Using machine learning to develop
natural, human like vehicle control

Measuring User's Comfort in Autonomous Vehicles

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Executive Summary

One key output of the HumanDrive project was the development of an Advanced Control System (ACS) by Nissan and Hitachi designed to allow the AV to emulate a natural, human-like driving style.

During the course of the project Human Factors based research was carried out by the University of Leeds, Connected Places Catapult and Cranfield University to evaluate the ACS in real-world and simulator based trials so as to gain insights into the perceived naturalness, comfort and safety of the system under evaluation. These attributes were measured during, and post experiencing, AV driving styles, via think aloud protocols, questionnaires and a hand-held marker which recorded participant feedback in real-time. The evaluations also considered how personality traits and personal driving style might influence perceptions of AV driving styles.

The HumanDrive project outputs complement an already existing and growing body of research exploring ride comfort in the context of AVs. The investigation of ride comfort should now be mindful of the occupant's expectations between the expected and actual driving style of the AV; the experienced loss of physical control of the vehicle; the potential for engagement in non-driving related tasks, and the creation of more novel seating configurations, which all alter the experience of riding in an AV, compared to conventional vehicle ride comfort.

The existing body of research suggests that longitudinal and lateral movement of the vehicle, along with its positioning in the road, vertical loadings, type of manoeuvre, weather conditions, environment type, presence of other road users influences perceived comfort. An individual's personal driving style, familiarity, personality traits and age also have the potential to influence occupants' overall perception and acceptance of AV ride comfort. The review of research also suggests that most users are in favour of an AV adopting a more defensive driving style. However, some driving scenarios could make it difficult to achieve this style of driving and further consideration should be made to explore the effect of route planning, vehicle design and cues, via the human machine interface to manage occupant ride comfort.

Further research is required to validate the summarised findings, with a wider population of potential AV users, and in real-world settings, within a variety of scenarios. Future research should also look to establish the wider factors of comfort (the overall perception of user comfort is not solely limited to the ride of the vehicle), how these systematically influence each other, and how factors might change over time. There is scope to tailor comfort to the preference of particular individuals or market segments, which may provide a greater array of services and opportunities both for the end user and for businesses.

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1. Introduction

Project Description

The HumanDrive project, led by Nissan, developed a prototype Autonomous Vehicle (AV), capable of achieving high levels of automation, with the aim being to successfully demonstrate an autonomous 'Grand Drive' from Cranfield to Sunderland (over 200 miles) in live traffic. This was completed in November 2019 and demonstrated successful navigation of country roads, motorways and dual carriageways. The project commenced in July 2017 and ran for a duration of 33 months, finishing at the end of March 2020.

The project was divided into 'work packages', with the Connected Places catapult (CPC) leading on the Project Management and Safety work packages, but also taking a key role in the supporting of work packages relating to 'Trials, Demonstration and Validation'. The HumanDrive consortium consists of the organisations shown in Table 1 below:

Organisation	Role
Nissan	Lead
Atkins Ltd	Collaborator
Cranfield University	Collaborator
Highways England	Collaborator
Hitachi	Collaborator
HORIBA MIRA	Collaborator
SBD Automotive	Collaborator
Connected Places Catapult	Collaborator
Aimsun Ltd	Collaborator
University of Leeds	Collaborator

Table 1 : Organisations involved in HumanDrive

One of the major innovative aspects of HumanDrive was the development of an Advanced Control System (ACS), designed to allow the AV to emulate a natural, human-like driving style. A key enabler for this is the integration of an Artificial Intelligence (AI) controller, developed by Hitachi, which utilised Artificial Neural Networks (ANNs), and deep learning, for perception and decision-making.

Background

AV technology could provide end users with benefits, including safer travel and increased personal time, as the driver is able to relinquish driving responsibilities to the vehicle and their journey time becomes their own time. AVs could also provide more independent and flexible travel for those who have had to forego their driving licence, or to those who do not have access to a vehicle, limited to travelling with others or by the availability of current public transport offerings.

Visionaries and marketeers are already proposing novel vehicle designs and suggesting that a vehicle interior might look more like an office or a relaxing pod within which to read or undertake other non-driving related activities. If such a vision is to be realised, ensuring comfortable and safe travel for users of AVs will be critical to the success of these novel concepts. Even if the design of AVs diverges little from the conventional design of the vehicles we know today, great consideration needs to be taken for ensuring the vehicle ride is a comfortable, one as well as being a safe one.

Exploring the requirements for comfort in the early phases of AV design is key to ensuring that the appropriate requirements can be built into the wider design, developed and explored appropriately through iterative testing. The overall cost of design has been proven to be reduced when user requirements are considered at the beginning of the design phase (Design Council, 2007, Steen, Kuijt-Evers & Klok, 2007 and Waller et al., 2015). This paper investigates the current research into the comfort of highly automated vehicles (SAE levels 4 and 5, SAE, 2019).

Figure 1: Proposals for AV configurations (for source see references (section 6))

2. Definitions of Comfort for AVs

Researchers who have explored user comfort in the context of AVs have quoted the broader definitions of comfort:

> *"Psychological aspects describe comfort as a pleasant state of physiological, psychological and physical harmony between a human being and the environment"*
>
> (Slater, 1985, cited by Hartwich, Beggiato & Krems, 2018).
>
> *"Comfort is a pleasant state of well-being, ease, and physical and psychological harmony between a person and the environment. Discomfort [is] a state where one experiences hardship of some sort, which could be physical, physiological or psychological"*
>
> (Wasser et al., 2017).
>
> *"Comfort is commonly associated with a feeling of well-being and an attribution of positive valence towards the eliciting entity and, depending on the view of comfort, associated with the absence of discomfort and uneasiness."*
>
> (Bellem et al., 2018)

Bellem et al. (2018) acknowledge that no widely shared and agreed-upon definition of comfort has been established in the scientific community, citing that it is also debated whether comfort and discomfort should be seen as opposite poles of one construct, or whether they can co-exist (Vergara & Page, 2000 and Zhang, Helander & Drury, 1996). Whereas, Wasser et al. (2017) cited Vink (2005) and considered comfort as a bipolar phenomenon, whereby comfort is positioned at the extreme positive end, and discomfort at the extreme negative end, of a continuum with a neutral point between. Bellam et al. (2018) also point to comfort as a pleasant state that is not experienced in the face of high arousal (Summala, 2007). Though overall, it is commonly agreed that there are a few key assumptions about this concept: comfort is subjective and can therefore, differ between and within individuals. Comfort is influenced by internal and external factors, it is affected by physical, physiological and psychological factors, it is experienced as a reaction to a stimulus or results from the interaction between individuals and their environment (Bellam et al. 2018 and De Looze, Kuijt-Evers & Van Dieën, 2003, cited by Hartwich, Beggiato & Krems, 2018).

In the context of AVs, researchers consider that the relationship between expected and actual driving experience, a loss of physical control of the vehicle, and the ability to engage in different tasks, could lead to the user engaging in non-driving related tasks, such as games or email, resulting in more novel seating configurations (as illustrated in

Figure 1). All of the above will further influence the design and management of user comfort (Elbanhawi et al., 2015, Bellam et al. 2018, Hartwich, Beggiato & Krems, 2018 and Ekman et al. 2019, Diels, 2014). Regarding the loss of physical control, Hartwich, Beggiato & Krems, (2018) specifically defined discomfort as states of tension or stress resulting from unexpected, unpredictable or unclear actions of the automated system.

3. AV Ride Comfort

Measuring AV Ride Comfort, for the HumanDrive Project

Comfort has been a popular measure for evaluating and proposing designs for an acceptable AV ride across a number of studies. The HumanDrive project sought to obtain feedback from both professional drivers and the general public to determine whether an AV could emulate a natural, human-like driving style, and if this was comfortable and felt safe for end users.

During the course of the project research was carried out by the University of Leeds, CPC, and Cranfield University to determine the driving characteristics and risk profiles of different drivers. Further to this, Human Factors evaluations were carried out on the HumanDrive Advanced Control System (ACS) in both real-world and simulator environments, to gain insights into the perceived naturalness, comfort and safety of the system behaviour.

Evaluation of the AV in the real-world was evaluated in two stages, initially with professional drivers, during the earlier stages of development and evaluated again at a later stage with participants from partner organisations but who were not part of the HumanDrive project itself. The initial study acted as a sense check to validate the intention to create a more natural and humanlike AV ACS and provided recommendations to develop a more robust system to be reviewed by potential users from the public. Both evaluations took place on the Cranfield University test track in controlled settings, the route included segments of straight road with two adjoining T-junctions, a bus stop and pedestrian crossing, a curved segment of road and a roundabout. This introduced a variety of driving environments to see how these influenced occupant comfort. Vehicle data, video footage, audio, vehicle (via Global Positioning System (GPS)) and other road user positioning was collected during the drives as well as the capture of subjective perceptions.

Real-world study one:

Seven professional drivers were recruited after completing a demographic questionnaire which captured age, gender, driving experience, job role and attitudes towards technology and automation. A selection of participants were invited to participate in the trial. The professional drivers were initially interviewed to understand their view about AVs, and then completed the Arnett Sensation Seeking (Arnett, 1994), Traffic Locus of Control (Özkan & Lajunen, 2005) and Driving Style (French et al. 1993, West, Kemp & Elander, 1993 and West, Elander & French 1992) questionnaires.

Two weeks later the participants were invited back to the test track, they were asked to drive a Nissan Leaf for a specific route. The vehicle then, in an automated mode, replayed the participant's own drive and that of the HumanDrive system. At this point of the trial the participants were not informed that it was their own drive or that of the HumanDrive system. These drives were randomised to manage the order effect. Only pedestrian actors were present, standing on the pathways and there was no other traffic on the roads. For the AV drives, the participant sat in the front passenger seat, a safety engineer sat in the driving seat and a test engineer and trials facilitator sat in the back of the vehicle. During each drive, the participant was asked to speak aloud about their experience, and they were given a hand-held controller to record when they felt the drive was natural or un-natural. The participants were asked to press one of the buttons on the hand controller, at thirty second intervals and at any moment they felt necessary to provide feedback. The marker data could be compared to the vehicle data and positioning within the environment. Following each drive, the trial participants completed a questionnaire of rating scales and comment boxes to provide feedback and to note their intention to use such a system in the future. The questionnaire included adaptions of questions from the Godspeed (Bartneck, Kulic & Croft, 2008) and the Unified Theory of Acceptance and Use of Technology (UTAUT), (Venkatesh et al. 2003).

At the end of the trial participants ranked the driving experiences in order of preference (their manual drive, the AV and the replay of their drive). A pictorial overview of the trial is presented within Figure 2.

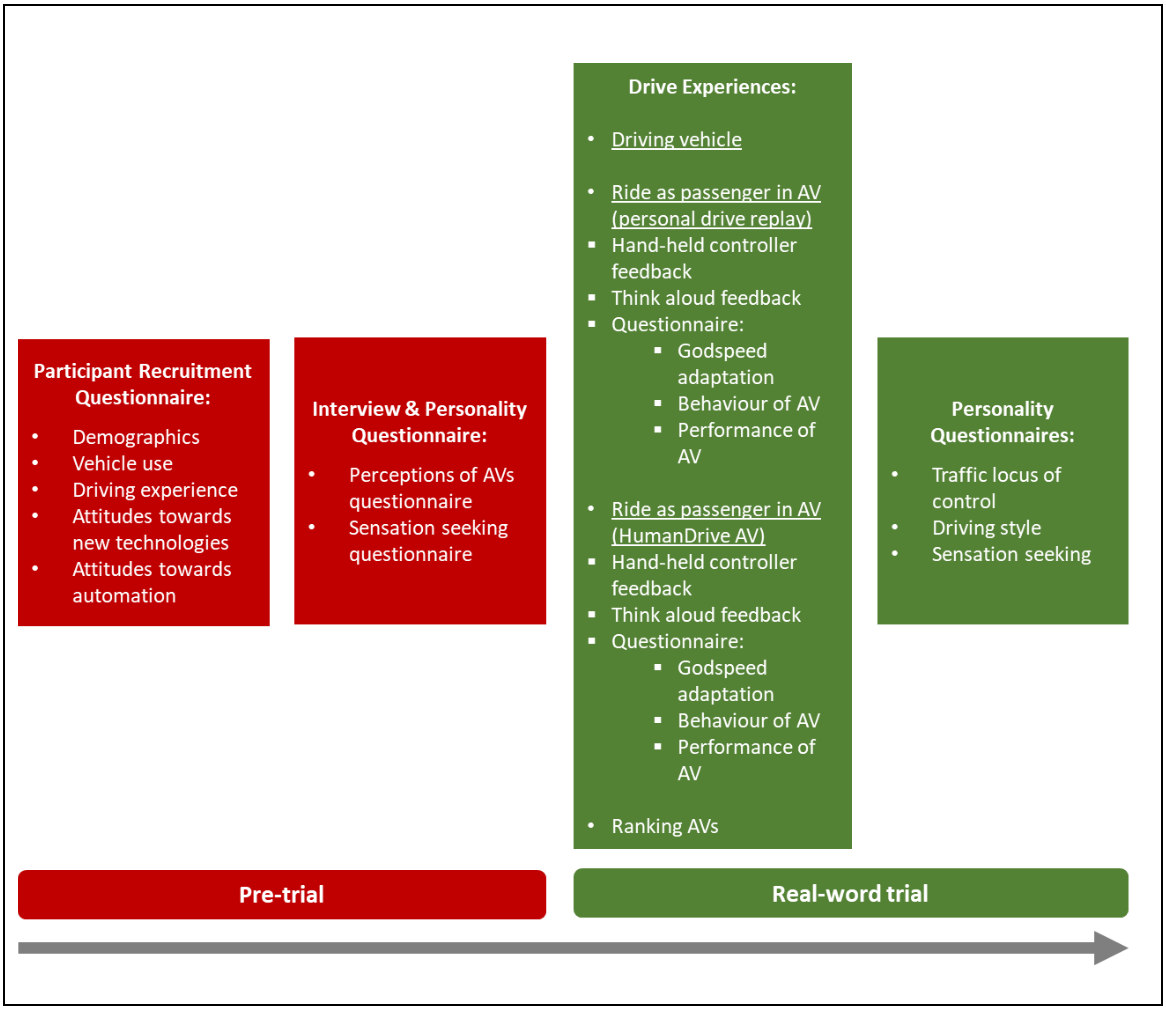


Figure 2: Real-world study one overview

Real-world study two:

The second trial invited twenty people from the general public to participate, again these participants completed a recruitment questionnaire as in study one.

The participants were invited to the test track and initially completed a questionnaire about their attitudes towards AVs and the Arnett Sensation Seeking questionnaire (Arnett, 1994). Each participant was asked to drive along a controlled roadway, either driving themselves, driven by the Nissan AV ACS or driven by a human driver. During each of these conditions, choreographed scenarios were present on the test track that included pedestrians on pathways, pedestrians at crossings, oncoming vehicles, parked vehicles and vehicles at T-junctions. The order of the drives was randomised. As in the real-world study one, feedback was captured during the AV and human driven drive, via the hand-held controller to mark events comfort and discomfort and each drive was followed by the completion of questionnaires. The think aloud process was removed when there was a human driver and the feedback questionnaire was adapted. This was because of the feedback during the pilot study which found that some participants did not feel comfortable commenting on the human driver, whilst they were sat next to them and that some of the questions were only applicable to an AV. After experiencing all driving conditions participants completed the Traffic Locus of Control (Özkan & Lajunen, 2005 and Warner, Özkan & Lajunen 2010) and Driving Behaviour (Reason et al. 1990) questionnaires.

Twelve participants who had provided a variety of feedback during the initial trial were invited back two weeks after the trial to be interviewed and provide further feedback about the drives, and their attitudes towards AVs. An auto-confrontational method was applied to the interview, whereby, video footage of the participant's drives was played back during the interview itself. This allowed the participant to discuss and comment on aspects of their experience for each drive as well as their overall experience. A pictorial overview of the trial is presented within Figure 3.

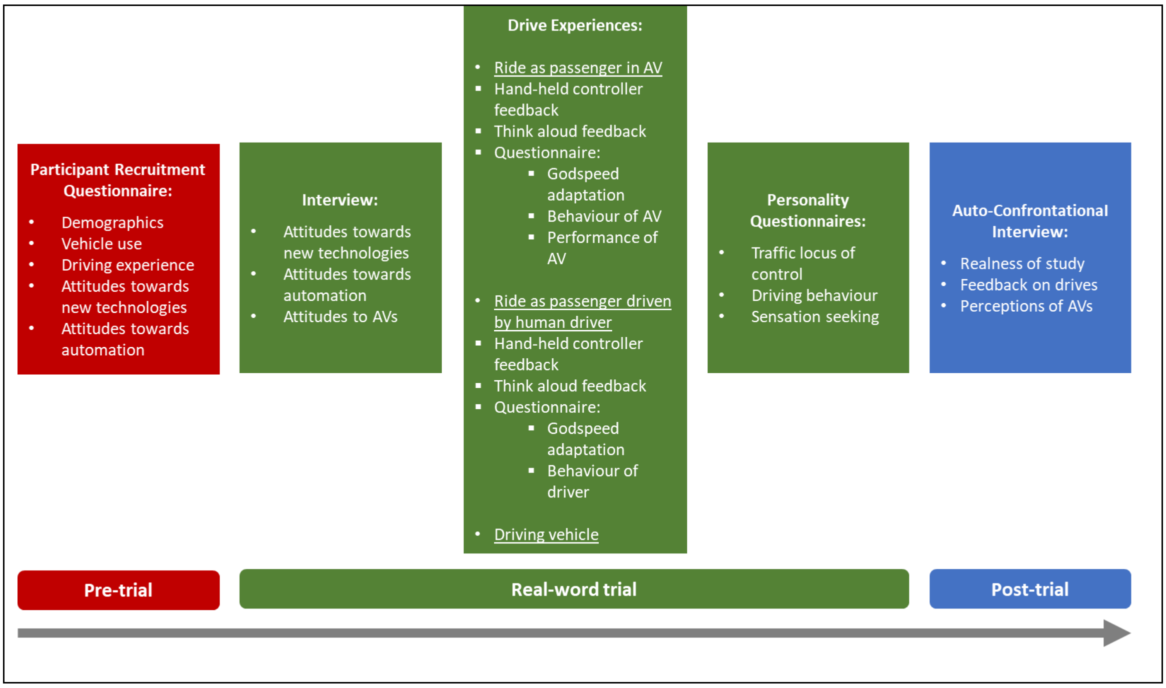


Figure 3: Real-world study two overview

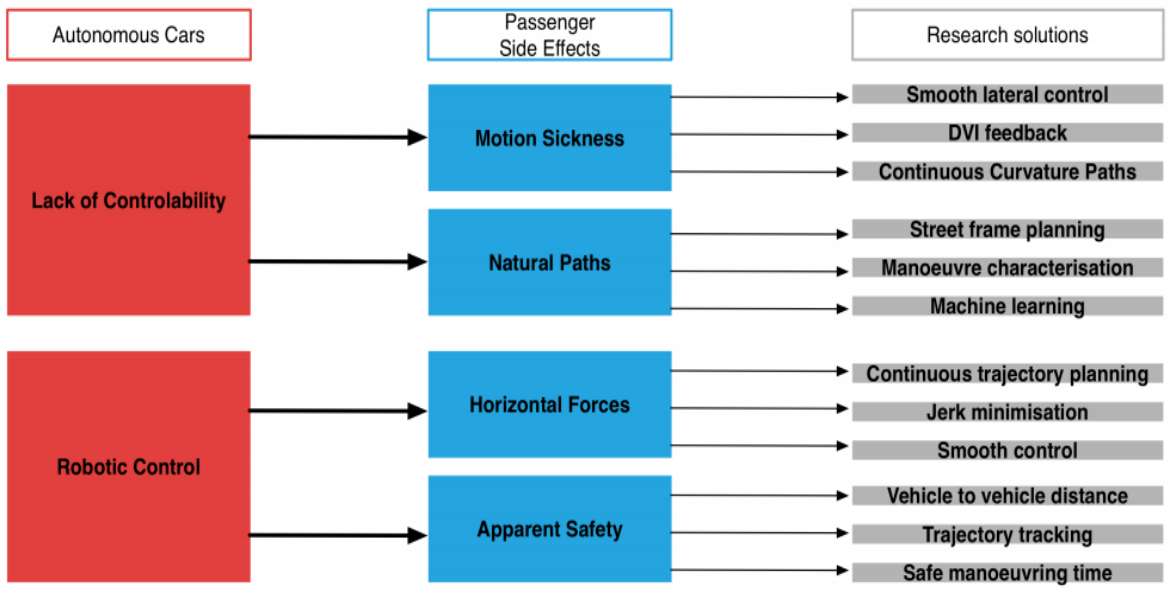
Some preliminary analysis of the trial participants' scoring of the overall behaviour of the AV was undertaken. They were asked to score whether they felt that the AV was safe or un-safe, unnatural or natural, comfortable or uncomfortable. The majority of participants provided positive feedback of their AV ride experience. Most positively agreed that the AV was comfortable (sixteen of nineteen participants) and that it behaved naturally (thirteen of nineteen participants) and safely (seventeen of nineteen participants).

The University of Leeds also carried out research studies within their simulator facilities to determine preferences for the different AV driving styles and behaviours, this also included the consideration of how humans drive and how these characteristics might be considered within an ACS.

For all studies, the subjective feedback continues to be analysed alongside the data capture of the vehicle performance and positioning. The capture of the participant's own drive shall also be compared to their feedback of the other drives.

Findings from other studies measuring AV Ride Comfort

Elbanhawi et al. (2015) provided an overview of measures to investigate ride comfort in autonomous cars. They advise that researchers need to consider factors such as vehicle control, motion sickness and safe distance keeping in addition to the more traditional in car ergonomics such as, Noise Vibration and Harshness (NVH), temperature, air quality and load/road disturbances. They found that few studies have begun to investigate and suggest appropriate AV behaviours to satisfice occupant comfort, trust and acceptance. On the basis, of their findings they suggest research solutions to manage the comfort of user's riding in AVs, as illustrated in Figure 4. They also advise that comprehensive human testing is still required, at this stage, to identify the effect of autonomous driving on passenger comfort.



(DVI is Driver-vehicle interface)

Figure 4 : Research solutions to manage the comfort of user's riding in autonomous vehicles (Elbanhawi et al, 2015)

A number of studies which have started to explore and recommend considerations for "comfortable vehicle motion" for AVs, are building on and adapting existing research techniques and applying them to this subject.

In a study where Bellem et al (2016) requested drivers to mimic dynamic, comfortable and everyday driving, they found that acceleration, jerk, quickness and headway are essential components of an automated driving style for comfort and ease. With small allowances, these metrics are applicable in both rural-urban environments and under highway conditions. Bellem et al (2018), later investigated the influence of manipulating acceleration and jerk through the course of different driving manoeuvres to identify comfortable driving strategies. They also considered whether they could identify a comfortable experience for as many people as possible and whether these preferences were dependent upon personality. Overall, they found that the main preferences remained the same across participants, regardless of age, gender or attitudes. Overall, a driving style characterised by lower jerks and eliciting a feeling of safety through early actions in situations in which a criticality might arise and a softer onset in 'regular' situations was perceived as comfortable. Though some significant differences in preferences could be found for those individuals who reported having risky and high velocity driving styles for acceleration and or lane change manoeuvres. They also suggested that there could be scope to tailor the AV driving style for different customer segments and also provide a style that could be adapted by all. The overall preferred driving style did not necessarily correspond to how a human driver might drive a vehicle manually.

Bae, Moon & Seo (2019) also focused on accelerations and jerks of vehicles to improve the comfort of passengers riding an automated shuttle bus. Consideration was made for both standing and seated passengers and their susceptibility to motion sickness. Basing their recommendations on previous literature, they opted for a driving style that would be accepted by a cautious passenger, who might favour softer steering, acceleration and braking control. Their summary of different driving thresholds and zones is presented within Figure 5. Acceleration and deceleration was also manipulated by Yusof et al. (2019), as presented within Table 2, to simulate a defensive and assertive AV driving style and a style to replicate Light Rail Transit (LRT). Given that LRT typically accelerates and decelerates at a slower rate than human driving, it provided more freedom for users to carry out non-driving related tasks. They also looked at whether assertive drivers or defensive drivers may prefer specific driving styles. Overall, they found that, participants agreed with the defensive AV style and found the LRT too defensive and the Assertive AV too assertive. Most participants with a defensive driving style agreed that the simulated defensive AV was similar to their own style and some participants with an assertive driving style stated that the simulated defensive AV was also a good reflection of their own driving style. All these drivers pointed out that the forces in the assertive AV should be lowered. Two of the participants also mentioned that, as a driver they may drive more akin to the assertive style but as a passenger the defensive style is preferable.

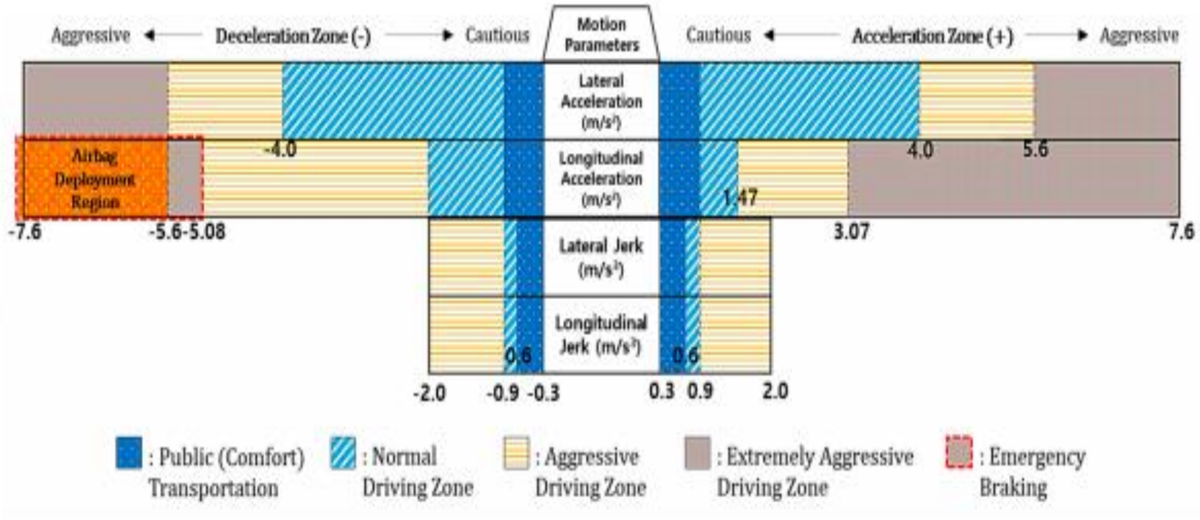


Figure 5: Summary of different acceleration and jerk criteria (Bae, Moon & Seo, 2019)

Type of Acceleration	Light Rail Transit AV Driving Style	Defensive AV Driving Style	Assertive AV Driving Style
Longitudinal acceleration	0.00 g to 0.14 g	0.14 g to 0.25 g	0.25 g to 0.5 g
Longitudinal deceleration	0.00 g to -0.14 g	-0.14 g to -0.33 g	-0.33 g to -0.76 g
Lateral acceleration	0.00 g to 0.15 g	0.15 g to 0.42 g	0.42 g to 0.54 g
Vertical acceleration	-	0.00 g to 0.16 g	0.16 g to 0.66 g

Table 2 : Ranges of accelerations for the AV driving styles in triaxial directions (Yusof et al. 2019)

In a study which investigated trust in autonomous driving styles, Ekman et al. (2019) invited participants to evaluate an aggressive and a defensive driving style. Based on previous literature, changing gears, starting and stopping behaviour, acceleration and retardation patterns, lane positioning and distance to objects were manipulated for each driving style, Table 3 presents these differences. They found that the aggressive driving behaviours affected the participants' ability to trust the vehicle and, in some cases, the participants stated that the poor comfort of the vehicle motion was what had contributed to their reduced trust in the vehicle.

Voss et al. (2018) specifically investigated the accepted comfort and safety thresholds of lateral vehicle control for an AV. Participants observed the lateral vehicle performance and provided subjective feedback. The findings indicate that vehicle position to the road centreline always had a significant influence on the participant's adequacy ratings, however, when oncoming traffic was present the threshold was lowered. Weather conditions, personality trait and sensation seeking attitudes were also influential for scenarios which included oncoming traffic. The preference of a reactive and static autonomous trajectory behaviour, which varied in lateral position was investigated by Rossner & Bullinger (2019). The reactive trajectory would shift to the curb-side edge of the lane when interacting with oncoming traffic, whereas the static trajectory would maintain positioning within the centre of the lane throughout the drive. It was found that overall passengers preferred the reactive trajectory and felt safer when the road lane was wider. Perceived safety was significantly influenced by a wider lane width. Driving comfort and joy was significantly greater for the reactive trajectory behaviour and perceived driving style was influenced by both trajectory behaviour and lane width for the reactive trajectory. Although overall the reactive trajectory received higher positive scores for perceived safety, driving comfort, joy and driving style. The static trajectory only received negative scores for perceived driving joy. Statistical analysis was not carried out for the position, type and quantity of oncoming traffic interactions which were studied, yet it appears that perceived safety is influenced by the on-coming traffic scenarios.

Driving Properties	Defensive Driving Style	Aggressive Driving Style
Changing gears	Use highest gear possible (low revs)	Use gear with most torque (high revs)
Starting and Stopping behaviour	Keep the vehicle rolling (avoid standstill)	Start and stop (comes to full stop)
Acc./Retardation pattern	Avoid heavy accel./decel. Measured to be within: 0.06 to 0.09g (accel.), -0.1 g to -0.13 g (decel.)	Heavy accel./decel. Measured to be within: 0.11 to 0.23 g (accel.), 0.17 g to -0.32 g (decel.)
Lane positioning	Early indicate right or left turn (through positioning in lane)	Indicate late right or left turn (through positioning in lane)
Distance of objects	Keep bigger gap (lateral & longitudinal) to other objects	Keep smaller gap (lateral & longitudinal) to other objects

Table 3 : Criteria for driving styles Ekman et al. (2019)

Hartwich, Beggiato and Krems (2018) studied the perceived comfort and enjoyment of experiencing, familiar and unfamiliar driving styles. By replaying the individual's own driving and by playing other drives more familiar to and not so familiar to their own replay, in doing so they unearthed some interesting differences between age groups. Younger drivers (aged 25-35 years) showed higher comfort, enjoyment acceptance with familiar driving styles, whereas, older drivers (aged 65-84 years) preferred unfamiliar, automated driving styles that tended to be faster than their age-affected manual driving styles.

Though, Basu et al. (2017), also found that a younger population for drivers (aged 18-31 years) tended to prefer more defensive driving styles than their own, but that preferences for driving style was also influenced by driving context. Interestingly, they did find that preferred styles were similar to the style that participants perceived mimicked their own, however, there was actually little similarity between what they thought was their own driving verses their actual driving.

Research approaches for studies measuring AV Ride Comfort

These overall findings suggest that the following factors could influence the comfort of vehicle motion:

- Acceleration, deceleration, jerk, headway, quickness and speed

- Lateral position
- Vertical loadings
- Type of manoeuvre
- Weather
- Environment type
- Presence of other road users (vehicles)
- Personal driving style and familiarity
- Age
- Personality traits (including attitudes towards sensation seeking)

These factors should, therefore, be considered within the scope of further research into the ride comfort of AVs. Given that these findings are based upon a limited number of research studies of various levels of fidelity (realness) and with limited representation of all possible autonomous car users, further evidence is required to confirm these factors. The inter-relationships between these factors, and the interaction between these scenarios and end users comfort needs to be further explored. For example, the scenarios explored for the presence of other road users might further consider the size of vehicles, and other road users. Table 4Table 5 (Annex A), provides a more detailed overview of the scope and limitations of the research discussed.

Given that this paper has reviewed studies regarding ride comfort, the adjective "comfort" was commonly used as an item to rate the preference of different AV driving styles. Other adjectives used to measure user experiences with the AVs have been listed within Table 4. As well as using questionnaires, other methods used to obtain these preferences included the use of think aloud protocol (Basu et al. 2017), marking feedback in real-time via hand-held devices (Hartwich, Beggiato & Krems, 2018 and Rossner & Bullinger, 2019) and by further interviews (Rossner & Bullinger, 2019 and Ekman et al. 2019).

Additional adjectives used alongside Comfort	Reference
"Acceptance"	Hartwich, Beggiato & Krems, 2018 Rossner & Bullinger, 2019)
"Enjoyment"	Hartwich, Beggiato & Krems, 2018
"Joy"	Rossner & Bullinger, 2019
"Pleasant"	Yusof et al. 2016
"Trust"	Rossner & Bullinger, 2019 Ekman et al. 2019
"Safety"	Rossner & Bullinger, 2019 Voss et al. 2018 Yusof et al. 2016).

Table 4: Adjective measures used in addition to "Comfort"

For the experiments carried out, the simulation of different AV driving styles were represented using simulators (of varied degree of fidelity) (Basu et al. 2017, Bellem et al. 2018, Bae, Moon & Seo, 2019, Hartwich, Beggiato & Krems, 2018, Rossner & Bullinger, 2019 and Voss et al. 2018) and Wizard of Oz set-ups in the real word with professional drivers (Ekman, 2019 and Yusof et al. 2016). Different driving styles were often categorised as defensive or aggressive (Bae, Moon & Seo 2019, Basu et al. 2017, Ekman et al, 2019 and Yusof et al. 2016). Rossner & Bullinger (2019) described the behaviour as more reactive or static based on the vehicle's ability to move in response to other traffic and Bellem et al. (2016) categorised driving styles as either dynamic, comfortable or everyday driving. The characteristics of current public transport vehicle behaviour were considered by Bae, Moon and Seo (2019) and Yusof et al. (2016).

The factors such as acceleration, deceleration, jerk, headway, quickness and speed, lateral position and vertical loadings were manipulated to create and develop an appropriate AV diving style, though Diels (2014) points out that high levels of accelerations are typically observed in urban or rush hour motorway traffic (Diels, 2014). Therefore, the traffic flow influenced by other traffic behaviour could make it more difficult to achieve the recommended driving criteria in all scenarios. Where there is a predominant fleet of AVs this might be better managed, otherwise, more optimum route planning could be utilised to avoid scenarios which are likely to induce discomfort. In addition, to avoid motion sickness the AV design should maximise the ability for the user to anticipate the future motion path. Forward and sideways visibility should be maximised and ideally occupants would have a clear view of the road ahead. Though if conditions do not allow for this, any visual information, that correctly indicates the direction of travel will reduce the amount of sensory conflict and enhance the ability to anticipate the motion path. Window surface areas or day light openings should, therefore, be maximised with minimal obstruction by A/B/C pillars, with low belt lines or seats of a sufficient height to enable occupants to see out of the vehicle. New lighting technologies such as Organic Light Emitting Diodes (OLED) may provide the possibility to provide simulated optic flow pattern displays inside the vehicle. See-through displays, such as head up displays will reduce the impact of incongruent motion cues. Future research may also explore the effectiveness of using visual, auditory, and/or tactile cues to provide an artificial horizon and signal the future motion path.

Altering the sensation of speed (user perception of the rate at which objects or the environment pass the vehicle) can also be achieved through changing the driving position, from lower in the vehicle (greater sensation of speed as it is harder to view relative positioning of objects to each other, and the lower centre of gravity also provides a feeling of being closer to the inputs of the vehicle) to a higher position (lesser sensation as a raised position allows the user to gain greater perspective of the relationship of different objects, and vehicle inputs are experienced at a different rate). This can be provided and manipulated through multiple senses. Through the visual field it is possible to provide passengers in AVs with display screens, instead of actual windows. This enables the ability to project visual information that can conflict or override the sensations provided by the vestibular system. Latency and delays between sensation and visual field are commonly known to cause conflicts, leading to a feeling of discomfort, but there is also potential to manipulate this for a more pleasant experience. Controlling acoustic information and other inputs through the vehicle have often been tested through NVH. This is a more traditional approach utilised by car manufacturers to addressing refinement and comfort with a relative relationship between magnitude and feelings of comfort. The greater the magnitude, the less pleasant the experience (although there are occasions where noise can be linked to enjoyment, through exhaust or engine for some passengers).Interestingly, a few of the studies have looked at comparing participants' driving behaviours to that of the AV behaviours, or investigating how this might influence preferences towards AV driving styles and behaviours, either by capturing data on their actual driving behaviour (Basu at al. 2017, Bellem et al. 2016 and Hartwich, Beggiato & Krems, 2018) or profiling drivers, based on their responses to questionnaires (Bellem et al. 2018, Voss et al. 2018 and Yusof et al. 2016). The use of questionnaires, however, relies on the validity of the subjective reporting from each individual. Basu et al. (2017) also found that when participants experienced the different drives there was actually little similarity between what participants thought was their own driving, versus their actual driving data. Questionnaires, which profile individuals based upon their overall personality types, should also ensure correlation to their driving style or preferences too. Yusof et al. (2016) also reported that how you may wish to be driven as a passenger could be different to the way in which you like to drive. Comfort is subjective and can therefore, differ between, and within individuals. Yosof et al. (2016) echoes this point, by suggesting that in some situations, individuals might prefer a more comfortable drive when utilising time or engaging in secondary tasks and for other situations a more assertive drive, for example to experience a thrilling drive, or when late for an appointment. As greater levels of personalisation are provided in the form of selectable options within vehicle settings, the way in which they are perceived by end users may vary considerably. One way in which this is mitigated is through the different touch points that a user engages with, once they are in the confines of the vehicle and additionally providing varying levels of configurability. These can be through seating, lighting levels, sounds and environmental conditions.

4. Further considerations regarding the overall comfort of AVs

When considering the design of AVs for occupant comfort, further factors should be taken into account in addition to the vehicle driving style to ensure a holistic experience. Wasser et al. (2017), acknowledges that the comfort of AVs is influenced by far more factors than the vehicle itself and spans across associated services. They discuss a much broader approach, which considers more holistic facets which contribute to the overall user experience, basing their approach upon the existing research established within aviation travel. This approach considers the physical designs of the vehicles, behaviours and social interactions within the wider service and infotainment offerings.

These authors considered the extent to which the eight factors proposed as being particularly important in determining comfort within the aviation industry by Ahmadpour et al. (2014), could be extrapolated to guide the design and evaluation of last mile driverless pods. Initially comparing this to the semantic environment descriptions for the assessment of vehicle interiors (Karlsson et al., 2003), as displayed within Figure 6.

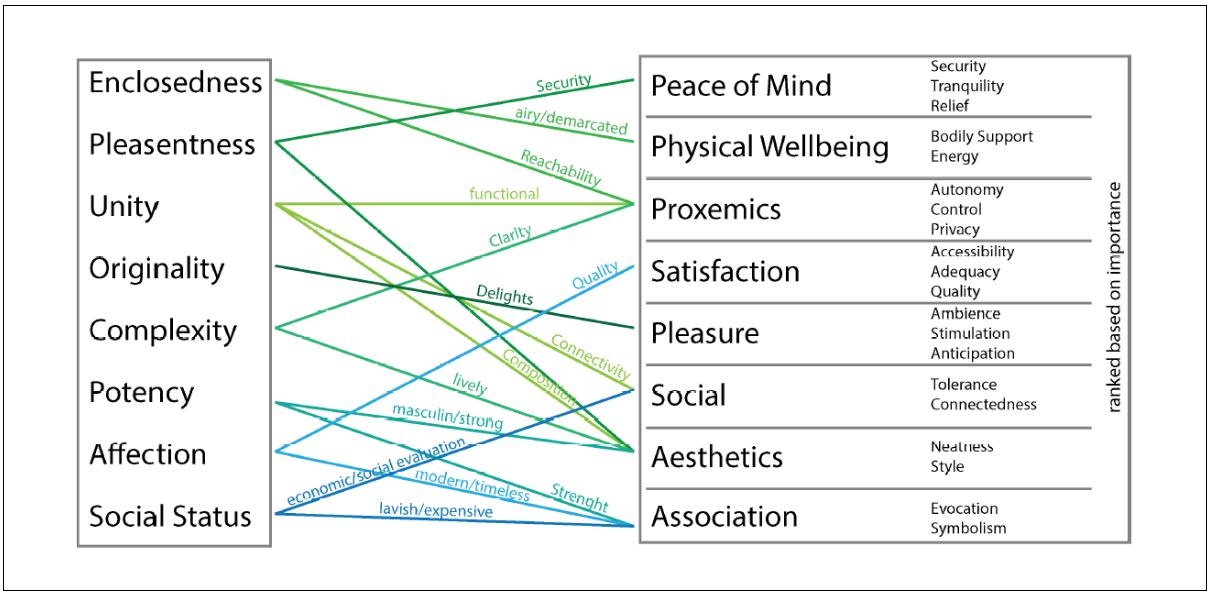


Figure 6 : Comparison between comfort factors for aviation and (Wasser et al., 2017)

In the context of driverless pods, the researchers advise that the following should be considered within each factor:

> **Peace of mind:** Providing an efficient interior layout. With consideration to offering secure storage for belongings, to rest mentally and physically. Providing an ability for the passenger to observe vehicle behaviour and to recognise intentions, for example via the HMI (human machine interface) or via a good view to the exterior, also important in instilling trust. Enabling passengers to intervene if they wish by prematurely terminating a route or choosing a different path.

Physical wellbeing: Attributes providing good body support but whilst also providing a degree of privacy and comfort from other passengers. This also considers the amount energy which maybe exerted by a passenger for example, by entry or restraint against vehicle movements. Ability to perform non-driving tasks and combat motion sickness.

Proxemics: Describing the feeling of autonomy over the space such as seats and HMI. Also including segmenting zones for personal space or specific scenarios.

Satisfaction: Includes symbolic, hedonic and functional considerations.

Pleasure: Linked closely to proxemics and satisfaction, it can be positively influenced by providing the passenger with the ability to make choices, adjustments and generally performing different activities during transit. The haptics of the vehicle materials that the passenger comes into contact with and quality of the infotainment system.

Social: This leads to a mixture of preferences whereby the passenger can interact with others but also seek personal space. Opportunities around Mobility as a Service (MaaS) will facilitate a wider range of interactions. The influence of network connectivity can also influence the ability for the passenger to socially interact.

Aesthetics: Including a clutter free and clean interior that is well maintained and a vehicle that conveys a sense of stability and protection.

Association: A symbolic satisfaction attribute, for example associating something as modern or perhaps during the early introduction of AVs, as something novel.

These factors were further considered for developing a set of criteria to analyse different driverless pod concepts. The criteria included consideration of accessibility, the interior space and seating. Interaction with booking and access systems and emotional experience such as sense of control and ability to observe vehicle movements.

(Nordoff et al, 2019) also found that participants attributed factors of comfort to service quality. In this study, interviews were carried out with people who had taken a ride on a shared, automated shuttle service demonstrator. The open interview approach enabled the researchers to capture a rich overview of the factors influencing users' expectations, both in terms of their expectations of automated driving technology, and whether this particular experience fulfilled these expectations. The interview quotes were analysed and assigned to six categories, and associated sub-categories, as presented within Figure 7. Suggestions around comfort included comfortable seating, travelling in or with their back to the driving direction, access to seating, including a place for luggage, free internet, outside visibility, cleanliness, air conditioning, an attractive interior room and the size of the shuttle. It was also suggested that automated public transport should be more comfortable and of better quality than existing public transport. In line with the factors considered within the research reported on ride comfort, some users also discussed braking behaviour and the capability to overtake obstacles as factors which affected their comfort.

Nordoff et al. (2018) also investigated how respondents rated a shared service automated shuttle, its potential as a feeder to transport systems in urban and rural areas, and its advantages in comparison to the respondent's existing form of travel. They found that there was a strong positive relationship between shuttle and service characteristics, and overall intention to use. Shuttle characteristics included, size, aesthetics, comfort of entry and exit, spaciousness, number of seats, seating comfort, space for luggage, the general atmosphere and safety considerations.

In a study which investigated the key factors which influence trust in driverless cars, a brief link was also made between comfort and safeguards within the design of the vehicle system. The findings confirmed that trust/safety was a valid and reliable factor to measure user adoption of autonomous driving, where the statement "Driverless cars have enough safeguards to make me feel comfortable using it" scored the second highest validity loading (Kaur and Rampersad, 2018).

