

Spolander, K. (1983). Bilförares uppfattning om egen körförmåga (Drivers' assessment of their own driving ability) (252). Retrieved from Linköping.

Yan, F., Liu, M., Ding, C., Wang, Y., Yan, L., 2019. Driving style recognition based on electroencephalography data from a simulated driving experiment. Front. Psychol. 10 (1254). https://doi.org/10.3389/fpsyg.2019.01254.

Yusof, N.M., Karjanto, J., Terken, J., Delbressine, F., Hassan, M.Z., Rauterberg, M., 2016. The exploration of autonomous vehicle driving styles: preferred longitudinal, lateral, and vertical accelerations. Paper Presented at the Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications.