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1 Conceptualising user comfort in automated
2 driving: Findings from an expert group
3 workshop

4
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1 Abstract

2 Automated driving needs to be comfortable to encourage the broad acceptance and usage of automated
3 vehicles (AVs). However, current research provides limited knowledge on the descriptions and influencing
4 factors of user comfort in automated driving, especially from the perspective of an AV's driving styles. This
5 paper presents results from an online workshop, in which nine experts with hands-on experience of AVs, and
6 a long track record of research in this context, brainstormed and discussed a series of topics related to user
7 comfort in automated driving. Results showed that a wide range of terms were used to describe user comfort
8 and discomfort, when the attendees considered being driven by either currently available transport modes
9 (e.g., taxi/bus/train) or higher-level AVs (with neither requiring control of the vehicle by the user). All of the
10 terms used for existing vehicles were found to apply to AVs, but additional aspects of comfort/discomfort
11 were revealed for AVs. This suggests that what makes existing transport modes comfortable is not the same
12 as that for higher-level AVs. Regarding the relationship between comfort and discomfort in automated driving,
13 seven and ten categories of terms were identified for comfort and discomfort, respectively, with both the
14 number and the nature of these categories differing across the two states. This suggests that, to ensure user
15 comfort in automated driving, additional factors that affect comfort must be considered, rather than solely
16 mitigating discomfort. By integrating these multiple aspects that affect user comfort, knowledge from the
17 workshop was used to develop a conceptual framework, to explain how AV driving styles, as well as other,
18 non-driving-related factors, affect user comfort, from both a physical and psychological perspective. This work
19 provides an overview of experts' insights on the factors that affect comfort in automated driving, and will
20 facilitate a more comprehensive definition, and more accurate measurement, of user comfort, facilitating the
21 design of more comfortable and acceptable automated driving for future vehicles.

22 **Keywords:** automated vehicles, user comfort, driving styles, expert workshop, conceptual framework.

23 1. Introduction

24 Comfort, as a positive user experience of automated driving, is essential for the broad acceptance of
25 Automated Vehicles (AVs), (Dichabeng et al., 2021; Nordhoff, Malmsten, et al., 2021; Paddeu et al., 2020;
26 Siebert et al., 2013). When being driven by a higher-level AV (SAE Level 4+, SAE International, 2021),
27 automated driving styles, such as the vehicle's kinematic behaviour, the distance it keeps with other, road-
28 based, objects, and how it negotiates different road geometries, play an important role in user comfort
29 (Beggiato et al., 2020; Bellem et al., 2016; Diels & Bos, 2015; Peng et al., 2022). Here, a wide range of factors
30 are considered relevant to user comfort when driven by AVs. For example, *perceived safety* and *trust* are
31 thought to affect comfort (Diels et al., 2017; Hartwich et al., 2021; Nordhoff, Stapel, et al., 2021), with research
32 showing that when users do not trust AVs, they will refrain from using automation, and not use the driving
33 time for other (non-driving related) activities. Another concern is the prevalence of *motion sickness*. While
34 manual driving does not necessarily result in motion sickness (Rolnick & Lubow, 1991), recent research
35 suggests that as many as two-thirds of adults have suffered from car sickness (Diels & Bos, 2015) with around
36 10% of passengers of AVs predicted to suffer from this condition in the future (Sivak & Schoettle, 2015). It is
37 assumed that such discomfort may also be associated with unexpected and abrupt manoeuvres of automated
38 driving. Therefore, understanding what factors affect user comfort, from the perspective of AV driving styles,
39 is critical. Without sufficient knowledge of user comfort in automated driving, such as how it is defined and
40 measured, it is challenging for automated system designers to develop comfortable, enjoyable, and acceptable
41 AVs. Thus, the main aim of the present explorative study, based on an expert workshop, was to enhance our
42 understanding of factors that contribute to an individual's comfort, when being driven by an AV.

1 1.1. Comfort and discomfort in automated driving

2 Comfort is a highly complex concept, affected by physical factors such as the vehicle's motion, the visual
3 context of the environment, the "driver's" posture, as well as the sound, climate and interior design of the
4 vehicle cab (e.g., da Silva, 2002; Osborne, 1978). It is also influenced by psychological factors such as feelings
5 of safety, pleasure, and peace of mind (Ahmadpour et al., 2016; Carsten & Martens, 2018; Summala, 2007).
6 Research in the automotive, air, rail and marine sector, and those related to general ergonomics of systems,
7 have resulted in ample definitions of comfort. For example, Slater (1986) defines comfort as "*a pleasant state
8 of physiological, psychological and physical harmony between a human being and its environment*". De Looze
9 et al. (2003) propose three main features, suggesting that comfort: a) is a subjective and personal construct;
10 b) influenced by physical, physiological and psychological factors; and c) comes from the interaction of the
11 human with the environment. Comfort is derived from positive experiences, such as pleasure and trust, and
12 the lack of negative experiences (discomfort), such as fatigue, anxiety and fear. However, an overall comfort
13 experience is easily marred by a minor change in discomfort (Cohen-Lazry et al., 2022; Helander & Zhang,
14 1997).

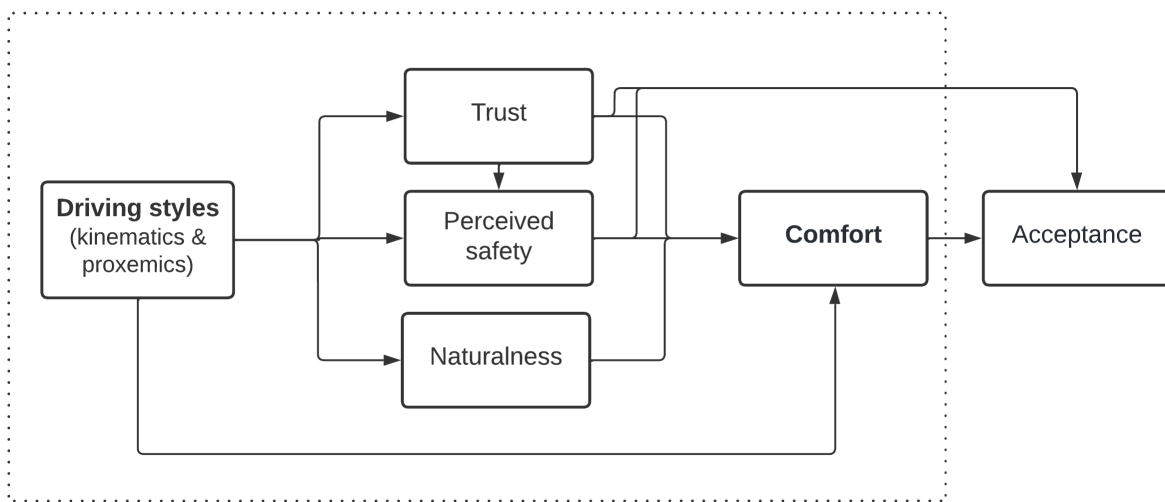
15 When using a highly or fully automated vehicle, control of the vehicle is shifted from the human driver to the
16 automated system. In such situations, users will no longer have to monitor the road and can use the driving
17 time for work or leisure. This means that users' experiences are likely to be affected by how the automated
18 system drives, i.e., its driving style. As the importance of comfort in AVs is gaining more interest, researchers
19 have used a wide range of definitions for user comfort. For example, some studies emphasise the absence of
20 discomfort (Bellem et al., 2016), where comfort is defined as "*a state which is achieved by the removal or
21 absence of uneasiness and distress*" (p. 45). Other studies address both positive and negative aspects of
22 comfort. For example, Carsten and Martens (2018) describe driver comfort as "*the subjective feeling of
23 pleasantness of driving/riding in a vehicle in the absence of both physiological and psychological stress*". Others
24 highlight the role of AV operations, such as "*a subjective, pleasant state of relaxation given by confidence and
25 an apparently safe vehicle operation, which is achieved by the removal or absence of uneasiness and distress*"
26 (Hartwich et al., 2018, p.1019). Similarly, Hartwich et al. (2018) describe discomfort as "*a subjective,
27 unpleasant state of driving-related psychological tension or stress in moments of a restricted harmony between
28 driver and environment, originating from unexpected, unpredictable or unclear actions of the automated
29 system*" (p.1021).

30 Thus, there are currently various descriptions for user comfort in AVs, emphasising either the lack of
31 discomfort, and/or the use of positive and pleasant terminologies, while descriptions for discomfort are few,
32 and are not exactly the opposite of that for comfort. When it comes to measurement of these states in
33 automated driving, some studies have measured comfort directly (Hajiseyedjavadi et al., 2022), while others
34 have solely measured discomfort (Radhakrishnan et al., 2020), by assuming that, for example, the physiological
35 changes associated with this state are easier to detect and quantify (Siebert et al., 2013). These inconsistencies
36 in the definition and measurement of comfort/discomfort for automated driving make cross-study
37 comparisons, for example, about whether a particular AV driving style is comfortable, challenging.

38 1.2. A conceptual framework for comfort in automated driving

39 Comfort in automated driving is an emerging research field which lacks definitions, methods, and models. In
40 the context of ergonomics, conceptual models for comfort have been proposed. For example, in the aircraft
41 cabin, factors such as peace of mind, physical well-being, and aesthetics, play a role in passenger comfort

1 (Ahmadpour et al., 2014). For sitting comfort, factors, such as physical characteristics of the seat (e.g.,
 2 softness), contextual factors (e.g., job satisfaction), and individual expectations, influence user comfort (De
 3 Looze et al., 2003). Gaining similar knowledge for AVs will support the design of comfortable vehicle interiors,
 4 such as information about seat position. However, to ensure the driving experience of an AV is also
 5 comfortable, new insights and models will be needed, in order to design comfortable driving styles realised
 6 through the AV's motion control strategies. Therefore, to assist with a better understanding of how AV driving
 7 styles, in particular, affect user comfort, the lead author proposed a conceptual framework (Figure 1), each
 8 element of which is outlined below. This original conceptual framework was used as a starting point for the
 9 discussions in the expert group workshop. Then, by incorporating the feedback from experts, the framework
 10 was refined, and a more elaborate version is provided in the Results and Discussion section of this manuscript.



11
 12 *Figure 1.* The original conceptual framework for comfort in automated driving. This literature-based
 13 framework focuses on the psychological perspectives of comfort. The concepts and terms included in the
 14 dashed box are discussed in the present study.

15 The link between driving styles and comfort

16 For the original framework, the focus was especially on how an automated driving style affects user comfort.
 17 Adapted from a description of manual driving styles (Elander et al., 1993), automated driving styles are related
 18 to vehicle kinematics (e.g., acceleration and braking behaviour), and vehicle proxemics (e.g., distance kept to
 19 other on-road or roadside objects). Driving style is also about how the vehicle manoeuvre is influenced by road
 20 surface and geometry, such as how it negotiates different road curvatures, or whether the ride is smooth or
 21 jerky. A number of studies have investigated the link between changes in these aspects of a driving style, and
 22 user comfort in AVs (Dettmann et al., 2021; Elbanhawi et al., 2015; Hajiseyedjavadi et al., 2022; Hartwich et
 23 al., 2018; Peng et al., 2022; Summala, 2007). For example, Bellem et al. (2018) propose a range of kinematics
 24 to assist with user comfort during different manoeuvres of highly automated vehicles, such as minimising
 25 acceleration and jerk – i.e. the rate at which the acceleration changes with respect to time. Peng et al. (2022)
 26 measured user comfort for two human-like and one machine-like driving style, and found that the replay of
 27 real human participants' driving (categorised as a “defensive” driving style - driving at lower speeds), was
 28 evaluated as more comfortable than the other two.

1 High levels of automation increase the importance of driving style for user comfort. Higher-level AVs (SAE level
2 4+, SAE International, 2021) can operate autonomously, without any input or action by users. This can detach
3 the on-board users from the surrounding environment, taking them “out of the loop” (Merat et al., 2019),
4 reducing their overall situation awareness, especially if they are engaged in other, non-driving related,
5 activities (NDRAs). In these situations, any unexpected or unpredictable manoeuvres of the AV (e.g., a sudden
6 brake) may not only interrupt the user’s engagement in the NDRA, but also cause concern, discomfort, or even
7 motion sickness (Beggiato et al., 2020; Carsten & Martens, 2018; Hartwich et al., 2018; Kuiper et al., 2020).
8 Elbanhawi et al. (2015) argue that a comfortable AV ride demands natural and familiar manoeuvres (see also
9 Peng et al., 2022), smooth control, safe operations, and the mitigation of motion sickness, in addition to the
10 traditional (physical) factors that enhance comfort (e.g., temperature, noise, and seat design; De Looze et al.,
11 2003; Silva, 2002). Therefore, for our original framework, we focused particularly on understanding what
12 *psychological aspects* affect comfort in AVs, to help enhance users’ psychological experience (i.e., how they
13 feel about different driving styles).

14 Perceived safety, trust, and naturalness

15 Perceived safety, trust, and naturalness (sometimes referred to as familiarity), have been linked to comfort in
16 automated driving (Elbanhawi et al., 2015; Paddeu et al., 2020), and each concept is also considered to be
17 influenced by a vehicle’s driving style (Hajiseyedjavadi et al., 2022; He et al., 2022; Lee et al., 2019; Oliveira et
18 al., 2019; Summala, 2007). Some of these concepts, together with comfort, are frequently used
19 interchangeably. For example, He et al. (2022) describe perceived safety as “*feeling relaxed, safe and*
20 *comfortable*” (p.179). Although a number of studies have described trust in automation, perhaps the most
21 cited is one provided by Lee and See (2004) as: “*the attitude that an agent will help achieve an individual’s*
22 *goal in a situation characterised by uncertainty and vulnerability*” (p.51). Finally, Peng et al. (2022) describe
23 natural driving as “*a driving style that is closest to your own*” (p.6), while Hajiseyedjavadi et al. (2022) use a
24 combined description of feeling “*safe/natural/comfortable*” to evaluate an overall pleasant experience with
25 automated driving. Overall, similar (positive) affects are used to describe these concepts and also comfort,
26 when discussing the effect of automated driving style on user experience. Hartwich et al. (2018) suggest that
27 feeling safe, relaxed and certain can all lead to a positive experience of automated driving, which will
28 ultimately enhance acceptance of these new forms of mobility (see also acceptance models reported by
29 Madigan et al., 2016; Motamedi et al., 2020; Nordhoff, Stapel, et al., 2021). Therefore, the original conceptual
30 framework included these mostly investigated concepts (i.e., perceived safety, trust, and naturalness), in order
31 to clarify the relationship between these, and establish if and how each contributes to comfort, based on
32 different automated driving styles.

33 1.3. The current study

34 Based on the above literature review, the aim of this study was to address the current gaps in knowledge
35 about definitions and measurements for comfort, by conducting an online expert workshop with a range of
36 experts who had experience with different types of AVs. Our objective was to improve the current
37 understanding of what contributes to user comfort/discomfort in automated driving, with a particular focus
38 on the role of driving styles. This knowledge can ease cross-study comparisons for future empirical studies in
39 this area, while helping AV designers have a better understanding of user comfort, to create more comfortable,
40 pleasant, and acceptable vehicles for a wide-ranging user group.

41 In particular, the main objectives of the present study were to:

- 1) Conceptualise comfort/discomfort in automated driving, by identifying the descriptions and terms used for both comfort and discomfort, as well as highlighting any differences and similarities between the terms used for these two states.
- 2) Elaborate our original conceptual framework of AV driving comfort, in terms of clarifying the relationship between a number of commonly used concepts, and comfort, especially considering AV driving style.

We expected a partial overlap between comfort when being driven by currently available human-driven vehicles (e.g., taxis, buses, and trains), and being driven by AV-controlled computer systems, because the human is a passenger not controlling the vehicle in both scenarios. To assess this partial overlap, we discussed comfort in, and between, these transport modes.

2. Method

In this section, we provide a brief introduction of the method used in the workshop. More details can be found in Appendix A, including the rationale for the method used, how the discussion was facilitated, and the method used for data analysis.

2.1. Experts and the group workshop

Due to the Covid-19 pandemic, we conducted an online workshop with nine internationally-recognised experts in this field. These attendees, and two more experts (MH and RH), who are collaborators in the first author's PhD work, were invited to comment on the manuscript, and are all co-authors of the manuscript, due to their verbal and written contributions. The group workshop loosely followed a focus group format, where experts discussed a range of proposed topics via the online meeting platform Microsoft Teams (<https://www.microsoft.com/en-gb/microsoft-teams/online-meetings>). In order to stimulate discussions, experts were encouraged to brainstorm a range of proposed topics, as well as write notes, grouping similar items, using the online collaborative whiteboard tool: Miro (<https://miro.com>). These notes were visible on the whiteboard, allowing the facilitators and experts to further discuss the evolving themes. The whole workshop was recorded via Microsoft Teams, and lasted two hours.

2.2. Procedure

Figure 2 shows the procedure used in the workshop. The workshop discussions were divided into four separate sessions, in which different, but connected, topics were covered:

Session 1: This session focused on a discussion of the terms used to describe comfortable and uncomfortable experiences when driven by currently available vehicles as a passenger, such as a taxi, bus, or train. This was done for two reasons: first, it helped experts familiarise themselves with the topic by talking about currently available transport modes. Second, we wished to understand if there were any similarities and differences in the perceived comfort/discomfort of "being driven" by a taxi/bus/train, compared to that of a Level 4 AV, because, in both cases, the user does not control the vehicle, and is also able to engage in NDRAs (Hecht et al., 2019).

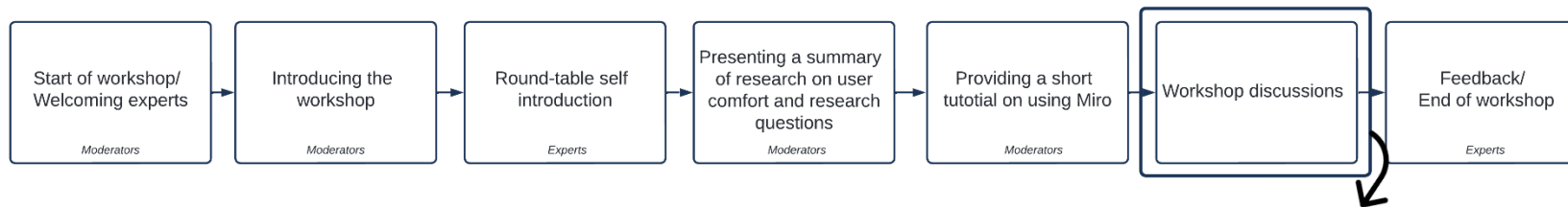
Session 2: This session involved a discussion of any differences between being driven by a taxi/bus/train versus an AV, in terms of the experienced comfort/discomfort. This session was expected to connect with, and facilitate, the discussions in session 3.

1 **Session 3:** This session involved a discussion of terms used to describe comfortable and uncomfortable
2 experiences of being driven by AVs. Discussions in this session were based on the previous two
3 sessions. After reflecting on the unique characteristics of AVs in session 2, it was expected that experts
4 would add or remove terms about comfortable/uncomfortable experiences of being driven by AVs,
5 based on existing terms for a taxi/bus/train from session 1.

6 **Session 4:** This session focused on discussing the original conceptual framework for user comfort in
7 automated driving (Figure 1), with an emphasis on how comfort is affected by different driving styles.
8 After discussions in the preceding sessions, experts were expected to give constructive feedback on
9 the original framework, in terms of complementing and revising relevant aspects and concepts, rather
10 than clarifying concrete terms. Here, we explicitly instructed experts to take driving styles into
11 consideration, compared to the preceding sessions, in which the term “being driven” was used to
12 implicitly remind experts of the driving scenario. However, we still encouraged discussions of broad
13 but relevant concepts, in addition to driving styles.

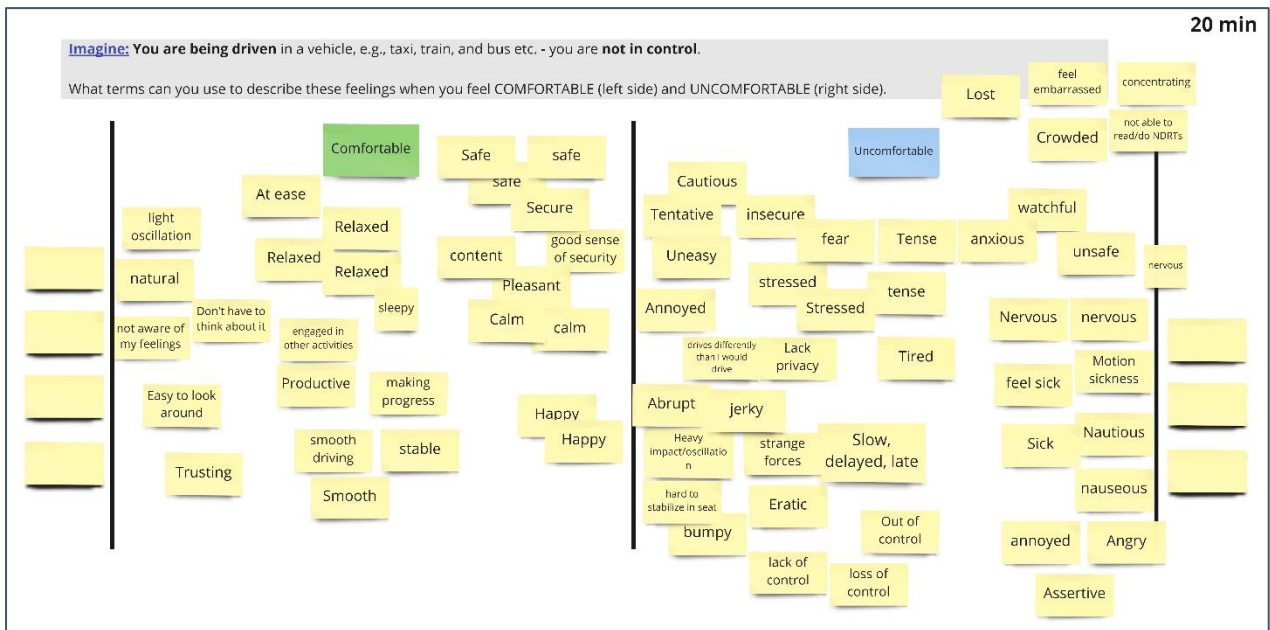
14 2.3. Data analysis

15 Figure 4 shows the approaches that we used to analyse the data. Written notes were categorised, and verbal
16 discussions were summarised. Experts were given an opportunity to suggest amendments to the
17 categorisation of notes, the summarisation of their discussions, and the refined framework.

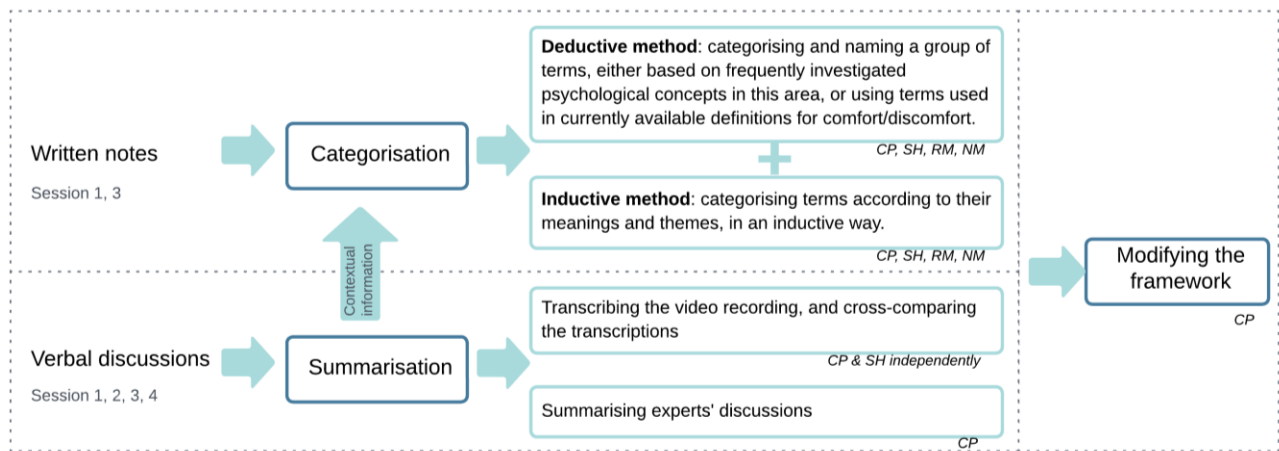


	Session 1 (20 min)	Session 2 (15 min)	Session 3 (15 min)	Session 4 (30 min)
Instructions	Imagine: You are being driven in a vehicle, e.g., taxi, train, and bus etc. - you are not in control. What terms can you use to describe these feelings when you feel comfortable and uncomfortable?	Do you think there are any differences between being not in control in a Level 4 automated vehicle, compared to being not in control in a taxi/bus/train?	Imagine: You are being driven in a Level 4 automated vehicle, not in control, don't need to monitor, you can engage in NDRTs. Is there anything different in the L4 automation, compared to the situation before, about your comfortable or uncomfortable feelings? If yes, please add / delete (based on output from session 1)	We found the following concepts are relevant to driving comfort. A) Are any relevant concepts missing? - If yes, please add. B) Do you think some of your feelings can be categorised into these concepts? If yes, please move them below the concept. If you think a feeling belongs to another concept, please copy & paste and move it. What are the relationships among them? How are they related to comfort / discomfort?
Steps	<p>Writing on Miro</p> <p>↓</p> <p>Grouping notes regarding similar meanings</p> <p>↓</p> <p>Discussing based on the written output</p>	<p>Writing on Miro</p> <p>↓</p> <p>Discussing based on the written output</p> <p>↓</p> <p>Discussing new thoughts</p>	<p>Writing on Miro</p> <p>↓</p> <p>Grouping notes regarding similar meanings</p> <p>↓</p> <p>Discussing based on the written output</p>	<p>Writing on Miro</p> <p>↓</p> <p>Discussing based on the written output</p> <p>↓</p> <p>Moving notes from S3 to relevant concepts</p>

1
2 *Figure 2.* Full procedure (top) and the four main sessions in the workshop. All introductions and the tutorial before the four sessions took around 15min,
3 followed by around 5min for feedback and reflection. A 10-min break was included between Session 3 and 4.



1
2 **Figure 3.** The Miro whiteboard used for workshop session 1, in which experts posted notes to describe
3 comfortable (left) and uncomfortable (right) experiences of being driven by a taxi/bus/train in the designated
4 areas. The text in the shaded area on the top is the written instructions about the discussed topic, and the
5 empty yellow sticky notes were “a pile of” notes for easy usage, prepared by the moderators in advance of
6 the workshop. The yellow sticky notes with texts were posted by experts during the writing session.



7
8 **Figure 4.** Procedures of the data analysis. Initials represent people who were responsible for different steps
9 of the analysis.

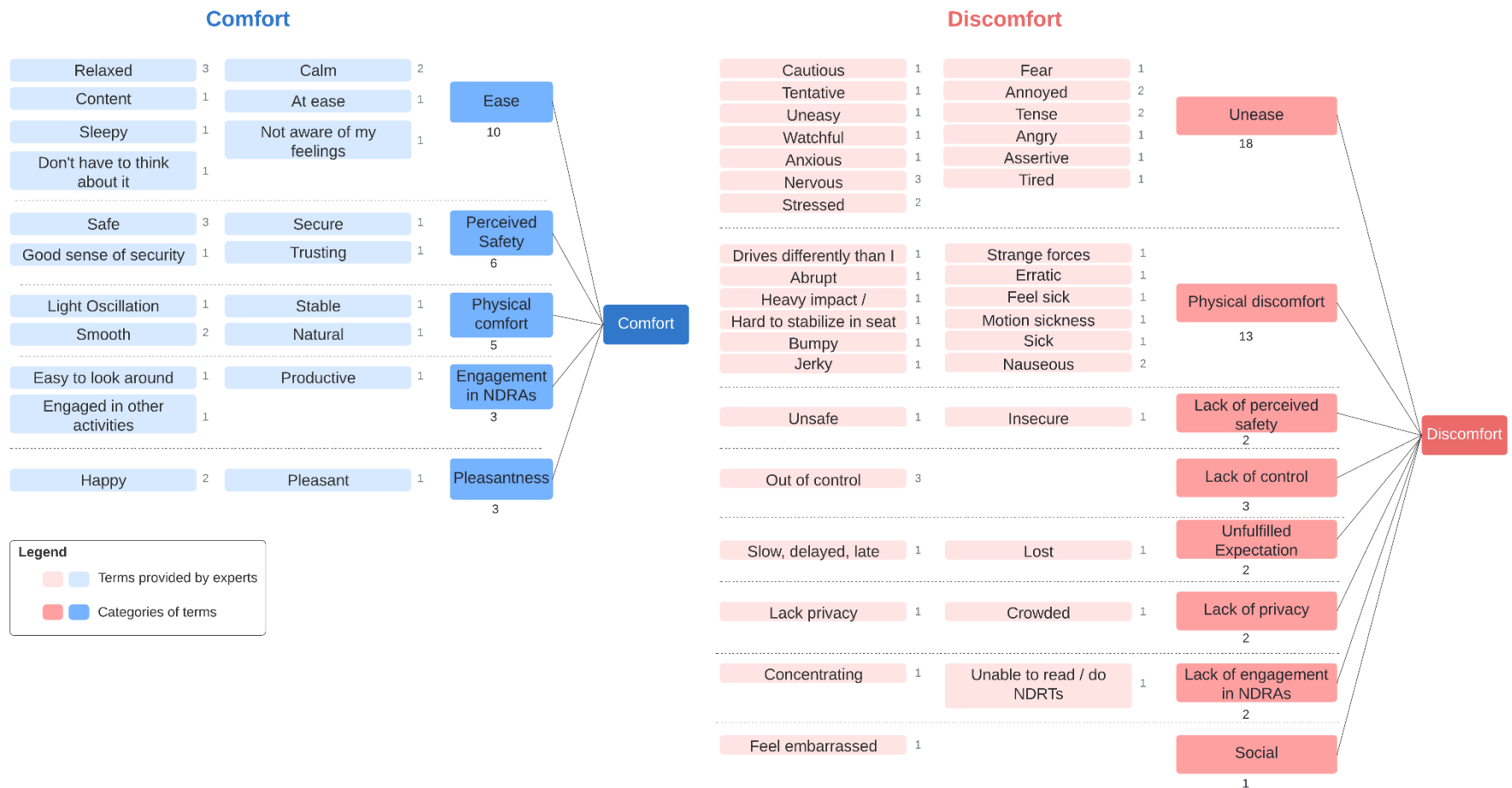
10 3. Results and Discussion

11 Results are presented in order, based on the timeline of the four workshop sessions, outlined above. We first
12 present the terms used by experts to describe comfort and discomfort when being driven by currently
13 available transport modes (e.g., taxi/bus/train), in Session 1. Then, differences between these transport
14 modes and AVs in terms of comfort/discomfort are summarised (Session 2), followed by additional notes
15 associated with the comfortable and uncomfortable aspects of being driven by AVs (Session 3). Finally, a
16 refined conceptual framework is outlined, by incorporating the input of this expert workshop into the original

1 model. In each section, we discuss and summarise the key findings, to interpret their theoretical and practical
2 implications.

3 3.1. Session 1: Comfort and discomfort of being driven by a taxi/bus/train

4 In this section, we present a categorisation of the terms used by the experts to describe comfort/discomfort
5 when driven by currently available transport modes (Figure 5). The terms were first provided and roughly
6 grouped by experts during the workshop, after which a categorisation of these terms into new groups was
7 done independently, and then as a team, by CP, SH, RM, and NM, after the workshop. We also provide a
8 summary of experts' comments on emerging patterns for these terms.



1
2 *Figure 5.* Categorisation of the terms describing comfort and discomfort when driven by a taxi/bus/train. Numbers next to each box represent the number of
3 times each term was mentioned by experts, and numbers below each category represent the number of terms in the category. Experts were instructed to
4 write as many notes as they could and avoid repetitions, but they sometimes could not avoid repetition when writing in parallel, so a larger number of a term
5 was not interpreted as more important.

1 3.1.1. Categorisations of terms provided by experts in Session 1

2 Regarding comfort, we categorised the terms used to describe a comfortable experience when being driven
3 by a taxi/bus/train into five groups (Figure 5). A single term was then used to define each category of terms
4 with similar definitions. These five categories were 1) *ease*, 2) *perceived safety*, 3) *physical comfort*, 4)
5 *engagement in NDRAs*, and 5) *pleasantness*. As mentioned in the Method section (section 2.3, and Appendix
6 A), when the content shared similarities with keywords from previously used definitions, we chose these same
7 terms or concepts, with new terms used for new, previously absent, groups of terms.

- 8 1) Terms such as calm, content, and relaxed, mostly describe a feeling of being at ease, and therefore
9 this group of terms was included in the category “*ease*”. This term was chosen because it has been
10 frequently used in previous definitions of comfort (e.g., Carsten & Martens, 2018).
- 11 2) A group of terms describing feeling safe, secure, and trust, was categorised as *perceived safety*; which
12 was selected because it is considered to contribute to comfort (Elbanhawi et al., 2015), and also used
13 previously (e.g., Hartwich et al., 2018).
- 14 3) The category, *physical comfort*, included terms describing physical vehicle movements (e.g., smooth
15 and stable), and natural driving styles; this theme was derived from “physical harmony” between the
16 user and the vehicle, used in previous studies (e.g., Slater, 1985).
- 17 4) *Engagement in NDRAs* is a category comprising terms about people’s willingness to do non-driving-
18 related activities; the reason we chose this as a theme is that engagement in NDRAs has been
19 considered as a key attractive feature of highly automated driving (Merat et al., 2012) and broadly
20 investigated in this area.
- 21 5) *Pleasantness* is another category consisting of terms describing feelings around happiness and positive
22 affect. This term was chosen because of its presence in previous studies (e.g., Summala, 2007).

23 Regarding discomfort, the terms used to describe an uncomfortable experience of being driven by a
24 taxi/bus/train were grouped into eight categories: 1) *unease*, 2) *physical discomfort*, 3) *lack of perceived safety*,
25 4) *lack of control*, 5) *unfulfilled expectation*, 6) *lack of privacy*, 7) *lack of engagement in NDRAs*, and 8) *social*
26 (Figure 5). Some terms are antonyms of the terms used for comfort, such as *unease*, *physical discomfort*, *lack*
27 *of perceived safety*, and *lack of engagement in NDRAs*, while explanations for other (new) terms are provided
28 below.

- 29 1) *Unease* contained the most terms used for discomfort, which were all about people’s negative
30 affective feelings (e.g., anxious, nervous, and annoyed).
- 31 2) *Physical discomfort* included terms describing uncomfortable vehicle movements (e.g., jerky, abrupt,
32 and erratic) as well as motion sickness.
- 33 3) *Lack of perceived safety* included two terms describing unsafe and insecure feelings.
- 34 4) The category *lack of control* comprised of terms about the user’s loss of active control over the vehicle;
35 this term was chosen because being a passenger without control over the vehicle is seen as one factor
36 resulting in discomfort and motion sickness (Rolnick & Lubow, 1991).
- 37 5) *Unfulfilled expectation* included the set of terms which describe unexpected operations (e.g., slow) or
38 consequences of an uncomfortable ride (e.g., was lost).
- 39 6) *Lack of privacy*, included two terms describing users’ privacy concerns, for example, because of the
40 presence of unknown co-passengers. The term crowded was grouped into this category as we
41 interpreted that being in a crowded vehicle reduces personal space and increases privacy concerns.
- 42 7) *Lack of engagement in NDRAs* contained terms describing the user’s inability to concentrate on NDRAs.

1 8) The category *social* only included one term describing how the social context and other people's
2 judgements affect user comfort.

3 3.1.2. Experts' discussions on emerging patterns from the written notes in Session 1

4 After writing and roughly grouping the notes, experts selected and discussed the pattern of results that were
5 of interest to them, rather than going through all of the possible terms and categories. In particular, the experts
6 highlighted the differences between comfort and discomfort, with regards to affective and physical aspects,
7 as summarised and presented below.

8 Two experts highlighted that affective feelings of comfort (e.g., calm, relaxed, pleasant) are less intense than
9 that of discomfort (e.g., anxious, stressed, tense). When feeling comfortable, people may be unaware of the
10 feeling, or unconscious of what is going on in the vehicle, whereas being uncomfortable is very "tangible and
11 extreme". Another expert added that if expectations about a comfortable experience cannot be fulfilled, all
12 aspects that cause discomfort become conscious, which may also cause them to feel insecure and
13 uncomfortable. On the other hand, this expert also added that: "*if we expect uncomfortable situations of a
14 taxi journey, but we are lucky that things turn out nicely and the taxi driver is skilled at everything, we are very
15 much aware of the comfortable aspects*".

16 With respect to the physical aspects of comfort/discomfort, four experts pointed out that terms related to the
17 vehicle's movement were used more often when describing discomfort than comfort, and one of them
18 emphasised the role of vibrations. This expert explained that in the vehicle and control domain, the concept
19 of ride comfort is not about comfort itself, but refers to the lack of oscillations or vibrations in the vertical
20 direction of the vehicle. For example, high-frequency vibrations and noise are both uncomfortable for vehicle
21 users. This expert argued that this is because "*vibrations that are far away from the natural frequency of the
22 humans make the user sick*". Therefore, it seems that the physical vehicle movement manifests more
23 uncomfortable than comfortable feelings.

24 To summarise, both categorisation of the terms and experts' discussions about the patterns arising from these
25 terms indicate that when being driven by currently available transport modes, the feelings and terms
26 associated with comfort are different from the lack of discomfort. For example, more (and more concrete)
27 terms were used to describe discomfort than comfort, whereas comfort demands more (and more positive)
28 psychological and emotional feelings than discomfort. This difference in the number of descriptions for
29 comfort/discomfort might also be explained by the fact that humans have a wider vocabulary for expressing
30 negative, than positive, emotions (Schrauf & Sanchez, 2004). This is also because negative experiences are
31 associated with more elaborate and detailed cognitive interpretations compared with positive experiences
32 (the psychological theory of *affect-as-information*; Schwarz, 1990). In terms of the intensity of these two states,
33 the *Circumplex Model of Affect* (Russell, 1980) is used to represent affective concepts in two dimensions:
34 *valence* (ranging from displeasure to pleasure) and *arousal* (ranging from sleep to arousal). Our results suggest
35 that the affect-related terms for comfort are lower in arousal, but higher in valence, compared to discomfort.
36 This implies that solely eliminating discomfort (e.g., lowering the arousal) does not necessarily lead to comfort,
37 because comfort is also associated with pleasantness and enjoyment. This finding also has implications for
38 measuring these two states, because physiological responses (e.g., heart rate, electrodermal activity) are more
39 suitable for identifying the high arousal associated with discomfort (Beggiato et al., 2019; Radhakrishnan et
40 al., 2020), and less likely to detect the lower levels of arousal linked to comfort.

1 3.2. Sessions 2 and 3: Differences between being driven by a taxi/bus/train versus 2 an AV

3 In Session 2, when considering the differences in comfort/discomfort of being driven by currently available
4 transport modes compared to an AV, experts focused on brainstorming and discussing the different terms,
5 rather than writing notes. Four main topics were highlighted as being relevant to AVs, compared to current
6 transport modes. These were: i) the duration of using AVs, ii) user expectations about AV driving styles, iii)
7 privacy concerns, and iv) the presence of a human operator.

8 In terms of the duration of using AVs, an expert suggested that, at the early stages of AV deployment, there
9 will either be no boundaries within what users believe the AV should and should not do, or no understanding
10 of how the AV should behave, compared to that of a human taxi driver. Two experts also pointed out that, in
11 the initial stages, the experience of comfort with AVs will be influenced by its novelty. Also, who will take
12 responsibility of controlling the AVs is unclear for users, compared with a taxi, where the driver is responsible.
13 However, it was also argued that these experiences and beliefs will likely change with the passage of time, and
14 repeated use of AVs.

15 Regarding driving styles, four individuals agreed that AV driving styles should meet *users' expectations*, in
16 order to ensure user comfort, which is thought to be different for expectations about how taxis/buses/trains
17 should be driven. Although how users' expectations will develop over time remains unclear, experts suggested
18 a number of factors, with regards to the AV's driving style, which might help with meeting expectations. First,
19 an expert advised that at the very least, the automated drive should be smooth. Furthermore, the use of
20 "human-like" and personalised driving styles (i.e., similar to the users' own driving behaviours) was also
21 suggested, to meet users' anticipated trajectories and behaviour for automated driving. However, what should
22 be personalised, and how, remained unclear. One expert mentioned a study on Level 2 vehicles which found
23 that participants preferred not to change lanes all the time. However, there was a debate on whether or not
24 users of personalised Level 4 AVs would like the AV to drive like a "good citizen" (e.g., staying in one lane or
25 not speeding). For example, an individual commented that: "*I would be unhappy with a car that is too cautious.*
26 *I do not want to totally waste time on my trip. But maybe it would change if I feel less stress about getting to*
27 *the destination*". There is a question here, therefore, regarding safety versus efficiency offered by these new
28 forms of transport, and further work is required to understand what driving styles users want from a Level 4
29 AV.

30 An expert highlighted a couple of examples regarding the privacy issues that influence user comfort in AVs,
31 compared to taxis/buses/trains. This included issues around invasion of privacy, for example because their
32 conversation may be heard by a remote operator, or unfamiliar co-passengers, which may or may not be
33 different to being heard by a taxi driver. There was also concern about the use of user information by data
34 owners, which can infringe user privacy, for example regarding route choice and location, and causing
35 discomfort.

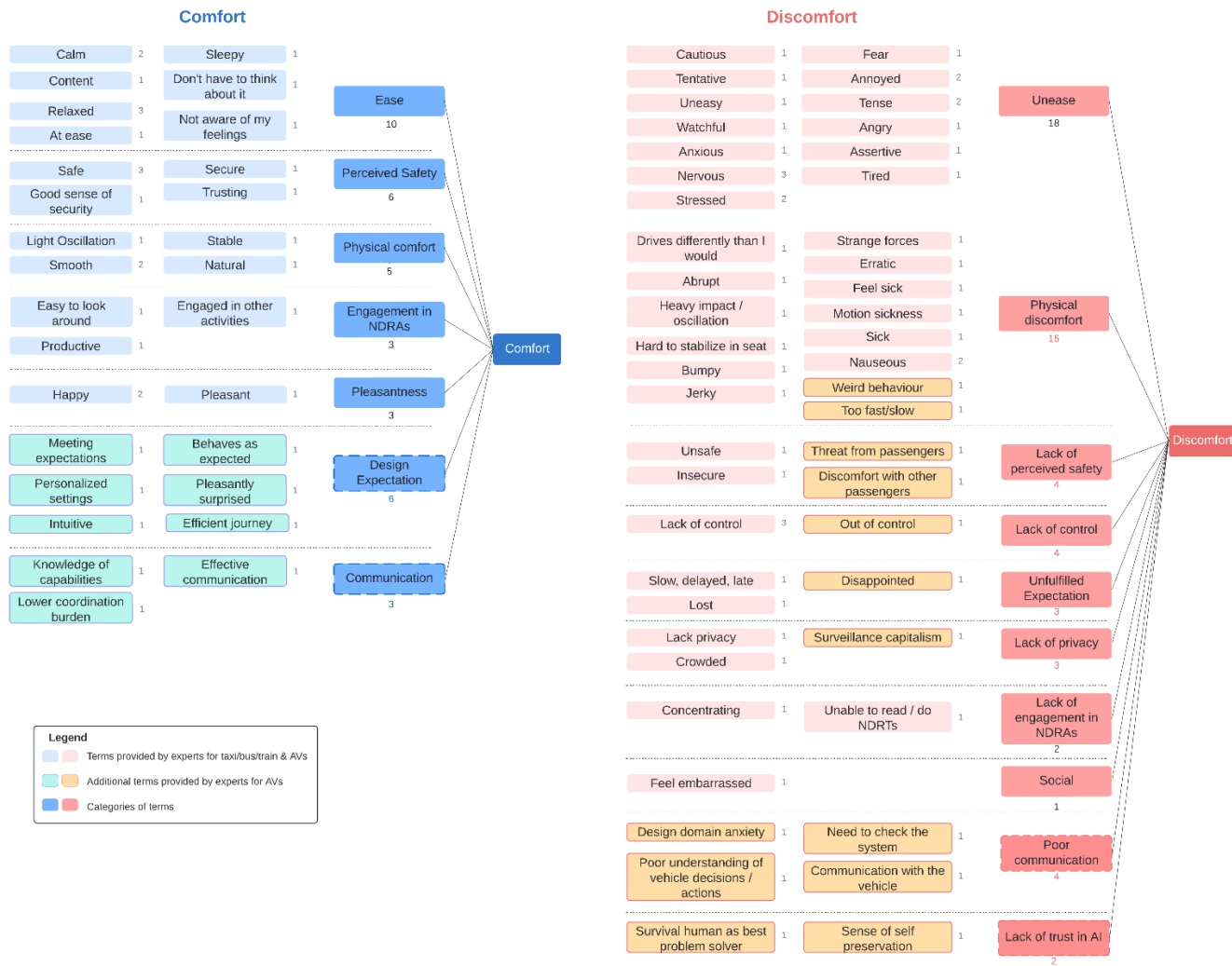
36 Three experts discussed how the presence of a driver in AVs might also affect user comfort. One expert
37 suggested that sharing a taxi with an unfamiliar man might be uncomfortable for a woman; but that the
38 presence of a driver might mitigate such discomfort. In comparison, when driven by an AV, where no driver is
39 present, users might be uncomfortable with other unknown passengers, rather than being uncomfortable with
40 the AV. On the other hand, it was noted that humans tend to trust other human beings more, even though
41 algorithms may be much better for controlling the vehicle. This expert speculated that the sense of "self-

1 preservation” of humans might play a role in this human-algorithm preference; in that human drivers do not
2 typically intend to cause a crash, while this is perhaps more of a worry for the algorithms that control AVs. This
3 led to the conclusion that such concerns cannot be solely mitigated by vehicle behaviour, its control or motion,
4 and is more related to features such as the role of AVs as social agents.

5 To summarise, the experts used knowledge about currently available transport modes to suggest how
6 different aspects of driving style for future AVs can be used to improve user comfort. This information can be
7 used by system designers and manufacturers of future AVs to create more comfortable driving, increasing the
8 acceptance and uptake of these vehicles. However, there is currently little understanding of whether/how AV
9 driving style should be personalised (e.g., Butakov & Ioannou, 2015), or human-like (e.g., Basu et al., 2017;
10 Wei et al., 2019). An understanding of the value of these changes for different user groups is also limited (e.g.,
11 Feierle et al., 2020). Current technological and infrastructure-based limitations mean that AV capabilities are
12 not matching user expectations, which can, in turn, lead to a more uncomfortable/unsatisfactory ride. This
13 corresponds with work conducted by Nordhoff et al. (2019), who found that users’ impressions of automated
14 shuttles were idealised and unrealistic, resulting in disappointment, after experiencing a ride in a very slowly-
15 operated automated shuttle prototype. Therefore, until the technology that enables these vehicles is
16 improved, educating users on AV capabilities will play a key role in calibrating user expectations about AV
17 driving styles.

18 Finally, experts’ concerns about privacy are in agreement with other studies which found that users were
19 worried and uncomfortable about access to their privacy, such as tracking their location and destination, or
20 image capturing, and issues around how this data is protected from abuse by others (Bloom et al., 2017;
21 Nordhoff et al., 2019). The importance of considering other factors not related to driving style in this context
22 can be supported by the theory of constructed emotion, which suggests that the way that feelings and
23 emotions are constructed is highly context-bound (Barrett, 2017). In our case, whether or not a particular
24 driving style is experienced as comfortable may depend on, for example, whether or not the user is concerned
25 about their privacy. However, this issue is unlikely to be solved via driving styles. Future studies should
26 investigate ways to cope with these concerns, via, for example, personalised data-sharing settings.

27 As highlighted above, some additional terms were identified in Session 3, that were specific to feeling
28 comfortable/uncomfortable when driven by AVs. Similar to the results of Session 1, we present the
29 categorisations of these terms, combining the previously suggested terms with those which were newly added
30 (Figure 6). We also provide a summary of the experts’ discussions about the observed patterns and the
31 commonalities between these additional terms.



1
2 *Figure 6.* Categorisations of terms describing comfort and discomfort of being driven by AVs. Numbers next to each box represent the number of times each
3 term was mentioned by experts, and numbers below each category represent the number of terms in the category.

1 3.2.1. Categorisations of additional terms provided by experts in Session 3

2 In addition to the five categories of user comfort already defined above (i.e., *ease*, *perceived safety*, *physical*
3 *comfort*, *engagement in NDRAs*, and *pleasantness*; see also section 3.1.1), we identified two more categories
4 for the terms describing a comfortable experience of being driven by an AV: *Design expectation*, and
5 *communication* (Figure 6).

- 6 1) The category *design expectation* includes terms describing users' high expectations about AVs, and
7 these expectations relate to design aspects of AVs, such as personalisation, being intuitive, and being
8 "pleasantly surprised".
- 9 2) *Communication* was used to include terms describing effective communication between the user and
10 the AV, such as sufficient communication of AV capabilities with users.

11 With regards to terms describing an uncomfortable AV ride, several new terms were used that could be added
12 to the existing categories, namely, *physical discomfort*, *lack of perceived safety*, *lack of control*, *unfulfilled*
13 *expectation*, and *lack of privacy* (see also Figure 6). For example, we added the term "*threat from passengers*"
14 to the category "*lack of perceived safety*", because the user may feel unsafe when sharing an AV with strangers,
15 in the absence of a driver (see also section 3.1.1). In addition to these categories, we grouped a number of
16 newly added terms into two more categories: *Poor communication*, and *lack of trust in AI*.

- 17 1) As the opposite to *communication* for comfort, *poor communication* summarised terms characterising
18 users' poor understanding of the AV capabilities and manoeuvres, and linked to discomfort.
- 19 2) *Lack of trust in AI* included two terms describing the reduced trust of users in the automated system,
20 compared to a human driver

21 3.2.2. Experts' discussions on emerging patterns from terms for comfort/discomfort of being 22 driven by AVs in Session 3

23 In Session 3, two experts commented that the *communication* with the AV is an important factor for user
24 comfort, with the lack of communication leading to discomfort. One expert suggested that communication
25 will become more important for users, especially when something unexpected happens, because this makes
26 the user uncomfortable, especially if there is no explanation from the AV, whereas explicit communication
27 might be unnecessary if the vehicle acts as expected. Another expert added that *interaction* will be needed to
28 improve human-AV communication, such as providing information about what the system is doing, its planned
29 manoeuvres, or a message at the end of the Operational Design Domain (ODD). Moreover, the information
30 provided by the AV system should not be disturbing, and, as an expert suggested, "*I would like to have a*
31 *choice to select how much information I want to get*". Another type of interaction mentioned was the user's
32 ability to change the settings of the system in certain circumstances. For example: "*for lane changing, if I am*
33 *not in a hurry, it is totally ok that the AV drives defensively and stays in the same lane, but if I have to reach*
34 *the destination in a certain time, I may change it to drive more aggressively*".

35 To summarise, when automated driving was considered (in both Session 2 and 3), further new terms and
36 categories were added, but the number of terms and themes for discomfort was again higher than those
37 provided for comfort. This pattern is in line with findings for currently available vehicles (section 3.1), and
38 those of other studies, on ergonomics and product design (Helander & Zhang, 1997; Vink & Hallbeck, 2012).
39 Thus, we suggest that the relationship between comfort and discomfort is not limited within a particular
40 transport mode or a specific product, but applies to a broader area. Moreover, the discussions from Session 2

1 and 3 suggest that the factors which affect user comfort in currently available transport modes are clearly
2 different to what is expected from automated driving; suggesting that actual experience with future transport
3 modes is needed to further enhance our understanding of how their comfort can be improved, especially with
4 respect to driving style.

5 3.3. Session 4: The refined conceptual framework of user comfort in automated 6 driving

7 In this section, we present the refined conceptual framework (Figure 7), by integrating the outputs from this
8 expert workshop, also following feedback from our experts (Session 4). Experts re-emphasised some concepts
9 that were discussed, but also suggested changes to the original framework. Using this conceptual framework,
10 we explain how driving styles, as well as non-driving-related factors, influence user comfort of AVs. As
11 suggested by the experts, we divided user comfort in automated driving into two layers: The physical layer
12 and the psychological layer, both of which can influence each other in an iterative manner.

13 Physical factors

14 Regarding the physical layer, apart from driving styles, one expert emphasised that traditional aspects of the
15 physical environment, such as stabilising the head and body, avoiding high G-force, reducing high levels of
16 vibration/temperature/noise, and considerations about seating comfort, should be thought out for AVs, just
17 as they are for traditional vehicles (see also section 3.1). This expert also suggested that although some of
18 these aspects may not actually hurt the user, they will cause strong physical discomfort, and may also affect
19 users' trust and perceived safety. Therefore, we highlighted *physical comfort* as a component of the model,
20 which is directly influenced by AV driving styles.

21 Psychological factors

22 Regarding the psychological layer, *psychological comfort* was highlighted in the model, because becoming
23 psychologically comfortable is linked to several positive affective feelings (e.g., happy, content, at ease) (see
24 also section 3.1).

25 A number of factors were considered to contribute to this state of feeling comfortable. In addition to *trust*,
26 *perceived safety*, and *naturalness*, proposed in the original model, the concepts *privacy*, *engagement in NDRAs*,
27 *situation awareness*, and *expectation*, were added to the psychological layer. Here, we provide explanations
28 for why and how these concepts fit the framework.

- 29 • Regarding *privacy*, although it may be considered somewhat irrelevant to driving styles, it is still an
30 important factor that will ensure user comfort of AVs (as outlined in section 3.2).
- 31 • In terms of *engagement in NDRAs*, this can also be influenced by driving styles, when, for example,
32 hard braking patterns impede users' ability to engage in reading, but a more comfortable ride
33 encourages engagement in NDRAs, which can, in turn, lead to a content passenger, reducing boredom
34 and increasing enjoyment/productivity. Conversely, experts commented that looking away from the
35 road and engaging in NDRAs may make some users feel sick.
- 36 • *Situation awareness* was added to the framework and linked to comfort, as suggested by experts in
37 Session 4. This can be influenced by the AV's driving style (e.g., by providing the user with particular
38 driving kinematic cues to keep them aware of the surrounding environment). Conversely, by allowing

1 users to engage in other tasks, and not paying attention to the driving task, the AV can actually reduce
2 situation awareness.

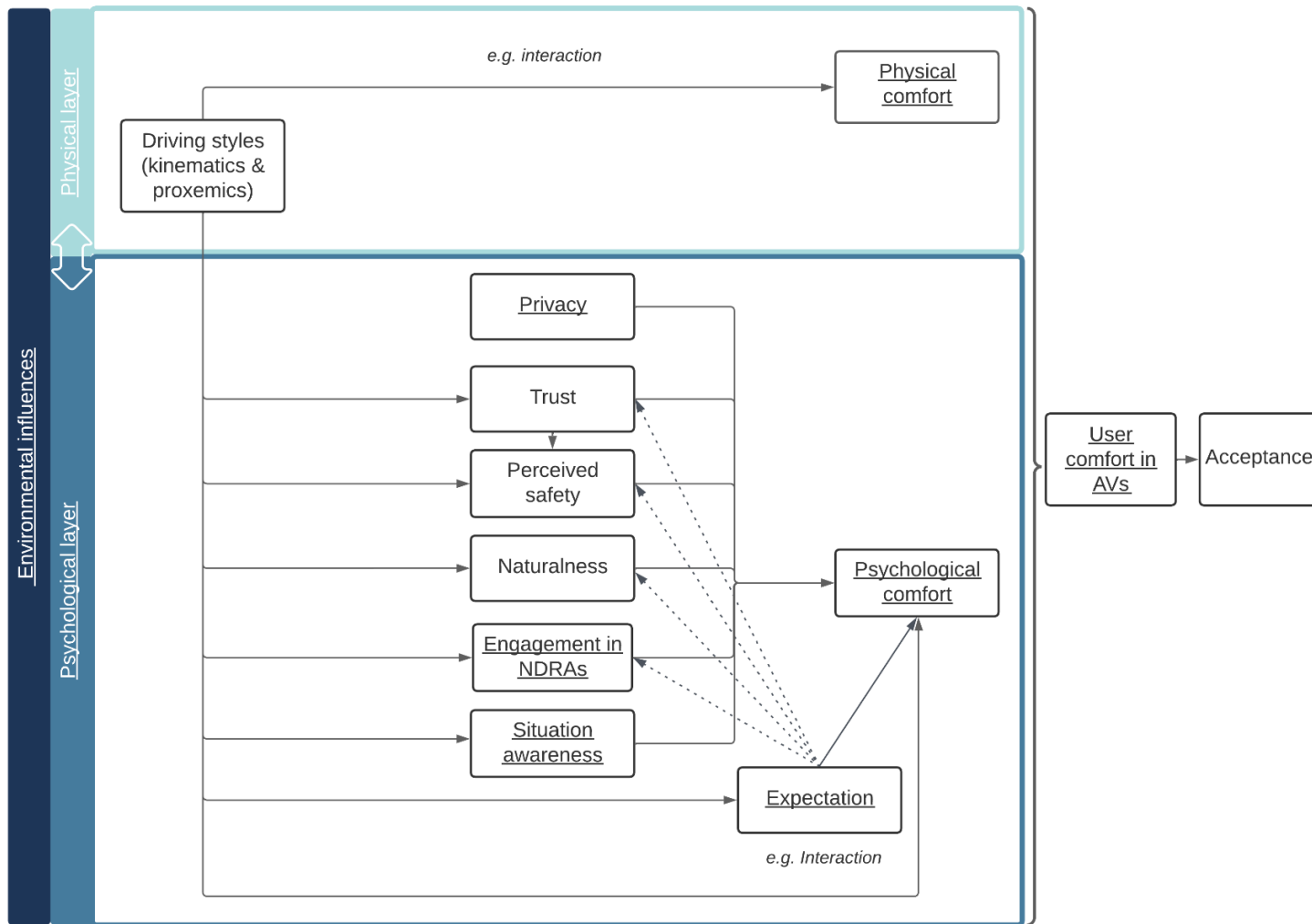
- 3 • With regards to the addition of *expectation* to the model, users are thought to hold a large number of
4 high expectations about AV capabilities and driving styles (e.g., linked to personalisation), and whether
5 or not these expectations can be realised and fulfilled leads to either pleasantness, or disappointment
6 (see also section 3.2). Moreover, we added links between *expectation* and *trust*, *perceived safety*, as
7 well as *naturalness*, because, for example, by having sufficient communication and interactions with
8 AVs to calibrate users' expectations, their trust and perceived safety of the system might be enhanced.
9 In terms of its link to naturalness, if the AV could drive as expected, users may feel the driving styles
10 are intuitive and natural. One expert also pointed out that *expectation* is heavily featured in the
11 Unified Theory of Acceptance and Use of Technology Model (UTAUT) and the Technology Acceptance
12 Model (TAM), which also supports the importance of taking this concept into consideration.

13 Factors across the two layers

14 Experts suggested that the influence of *environmental* and traffic conditions on the comfort of AVs is broad
15 and applies to both physical and psychological layers in the framework. This is because the behaviour of the
16 automated vehicle is not independent of the surrounding infrastructural and road geometry, and is likely to
17 be influenced by the behaviour of other road users sharing the same space.

18 Across the two layers, physical *driving styles* can influence *psychological comfort* directly, not solely because
19 of an enjoyable driving style, but also because being driven by an AV is in a social context, as suggested by
20 experts (see also section 3.1). Other road users will look at the AV, and the way they think about the user can
21 influence the user's wellbeing. For example, an expert explained that the AV user would be embarrassed to
22 be stuck waiting for road obstacles due to the AV's limitations, if all other manually driven cars can pass the
23 obstacle. Another example included the use of ACC: "*I do not use my ACC very often because I have to override*
24 *it - speed up or change lane. When it strictly follows the speed limit, everyone around me is like going faster*
25 *than me.*"

26 *Interaction* is embedded in the framework on both layers, rather than being an independent concept. As re-
27 emphasised by an expert, users will demand different types of interaction to communicate with the AVs. For
28 example, on the physical level, users may be willing to set up a slower AV driving style for better physical
29 comfort (e.g., avoiding motion sickness), and from a psychological perspective, users might expect to have
30 various information about the system to feel secure.



1
 2 *Figure 7.* The refined conceptual framework of user comfort in automated driving. Newly added concepts are underlined.
 3 Dashed lines are used to ensure relationships are visible when lines intersect with each other.

1 4. General Discussion

2 In the present study, we used an online workshop to gather experts' insights on user comfort/discomfort when
3 driven by automated vehicles (AVs). Based on the output from the workshop, we refined a conceptual
4 framework of user comfort in automated driving, focusing on the effect of driving styles, but also taking into
5 account the effect of factors, not immediately related to driving style. To help discussions, we compared the
6 concepts used for defining comfort and discomfort in current modes of transport where the user is "driven",
7 with that used for AVs.

8 Our results identified seven aspects of user comfort (Defined as: *ease, perceived safety, physical comfort,*
9 *engagement in NDRAs, pleasantness, design expectation, and communication*) and ten related to discomfort
10 in automated driving (Defined as: *unease, physical discomfort, lack of perceived safety, lack of control,*
11 *unfulfilled expectation, lack of privacy, lack of engagement in NDRAs, social, poor communication, and lack of*
12 *trust in AI*). For both of these states, more terms were used for AVs, when compared to current modes of
13 transport. When it comes to definitions and measurements of comfort, we recommend that future studies
14 consider a wider range of concepts when assessing comfort and discomfort to help support the research,
15 design and evaluation of these states in AVs. This calls also for new measures, including suitable questionnaires
16 that can be validated in terms of their ability to discriminate a wide range of aspects of comfort and discomfort.

17 Apart from the content of the workshop, we found that the format of the online setup worked well in this
18 study. By guiding experts to brainstorm, write, and discuss a series of devised topics, we gained clear and novel
19 insights on user comfort/discomfort, such as how these can be described, and the relationship between these
20 two states, to support future studies in this context.

21 In terms of follow-on work, we suggest a number of possibilities. First, the conceptual framework was
22 developed based on the current literature, and discussions between a group of selected experts, but this needs
23 further examination and validation, based on empirical studies. Second, our results illustrate that comfort is
24 not the opposite of discomfort; since many more terms were used to define the latter. Therefore, further
25 investigations will help identify the best methods for measuring user comfort in automated driving, focusing
26 on how to quantify the relationship between the two states and the underlying aspects. Finally, it will be
27 valuable to consider the opinions of other, non-experts, for example, members of the general population, and
28 users with mobility challenges (e.g., the elderly and physically impaired people) who are expected to benefit
29 most from such AVs (Milakis et al., 2017; Reimer, 2014). Comparing these findings with our results from
30 experts can provide a more comprehensive understanding of user comfort.

31 In terms of study limitations, the conceptual framework is currently limited by how different factors influence
32 comfort at different timeframes. For example, the impact of driving styles on the ability to engage in NDRAs
33 can be immediate, whereas understanding the influence of trust on comfort may need a longer timeframe,
34 following a period of user interaction and experience with the AV (Hoff & Bashir, 2015). Therefore, further
35 work is required on how these factors influence user comfort over time, with repeated use of AVs. Finally, to
36 encourage discussions in this workshop, we did not limit debate on how the *type* of automated vehicle might
37 affect comfort. We therefore found that experts mentioned both privately-owned, and shared automated
38 vehicles during the workshop. However, it can be argued that due to some fundamental differences between
39 these two categories of AV, such as the presence of co-passengers or an on-board safety driver, and the pre-
40 planned route of AVs (Wang et al., 2020), future work should consider how comfort might differ between
41 these two AV categories.

1 To conclude, using an expert group workshop, this study discovered a range of aspects of user comfort and
2 discomfort in automated driving. We hope our findings improve the understanding, definitions, and
3 measurements of user comfort in automated driving, and help system designers and manufacturers to design
4 and develop more comfortable, pleasant, and acceptable automated vehicles.

5

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15

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1 Appendix A

2 Method

3 Experts

4 Due to the COVID-19 pandemic, and related travel restrictions, we conducted an online workshop with nine
5 internationally recognised experts in this field, chosen due to their long-term research experience with AVs,
6 and balanced between industry and academia, as well as background expertise (engineering, psychology,
7 human factors, and industrial design). These attendees, and two more experts (Prof Marjan Hagenzieker and
8 Prof Riender Happee), who were invited to comment on the manuscript, are all co-authors of the manuscript,
9 due to their verbal and written contributions to the work. We were keen to include experts with some hands-
10 on experience with higher-level AVs, because these vehicles are currently unavailable on the market (Madigan
11 et al., 2017), yet research shows that actual experience with new technology is effective for highlighting their
12 limitations and capabilities (e.g., Hancock et al., 2020; Kyriakidis et al., 2019; Tabone et al., 2021). Moreover,
13 because comfort/discomfort is the actual experience that results from interaction with AVs, we considered
14 experts' direct experience with AVs as crucial and valuable. Experts were invited via emails, in which the date,
15 estimated duration, the main topic of the workshop, and the expected output (i.e., an academic paper with
16 attendees as co-authors) was briefly stated. Eleven out of thirteen experts accepted the invitation, and nine
17 of them attended the workshop.

18 Techniques used for the workshop

19 A group workshop, loosely following a focus group format was considered more useful than individual
20 interviews for this research. Focus groups are considered useful for investigating complex topics, allowing in-
21 depth discussions between the participants, and gathering diverse information from a small group of people
22 (Caretta & Vacchelli, 2015; Morgan, 1998; Ørngreen & Levinsen, 2017; Stewart & Shamdasani, 2014). By
23 fostering discussions and interactions between the experts, a wide range of aspects related to this topic could
24 be explored and uncovered, and it was favoured over individual interviews which only collect opinions from
25 individuals, without interactions between interviewees, and thus produce less comprehensive information
26 than group work (Coenen et al., 2012).

27 Apart from the group discussion via the online meeting platform Microsoft Teams
28 (<https://www.microsoft.com/en-gb/microsoft-teams/online-meetings>), in order to stimulate discussions,
29 experts were encouraged to brainstorm a range of proposed topics, as well as write notes and group similar
30 notes, by using the online collaborative whiteboard tool; Miro (<https://miro.com>) (see examples of
31 approaches of facilitating group discussion: Hagger et al., 2016; Iliffe et al., 2005). This combination of
32 brainstorming and writing is sometimes called “brain-writing” (VanGundy, 1984). Writing notes in a shared
33 workspace helps both the individual and the group to brainstorm ideas, while also providing an overview of
34 all notes, with existing notes providing inspiration for new ideas (Aiken et al., 1996; Lockton et al., 2016;
35 Michinov & Jeanson, 2021; Wilson, 2006). Grouping notes with similar themes together can highlight
36 similarities and differences between individual notes, similar to a card-sorting task (Bussolon et al., 2006).
37 These notes would then be visible on the whiteboard, allowing the facilitator and experts to further discuss
38 the evolving themes.

39 Procedure

1 Before the main workshop, we conducted an online pilot session with six participants, who were all PhD
2 candidates from the Human Factors and Safety research group at the Institute for Transport Studies, University
3 of Leeds. The backgrounds of these pilot participants included psychology (N=1), design (N=2), control
4 engineering (N=2), and modelling (N=1). The aim of the pilot session was to test the length and format of the
5 main workshop and gather participants' views about the format and nature of our questions (see Appendix B).
6 Ambiguous questions and instructions were modified following this pilot session, and we also simplified the
7 procedure, and adjusted the time estimation for each session.

8 For the main workshop (which took place on 27th July, 2021), after welcoming all experts, the moderators
9 provided a short introduction of the workshop, including its main aim, the topic to be discussed, an estimation
10 of the likely duration of the event, and re-emphasised the anticipated academic paper as the output of the
11 workshop. This was followed by a round-table session in which all experts introduced themselves, their
12 backgrounds, and their expertise. The moderators then presented a brief summary of the state-of-the-art
13 research on user comfort in automated driving, including an overview of the diverse descriptions and
14 measurements used for comfort, and provided the list of research questions that were to be considered for
15 the workshop discussions. A short tutorial on the use of the Miro whiteboard was provided. The workshop
16 was divided into four separate sessions, in which different, but connected, topics were covered:

17 **Session 1:** This session focused on a discussion of the terms used to describe comfortable and
18 uncomfortable experiences when driven by currently available vehicles as a passenger, such as a taxi,
19 bus or train. This was done for two reasons: first, it helped experts familiarise themselves with the
20 topic by talking about currently available transport modes. Second, we wished to understand if there
21 were any differences in the perceived comfort/discomfort of "being driven" by a taxi/bus/train,
22 compared to that of a Level 4 AV, because, in both cases, the user does not control the vehicle, and is
23 also able to engage in NDRAs (Hecht et al., 2019).

24 **Session 2:** This session involved a discussion of any differences between being driven by a
25 taxi/bus/train versus an AV, in terms of the experienced comfort/discomfort. This session was
26 expected to connect with, and facilitate the discussions, in session 3.

27 **Session 3:** This session involved a discussion of terms used to describe comfortable and uncomfortable
28 experiences of being driven by AVs. Discussions in this session were based on the previous two
29 sessions. After reflecting on the unique characteristics of AVs in session 2, it was expected that experts
30 would add or remove terms about comfortable/uncomfortable experiences of being driven by AVs,
31 based on existing terms for a taxi/bus/train from session 1.

32 **Session 4:** This session focused on discussing the original conceptual framework for user comfort in
33 automated driving (Figure 1), with an emphasis on how these are affected by different driving styles.
34 After discussions in the preceding sessions, experts were expected to give constructive feedback on
35 the original framework, in terms of complementing and revising relevant aspects and concepts, rather
36 than clarifying concrete terms. Here, we explicitly instructed experts to take driving styles into
37 consideration, compared to the preceding sessions, in which the term of "being driven" was used to
38 implicitly remind experts of the driving scenario. However, we still encouraged discussions of broad
39 but relevant concepts, in addition to driving styles.

40 Each session began with a verbal instruction provided by the moderator, including the topic of the session, the
41 place to write notes, and the duration of the writing session. The workshop then began with writing and

1 grouping notes on the Miro whiteboard, followed by a group discussion of the written notes and the patterns
2 of the categorisations. For the note-writing, experts were advised to use one to two terms for each note, to
3 keep descriptions succinct and easy to follow, so that other experts could read these through, within the
4 limited time of a session. In order to get a comprehensive output, experts were encouraged to write as many
5 notes as they could, and to avoid repetitions (i.e., to avoid writing a description that was already posted,
6 allowing a maximisation of the number of concepts used). Instructions about the topic covered in each session
7 was also shown on the Miro whiteboard, to remind experts of the focus of the current session. Along with
8 writing, experts were instructed to move their notes closer to existing notes with similar meaning/themes.
9 Figure 2 shows instructions of topics for discussions on the Miro whiteboard, the order of events and rough
10 length of each session. Figure 3 shows the Miro whiteboard of session 1, as an example, which includes the
11 written instructions, separated whiteboard areas for comfort and discomfort, the empty notes provided to
12 experts, and an overview of the final notes provided by the experts. After the writing task, experts saw an
13 overview of the whiteboard, and discussed the emerging patterns which were of interest to them. The Miro
14 whiteboard screen was shared via Teams throughout the workshop, to ensure participants worked on and
15 looked at the same area. All experts were thanked for their contribution after the workshop.

16 Both the pilot and the main workshop were moderated by the first two authors (CP and SH). These individuals
17 also devised the questions and workshop format. For the main workshop, one moderator (CP) instructed and
18 guided the discussion, while the other moderator (SH) monitored the online tools (e.g., timer setting and
19 reminder in Miro).

1 Data analysis

2 For the two types of data (written notes and verbal discussions) collected from the workshop, we adopted
3 different approaches to analysing data. For written terms describing comfort/discomfort of currently available
4 transport modes and AVs (mostly from session 1 and 3), although experts have grouped most terms and
5 discussed some patterns at a group level in the workshop, further categorisations were needed for two
6 reasons. First, not all terms were moved into groups, while some groupings were roughly done with flaws,
7 likely because, for example, experts overlooked some terms due to too much information on the whiteboard,
8 and had insufficient time to refine these groups. Second, no explicit names were given to each group of terms
9 to summarise the theme; however, it is important to identify the theme of a group of terms with similarities,
10 because a theme summarises commonalities of these terms, and indicates one aspect of comfort/discomfort.
11 Sorting text into meaningful categories is usually done by participants in group brainstorming (Clayphan et al.,
12 2014), while it is also an approach of qualitative content analysis used after data collection (Ahmadpour et al.,
13 2016; Hsieh & Shannon, 2005). Therefore, to complete the categorisation and highlight patterns of these terms,
14 the categorisation was conducted as part of data analyses. The categorisation combined the theory-driven
15 deductive approach and the data-driven inductive method (Berg & Lune, 2017; Duboz et al., 2022). To be
16 specific, we tended to deductively categorise and name a group of terms, either based on frequently
17 investigated psychological concepts (e.g., “perceived safety”, “trust”, and “engagement in NDRAs”) in this area,
18 or using terms used in currently available definitions for comfort/discomfort (e.g., “ease/unease”, and
19 “pleasantness”). We referred to these frequently used terminologies in academic literature rather than
20 preparing a predetermined codebook based on existing research theories, because an elaborate theoretical
21 framework of user comfort in automated driving is currently lacking. In the meantime, we categorised terms
22 according to their similar meanings and themes, in an inductive way. Three individuals (CP, SH, RM) completed
23 the categorisation (incl. grouping similar terms and naming the group) independently, and then discussed it in
24 a team of four (the three raters, and NM). This team included moderators and experts from the workshop and
25 thus had enough background knowledge for the categorisation. Other experts were given the opportunity to
26 provide feedback at the time of writing. It is worth noting that the number of repeated notes was counted;
27 however, we do not interpret the importance of a term according to the times it was repeated, because the
28 purpose of the workshop was to have a comprehensive overview, and experts were instructed about this.
29 Some terms were repeated because experts wrote in parallel, whereas monitoring the whole whiteboard in
30 the meantime to avoid repetition was challenging.

31 For verbal discussions (from all sessions), the video recording was gone through and transcribed by the first
32 two authors independently, and cross-compared to ensure no misunderstandings of the transcription. Then
33 experts’ discussions were summarised by the lead author. Summarising statements and discussions of experts
34 is an approach used by some studies based on expert work, for example, expert interviews (Kyriakidis et al.,
35 2019; Tabone et al., 2021) and expert round-table discussions (Elliott et al., 2019). All other co-authors also
36 had a chance to comment on the statements and suggest amendments. Moreover, as the discussions added
37 contextual information to the simpler notes, some categorisations of the written notes were then further
38 revised.

39 The original conceptual framework was refined based on the workshop (see examples of using group
40 discussions to refine conceptual frameworks: Agbali et al., 2019; Pettit et al., 2010). It is worth mentioning
41 that, the output and discussions in both preceding sessions and session 4 were all relevant to the framework.
42 Therefore, we combined results from all sessions to modify the conceptual framework, for example, categories
43 of comfort/discomfort that were identified in session 1 and 3, discussed differences in user comfort in

1 automated driving compared to a taxi (session 2), and experts' direct comments on the original conceptual
2 framework (session 4). The refined version of the framework was drafted by the lead author and revised based
3 on the co-authors' feedback.

4

1 Appendix B

2 Questions and instructions used in the pilot session

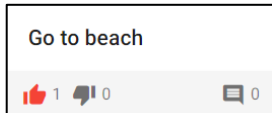
3 **Session: Warm-up questions**

- 4 Do you think understanding and defining driving comfort for AVs is important? (Slido)
- 5 Do you think it's easy to measure comfort in AVs? (Slido)
- 6 Do you think it's easy to manipulate driving comfort in AVs? (Slido)

7 **Quick tutorial to Padlet**

8 **Session A: UNDERSTANDING DRIVING COMFORT** (Padlet)

9 Imagine, you are being driven in a vehicle, e.g., taxi, train, and bus etc., not in control. A) During this
10 journey, you feel comfortable ... B) During this journey, you feel uncomfortable ...
11 What terms can you use to describe these feelings? Use thumb up and thumb down reacting to
12 all answers, for example,



13
14 How relevant is the term to describe comfort?

15 **Session B: CREATING**

16 First, let's talk about your experience and feelings about the existing automation functionalities...
17 (Slido)



- 18 Have you experienced adaptive cruise control (ACC) in real cars or in prototype? - Y/N
- 19 Have you experienced Lane Keeping Assistance (LKA), in real cars or in prototype? - Y/N
- 20 Have you experienced any other ADAS functionalities, regarding vehicle motions or distances to
- 21 other objects? - WordCloud
- 22 Regarding vehicle motions/distance to other objects, how does the system behave when you felt
- 23 comfortable or uncomfortable? Why do you like it, or dislike it? (No tool; just discussion in Teams)
- 24 Imagine. You are being driven, not in control, don't need to monitor, can do NDRTs...
- 25

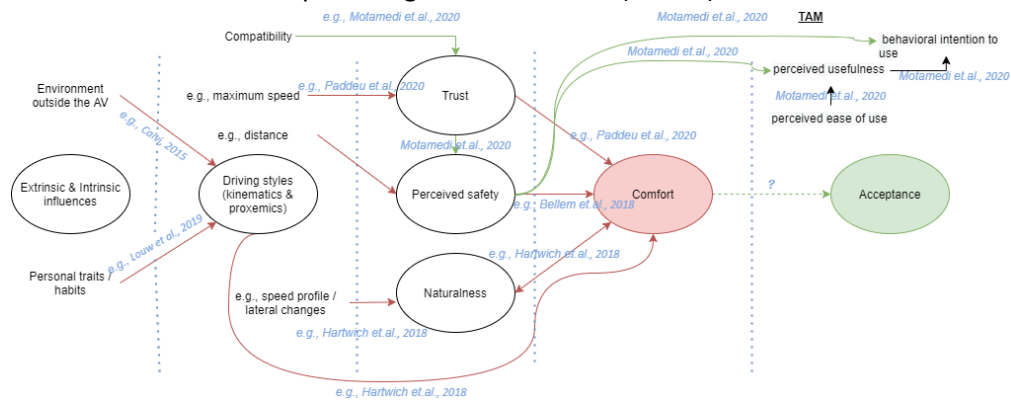


26 Regarding driving styles / environments, is there anything different in the L3/L4 automation,
27 compared to the L1/L2 automation, about comfortable or uncomfortable experience?

29 **Break**

- 30 Consider the concepts - Trust, Perceived Safety, Naturalness, User acceptance - that are related to
- 31 kinematics and/or proxemics, and this suggested conceptual framework...
- 32 Are there any other relevant concepts are missing? – add (Teams)

1 What are the relationships among them? – discuss (Teams)



2
3 **Session C: LOOKING AHEAD**

4 What else in this area, apart from kinematics and proxemics, are important to be understood? -
5 Slido; word cloud

6 Are there any other different user groups that should be considered in this context? - If yes, please
7 explain your answer – Slido

8 **Session D: MEASURING**

9 Among the range of measures to measure comfort in the driving context...
10 Which one is most successful?

11 **Feedback question**

12