Further research investigating the wider factors of comfort may be found within research investigating acceptance and satisfaction in AVs. The KANO model, as presented within Figure 8 and cited as important by Wasser et al. (2017) , is a theoretical model which enables designers to determine which features could be included within a product or service to improve customer satisfaction. The model is constructed of five categories of customer preferences which are classified depending on their ability to create customer satisfaction or to cause dissatisfaction. The five categories include

- **Performance** (requirements at the top of the customer's mind),
- **Basic** (requirements expected and taken for granted, "must-be's"),
- **Excitement** (unexpected and pleasant surprises),
- **Indifferent** (neutral requirements which the customer does not care for), and
- **Reverse** (requirements which cause dissatisfaction when present and satisfaction when absent), (Verduyn, 2014).

The model highlights that user preferences change across time, and that providing specific features can move from the excitement category and into a basic requirement as technology develops and therefore, such attributes for comfort should be continuously reviewed. It would also be appropriate to acknowledge the model for different service scenarios and use cases.

The research approaches which have been utilised to explore comfort more broadly have been discussed in Table 6, (Annex B).

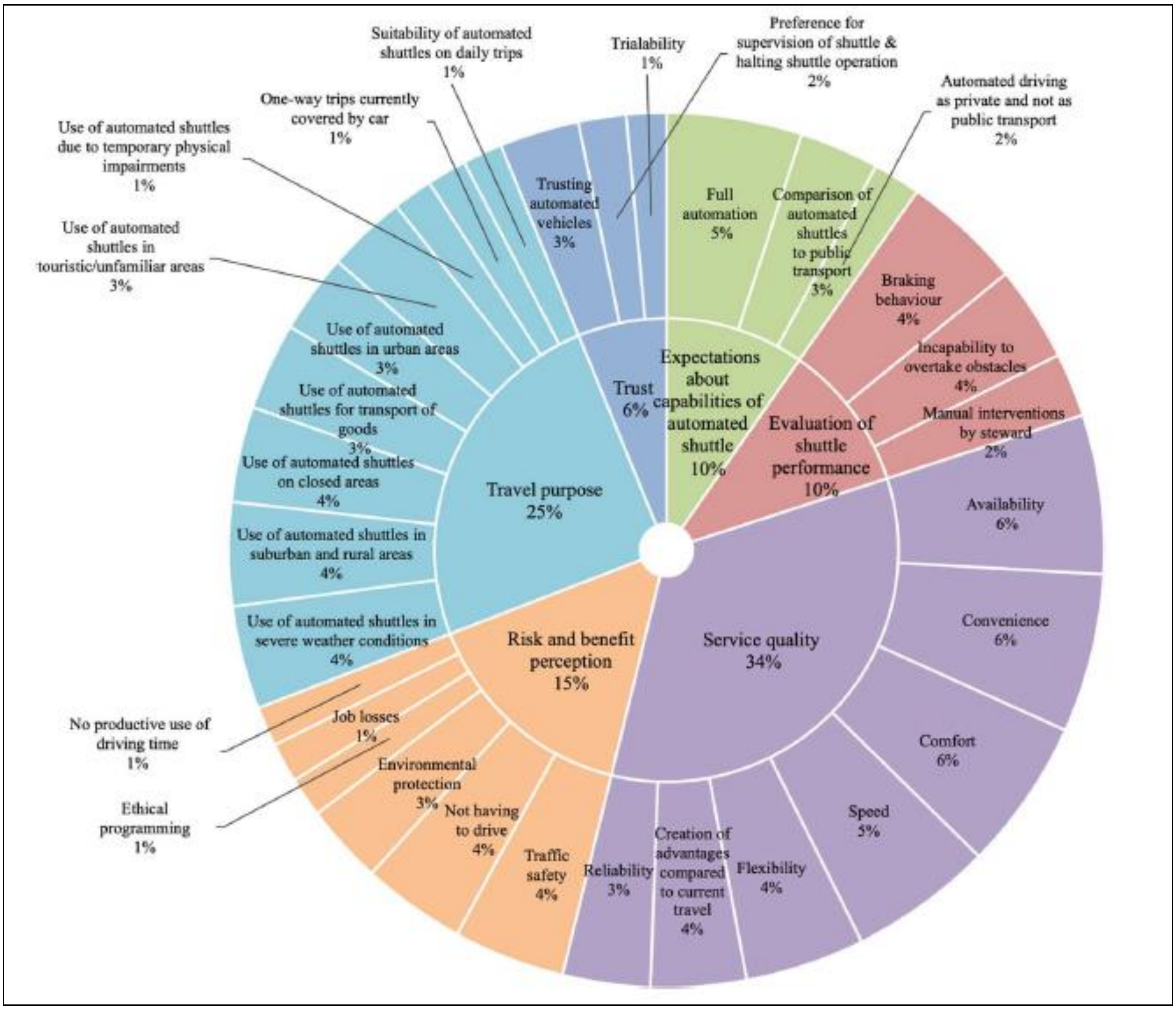


Figure 7: Pie chart presenting the main categories and corresponding sub-categories derived from the interviewee quotes (Nordoff et al, 2019)

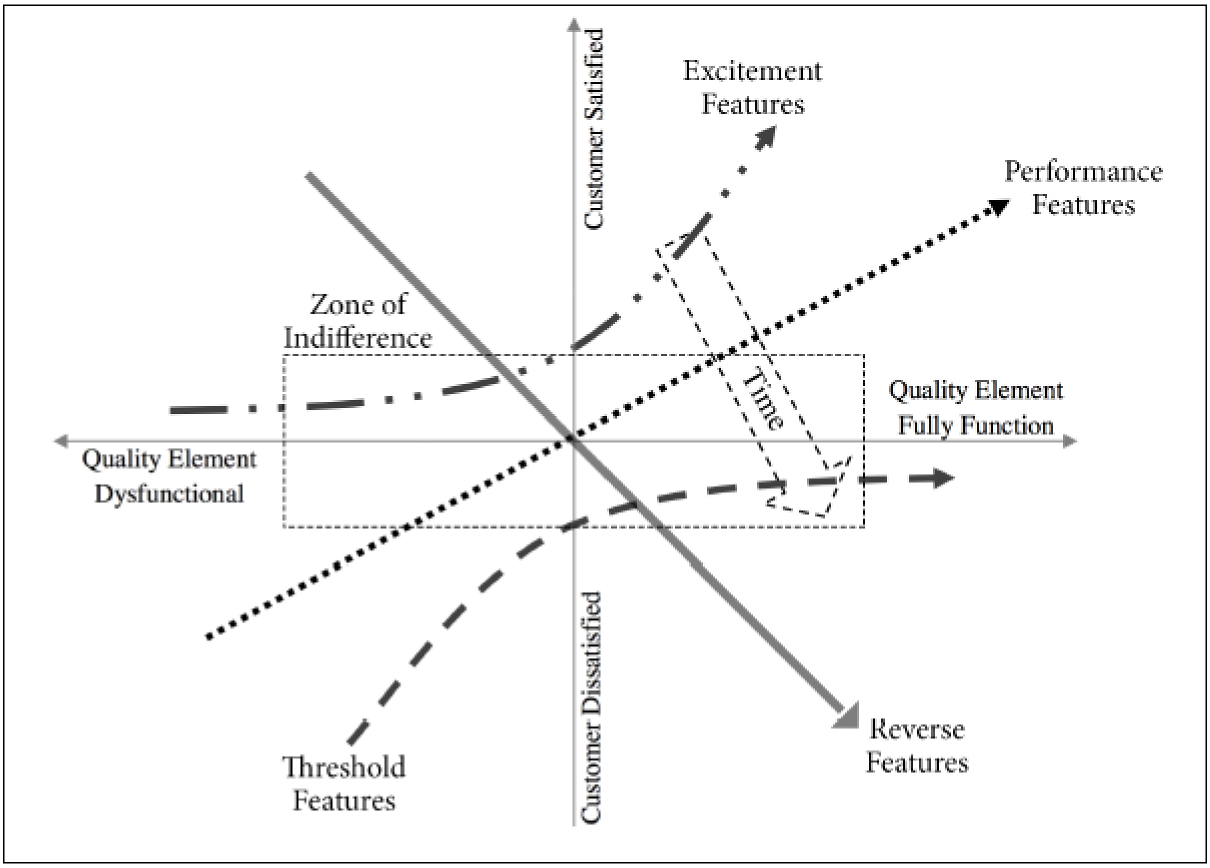


Figure 8 : The Kano Model (Lee, 2011)

5. Conclusion and Further Research

This review can report that researchers are beginning to explore the ride comfort of AVs, which allows the outputs from the HumanDrive project to complement any existing approaches and findings, enabling engineers, designers and policy makers to make more informed and evidence-based decisions regarding the specification and successful deployment of AVs.

Factors found to influence ride comfort for AVs can be comparable to those which may influence passenger or driver comfort in today's conventional vehicles. However, further consideration into the loss of occupant control and the will of users to engage in non-driving related tasks need to be considered within the design process. There is certainly potential for ride comfort to be managed by the manipulation of the driving style and behaviour, but also via the design of the vehicle and the routing it may take.

There is a possibility that one driving style might suit all, with research suggesting that more "defensive" driving styles are more favourable by the vehicle occupants. However, preferences for situation, personality type, gender, age and driving experience could be further investigated to determine whether a range of driving styles should be on offer, and selectable by users.

Current research has predominately focused on the experience of the participant in the passenger seat of a conventional vehicle. However, if the occupant of an AV is to engage with a variety of tasks and be seated in a more novel vehicle configuration, the management of ride comfort needs to be further assessed.

Further research should also look to establish the wider factors of comfort, how these systematically influence one and another, and how different factors might adapt over time, and by scenario. Current research has mostly been carried out with hypothetical use cases, simulation or demonstrators. We suggest that comfort should be considered in the early stages of the development process for a vehicle design and continue to be tracked as more sophisticated systems are deployed. This is because comfort is likely to be greatly influenced by performance and excitement features, which in time will be expected as a standard feature by the costumer or user. It also appears that there could be opportunity to tailor comfort to the preferences of individuals, or market segments, which may provide a greater array of services and opportunities, both for the end user, and for businesses.

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Annex A Research approaches for investigating AV ride comfort

Research and Aim	Approach and Method	Limitations and Further Recommendations
Toward comfortable driving experiences for a self-driving shuttle bus (Bae, Moon & Seo. 2019) To develop a self-driving shuttle bus controller and planning method to provide a comfortable driving experience for both seated and standing passengers which can be verified within a real-time simulation test.	Reviewing desktop research to create a comfortable driving experience criteria/specification Developing a controller and planning method able to follow the criteria/specification Verifying the controller and planning method within a real-time simulation test	The criteria/specification was based on previous research and was not validated by end users. Once the controller and planning method are verified, further evaluation of the criteria/specification and/or the ability of the technology to deliver is required with end users.
Do You Want Your Autonomous Car to Drive Like you? (Basu et al. 2017) To understand where autonomous car users want the vehicle to drive as they would or differently	The driving of fifteen participants (aged 18-31 years) was captured using a desk-based driving simulator. The simulated drive consisted of different driving tasks manoeuvres in varied everyday traffic conditions. To ensure that the drive captured was realistic, participants were asked whether they enjoyed the drive? Whether there were any positive/negative aspects of the simulator environment, the driving control and the traffic conditions? They also rated on a scale how similar or different (+3 to -3) they rated the experience in compared to their daily drive. Perceptions about how each participant perceived their own driving was also captured. By rating a seven-point scale they were asked to rate whether they thought they were: - A conservative or adventurous drive - Whether they prefer the “joy of motion, like feeling the force when you accelerate” and or “comfort in steadiness” when driving - Whether they varied they’re driving by road condition, traffic and time availability	This study was based on a very small sample of younger drivers with limited driving experience. The findings, therefore, cannot be applied to a wider population. The driving simulator was fixed to a desk with the use of an on-wall screen which is of relatively low fidelity. Some participants also criticised the steering re-centring and brake insensitivity by quoting it as being difficult. Efforts were taken to hide the participants original drive by mixing up the order of

	- Rating their experience as somewhat experienced to very skilful. Following the data capture of their drive, participants were invited back to experience their own drive (not knowing it was their own drive), a defensive, an aggressive and a distractor (other participants drive) driving style. These conditions and the driving tasks were randomised for participants. Feedback on the drives was captured by asking participants to think aloud their feelings and emotions during the drive. After experiencing each driving style for a given task, participants rated the comfort, safety, preference for everyday use and similarity to their own driving on a seven-point scale. The aggressive and defensive driving style were based on insights from prior literature.	
Objective metrics of comfort: developing a driving style for highly automated vehicles (Bellem et al. 2016) To identify metrics which can be used to parametrise comfortable automated driving.	Participants were asked to manually drive a route and mimic three driving styles: dynamic, comfortable and everyday driving. The real-world route included rural, urban and highway scenarios. The rural/urban and the highway drive were captured in a separate study. They drove four manoeuvres common to urban, highway and rural settings: decelerating to a moving target, accelerating from non-zero speed, lane change and following at a non-varying speed. Objective data was captured to quantify the different driving styles (acceleration, jerk, quickness*, minimum headway captured in seconds, standard lane deviation *Quickness: the swiftness with which the manoeuvre takes place, derived from longitudinal acceleration & change in longitudinal velocity and lateral velocity & lateral offset) Measures were dependant on manoeuvre type Camera footage of each manoeuvre was captured.	This study is based on the subjective ideas of driving styles and manipulation of these from sample of participants. Participants who worked for an automotive firm were selected, overall the participants were aged between 25 and 60 years. In both studies there were far more males than females. The captured driving styles were therefore, limited to a small segment of the wider population of possible autonomous vehicle users. Future research could also identify possible interindividual differences across the participant drives. Due to the variance of behaviour of other road uses in the real-world, it was difficult to manage the interactions to ensure that there was a frequency of very similar manoeuvres.

	Participants also scored how well they thought they had been able to implement each manoeuvre for the respective style on a five-point scale (5=exactly as instructed to 1=not having driven as instructed at all)	
Comfort in automated driving: An analysis of preferences for different automated driving styles and their dependence on personality traits (Bellem et al. 2018) To identify what a comfortable experience is for as many people as possible and whether these preferences are personality dependent.	Three different variations of an acceleration, lane change and deceleration manoeuvre were presented to the participants via a moving base simulator. The criteria for variations was based on existing findings in literature. Seventy-two drivers (aged 21-66 years) participated. There was an almost even divide of males and females. Each participant experienced each manoeuvre six times. Questionnaires used to assess personality included: - Demographic questions - General attitudes towards autonomous driving - Attitude towards risk on a seven-point, one item scale - Multidimensional Driving Style Inventory (MDSI) (Tuabman-Ben-Ari et al., 2004) a forty-four-item scale cluster into eight subscales which inquires whether certain behaviours are shown during manual driving - Thrill and Adventure Seeking a subscale of Sensation Seeking Scale V (TAS in SSS) (Zuckerman, Eysenck & Eysenck, 1978) - Locus of Control (Rotter, 1996) Trust in Automated Systems (Jian, Bisantz & & Drury, 2000), this was asked after the drive The preference for the variations were analysed and an order of preference was developed. Participant wellbeing was measured using the Fast Motion Sickness Scale (FMS) (Keshavarz & Hecht, 2011) before and after the drive to identify is rating were influenced by this.	Most participants looked favourably on automated driving. Therefore, the overall findings may not be representative of preferences of a population with mixed views. Only results for the MDSI scales for anxious, angry and high velocity driving style could be analysed because internal consistency across participants was not met for the other scales. Recruitment of participants who report can be categorised across more of the scales may present further insights about personality traits and preference of automated driving style. As this study was conducted within a simulator the transferability of the results should be validated in the real-world.
Exploring automated vehicle driving styles as a source of trust information (Ekman et al. 2019)	Eighteen participants (aged 20-55 years and evenly distributed by gender) experienced a “Defensive” and “Aggressive” drive presented via a Wizard of Oz setup. Whereby a professional driver who was	Although an order effect had been applied to balance participant responses, an effect was found that when participants experienced the

To investigate whether user trust in automated vehicles is affected by vehicle driving style	concealed from the participant's view, drove a vehicle from the back seat. The drive took place on a test track with a city centre setting and rural road. Various driving situations including interaction with other road users and road infrastructure occurred along the drive. User trust in the drives was measured after each driving situation by: - Rating their trust level on a seven- point rating scale (1=low trust to 7=high trust) and verbally explaining their reasoning for the score - Completing an eight-item Likert scale Trust questionnaire adapted from Jian, Bisantz, and Drury (1998) and including questions regarding purpose, process and perfor,ance by Lee and See (2004) - Plotting level of trust on a Trust Curve (y=level of trust, X axis=different traffic situations over time) - In-depth interviews	"defensive" style first they rated trust in this style more highly. It is suggested that if more risky situations, if the participant had been alone in the car or if the experiment was carried out in real traffic, then this would have decreased the initial level of trust and thus counteracted the ceiling effect.
In the passenger seat: investigating ride comfort measures in autonomous cars (Elbanhawi et al., 2015) To provide an overview of traditional and autonomous factors which influence ride comfort	A review paper where traditional comfort measures are examined, and autonomous passenger awareness factors are proposed.	A good basis to continue further research
Driving comfort, enjoyment, and acceptance of automated driving – effects of drivers' age and driving style familiarity (Hartwich, Beggiato & Krems, 2018). To explore the effects of automation and driving style familiarity on driving comfort, enjoyment and acceptance of automated drives.	Forty drivers were divided into a younger driver group (25-35 years, n=20) and an older driver group (65-84 years, n=20). Both groups had an almost even split of genders. Each participants' drive was captured and replayed back to them as a familiar drive in a fixed base simulator. Six weeks later their drive was replayed back to them again and two additional drives (unfamiliar) captured from other participants was also simulated. These drives which represented natural driving styles or varying differences from their own styles.	The pool of unfamiliar drives was limited to the drives captured from the participants sample; therefore, it is suggested that future research should focus on method to extract characteristics of individual driving styles while keeping the quality of driving performance at a comparable level.

	The simulated route included scenarios on a rural road and highway road. User acceptance, comfort and enjoyment was measured by: - Rating acceptance of an automated drive firstly after reviewing a written system description and then after experiencing each drive. This was assessed using the Van Der Laan (1997) acceptance scale questionnaire which evaluated satisfaction with the system and its perceived usefulness across nine five-point rating-scale items. - Comfort and enjoyment were assessed after each drive using a questionnaire developed by Engelbrecht (2013). Which consists of thirty-two, five-point agreement-scale items that represent convenience (or comfort), joy (or enjoyment) and their contrary states lack of convenience and lack of joy. - Driving discomfort* was assessed continuous during all drives with a handset controller. Participants indicated their current level of discomfort on a 0-100 scale (0=comfortable, 100=uncomfortable) by pressing a button, a harder press corresponded to higher discomfort. A dashboard display provided feedback of the current entered value. *Discomfort was defined as states of tension or stress resulting from unexpected, unpredictable or unclear actions of the automated system.	This study took place in a fixed-based simulator so further research should seek insight or validate these findings in more real settings.
Do You Shift or Not? Influence of Trajectory Behaviour on Perceived Safety During Automated Driving on Rural Roads (Rossner & Bullinger, 2019) To investigate natural-looking reactive technologies on rural roads and in on-coming traffic scenarios to understand people's preferences regarding driving styles.	Thirty drivers experienced two trajectory behaviours as if they were a passenger within an autonomous car. The reactive trajectory (whereby, the vehicle would move to the far edge of the lane when meeting oncoming traffic) and a static trajectory (whereby, the vehicle maintained a position in the centre of the lane throughout the drive) were played within a fixed-base simulator. During the drive these two conditions also interacted with two lane widths (2.75km and 3km) and oncoming traffic scenarios; varied vehicle type (trucks and cars), quantity (one or two vehicles in a row) and position (lateral offset of oncoming traffic to road centre line).	The study was carried out with a sample of drivers with a mean age of about thirty years. The study should, therefore, be carried out with a greater mix of drivers. The study will need to be further proven out of the simulator within a real-world setting. Only statistical analysis was carried out for data captured regarding the perceived safety, driving

	Participants provided feedback by using a handset controller to mark their perceived safety in real-time during the drive. After each experimental drive condition participants completed questionnaires regarding: -Acceptance -Trust in automation -Subjectively experienced driving performance The questionnaire included single item ratings regarding perceived safety, driving comfort, driving joy and driving style on a 11-point Likert scale (from 0=very low to 10=very high). The drive was followed by an interview	comfort joy and style for trajectory behaviour and lane width.
Investigation of driver's thresholds of subjectively accepted driving performance with a focus on automated driving (Voss et al., 2018) To determine the subjectively accepted thresholds of driving performance regarding lateral control of an autonomous vehicle	One-hundred-and-sixty-one people (aged 19-64 years) participated in an online study. The participants were divided into groups based on driving experience (inexperienced <500km/year vs. experienced, and sensation seeking (low vs. high) Video clips of a forward-facing view out of a driving car in the sun or rain, with no oncoming traffic and oncoming traffic were presented whereby the vehicle's lateral offset varied. Personality factors were captured via questionnaire which included: - Socio-demographic questions (e.g. driving experience) - The Arnett Inventory of Sensation Seeking (AISS) by Roth & Mayerhofer (2003). Which assesses tendencies for experience seeking and risk motivation across twenty statements, rated on a four-point Likert scale (does not describe me at all - describes me very well) Subjective acceptance of drives was captured by: - Providing an overall rating on a four-point Likert scale (not adequate at all, rather not adequate, adequate, totally adequate). - A questionnaire assessing the construct of subjectively experienced driving performance (Voss et al., 2016), consisting of twenty-two comfort and safety related adjectives which are rated on a six-point Likert scale (1=disagree – 6=agree) -	The vehicle performance was viewed on a video and therefore, needs to be validated in much more realistic settings. The setup in which the video was viewed will vary per participant because this was distributed as an online survey. The participants were asked to imagine being the driver, however, in a fully automated vehicle it is likely that their role will be closer to a passenger.

The exploration of autonomous vehicle driving styles: preferred longitudinal, lateral and vertical accelerations (Yusof et al., 2016) To explore the experienced comfort, pleasantness and safety of different autonomous vehicle driving styles	The study took place in the real road and the autonomous aspect of the vehicle was simulated within a Wizard of Oz style set-up. Three driving styles; an assertive and defensive and a replica of light rail transit were experienced by twelve drivers (aged 24-39 years). The styles were simulated by an experienced driver with the support of an automatic acceleration and data controller. This device provided continuous real-time feedback about the induced acceleration forces at desired locations. Longitudinal, later and vertical acceleration and longitudinal deceleration were manipulated for each style. Before the drive participants were classified as either an assertive of defensive driver upon completion of Zuckerman et al. (1993) personality questionnaire. During the drive participants experienced points of interest including a speed hump, approaching and leaving a junction on a straight road and driving on a curved road. Five different rating scales were used to elicit the participants opinion for each point if interest: 1. Very comfortable (1) to very uncomfortable (5) 2. Very pleasant (1) to very unpleasant (5) 3. Very safe (1) to very dangerous (5) 4. Very true of me (1) to very untrue of me (5) 5. The force [of acceleration] is much too high (1) to the force is much too low (5)	Although a device was introduced to aid control of the acceleration forces the experienced driver was not always able to replicate exactly the same forces for each participant. A small sample of users experienced the drives and their driving styles were profiled based on subjective questionnaire scorings. Further research with a larger population and more understanding into their own driving style would be recommended. The study suggests further research into the preferred driving style for different situations e.g. more comfortable when utilising time or engaging in secondary tasks or more assertive for a thrilling experience or when late for an appointment and may wish to sacrifice comfort.

Table 5: Research approaches for investigating autonomous vehicle ride comfort

Annex B Research approaches for more broadly investigating AV comfort

Research and Aim	Approach and Method	Limitations and Further Recommendations
Trust in driverless cars: Investigating key factors influencing the adoption of driverless cars (Kaur & Rampersad, 2018) Investigating perceptions of benefits, concerns, trust and situations when users are more willing to adopt driverless cars	The research was based on a case study site, whereby a closed campus university hoped to introduce and driverless shuttle service. One-hundred and one university staff and students completed a survey which asked them to rate their agreement, concern and the likelihood for the following factors: security, privacy, reliability, performance expectancy, trust/safety and adoption scenarios. Ratings were scored using 5-point Likert scales. Demographics were also collected. These factors were assessed to see if they increased trust in driverless cars.	The findings are based on one hypothetical case study, with a limited sample size from one area. Therefore, further research would need to be carried out to see if the wider population agreed with the influencers.
User acceptance of automated shuttles in Berlin-Shöneberg: A questionnaire study (Nordoff et al., 2018) Explored the intention to use, shuttle and service characteristics and shuttle effectiveness compared to existing transport of an autonomous shuttle service	Three-hundred and eighty-four riders of an automated shuttle service based at an office campus completed a questionnaire. The questionnaire collected demographics, rating of the shuttle and shuttle service, perceived enjoyment, perceived usefulness, perceived ease of use, perceived level of control, environmental attitudes, willingness to pay and indications of acceptance, including the Van der Laan (1997) acceptance scale. Most questions were measured as statements	The mean age was around 35.5 years and the researchers highlighted that the demonstrator may have attracted those who were curious to try out the automated shuttle and therefore, the study may be prone to selection bias and includes a young demographic. The study also found that employees on the campus rated the shuttle as more negative than outside visitors. It is further recommended that this research should be carried out in naturalistic rather than trial-based settings, with more users and where data regarding actual usage of the shuttle are recorded as well as self-reported attitudes towards the shuttle. Further experiments with a control group and objective measures, e.g. actual use rather than intended use, are needed to understand the causal determinants of the acceptance of automated shuttles.

What impression do users have after a ride in an automated shuttle? An interview study (Nordoff et al., 2019) To understand automated shuttle users' expectations of the automated driving technology and whether the experience fulfilled these expectations.	Semi-structured interviews (with open ended questions) were carried out with thirty people who had used a shared, automated, shuttle service as part of a demonstrator. The interview framework included: enquiring about their current transport use, their perceptions and experiences during the ride and identifying factors which influence acceptance and use. Socially how others close to them perceive automated shuttles, how this service might integrate with other transport and their transport use and their ideas about future mobility.	This provided a basis of understanding end user thoughts and motives and further research could investigate if these expectations are also considered by the wider population and for other automated vehicle services.
Driverless Pods: from technology demonstrators to desirable mobility solutions (Wasser et al., (2017) To develop a conceptual framework for the design of driverless pods and analyse and compare the current concepts in the context of the passenger comfort experience	The researchers looked to what extent the eight factors, Ahmadpour et al, (2014) recommended as being particularly important in determining comfort within the aviation industry could be extrapolated to guide the design and evaluation of last mile driverless pods. Initially comparing this to the semantic environment descriptions for the assessment of vehicle interiors (Karlsson et al, 2003). This led to the development of criteria to assess six driverless pod concepts. The criteria included sixteen items, categorised within five themes. A five-point rating scale (unacceptable, poor, average, god excellent) was used to score each time.	The development of the criteria or design reference seemed to be based upon expert review. The factors within the criteria should be further validated with last mile mobility users.

Table 6 : Research approaches for investigating autonomous vehicle comfort

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