Using virtual reality and physiological data capture to understand travel behaviour in an autonomous vehicle future

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Extended Abstract

1 Introduction

Travel behaviour data is usually collected through surveys where users recollect their behaviour or state their perceptions, attitudes, and preferences. These methods are insufficient in the case of Autonomous Vehicles (AVs) because most people have not yet used these vehicles and find it hard to imagine and assess the experience of using them. While trials and demonstrations provide this experience, they do not account for the travel environments that will exist in the future, when all vehicles on the road will be fully autonomous.

Virtual Reality (VR) provides an immersive experience that can realistically represent these future scenarios, while also testing for variations in the characteristics of those scenarios. It can also be combined with physiological data capture. This involves sensors to measure heart rate, skin conductance, and electroencephalogram data (EEG), the analysis of which can infer mental states such as stress, anxiety, arousal, and discomfort.

While existing studies have deployed VR for the study of AVs (e.g., Helgath *et al*. 2018, Djavadian *et al*. 2019), most studies focus on a single type of vehicle (usually a private car) and tend to assess user reactions to fully autonomous vehicles in comparison with partially autonomous or conventional vehicles. However, perceptions for different types of fully autonomous vehicles, and how this might influence modal choice, remain underexamined. In particular, the choice between private and public transport may have different determinants, if both vehicles are autonomous, compared with the case when both vehicles are human driven. In addition, events during the trip (e.g., incident on public transport or increased congestion) might trigger en-route mode-switches. For example, a user of a public AV will be able to get off and call a private AV. Likewise, a user of a private AV will be able to get off without having to search for parking and get on a public AV.

Additionally, existing studies seldom account for in-vehicle use of time. However, not having to drive opens up possibilities for using travel time for other purposes, even in private vehicles, and this may affect the choice between private and public transport.

Finally, there is also little reflexion about the effectiveness of the methods used. Both VR and physiological data capture are relatively new data collection methods in transport research and their usability, deployment issues, ethical aspects, and sample representativeness are scarcely discussed.

In this context, our study aims to address some of these gaps with the design and deployment of VR experiments that cover mode-choice, mode switch, and use of time choices for AVs that are accompanied with physiological measurements, with 90 participants across three sites in the Netherlands, Poland, and Greece. Specifically, the contributions of this work relate to

a) modelling the user experience determinants of choices between private and public AVs.
b) estimating preferences about different uses of travel time when travelling in AVs.
c) measuring physiological reactions to different aspects of travelling in private and public AVs
d) exploring views about the realism and other characteristics of VR scenarios

2 Virtual reality scenarios

We designed a 10-minute VR experienced for Meta Quest Pro headsets, representing a future reality where AVs are widely available. The experiment includes two scenarios: a trip on a car (private or car-sharing) and a trip on a bus. Participants are given the option to choose between them at the start of the experiment (**Figure 1**). The car and bus trip both start at the city centre and end at the participants' home, travelling along the same route. Both are initially estimated to take the same time, but the car is significantly more expensive.

During the run-time of trip, participants are presented with choice scenarios regarding a) the use of travel time (e.g., read a book, look at a phone or tablet computer, or just look around); b) mode-switch (from bus to car or walking, or from car to bus or walking), when confronted with unforeseen events, such as borderline antisocial behaviour or increased travel time due to congestion respectively. The two scenarios incorporate attributes that assume different levels in each trip stage, possibly triggering a switch from/to car to/from bus, and/or physiological reactions. Each stage lasts for 40 seconds and ends at a bus stop.

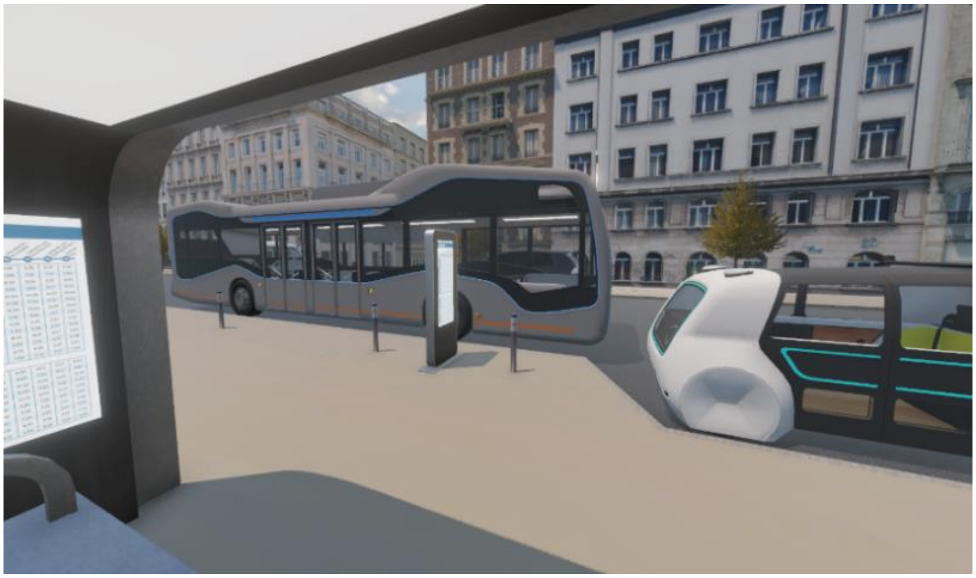

Figure 1: Initial choice between autonomous bus and car

2.1 Autonomous bus scenario

The participant boards the bus and is greeted by a human assistant. The participant then sits in a vacant seat at the back of the bus (**Figure 2)**. The bus departs travelling in a dedicated bus lane and moves faster than private cars. At each bus stop, new passengers join, and others leave the bus. At some point mid-journey, the participant is asked to choose what they would prefer doing (e.g., read a book, watch a movie, look outside). At each bus stop, some attributes of the scenario change (**Table 1**). The participant has the possibility, at any moment, to notify their intention to get off at the next bus stop and get on a car or walk. The participant is reminded of this option just before each bus stop, and relevant attributes (cost and travel time), are presented. If the participant decides to get off, the experiment continues with the car or ends with walking. If not, the bus continues. At the end of Stage 9, the bus stops and the passenger gets off. Their destination is just opposite.

Table 1: Bus scenario

Attribute	**Stage**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Landscape	City centre			Industrial wasteland	City centre	Industrial wasteland	City centre	Industrial wasteland	Destination
Crowding	Not crowded	Crowded		Not Crowded					
Supervision	Human assistant inside the bus				No human assistant				
Time of day	Daytime		Gradually starting to get darker					Night-time	
Behaviour of other passengers	Mind their own business					Anti-social			No other passengers

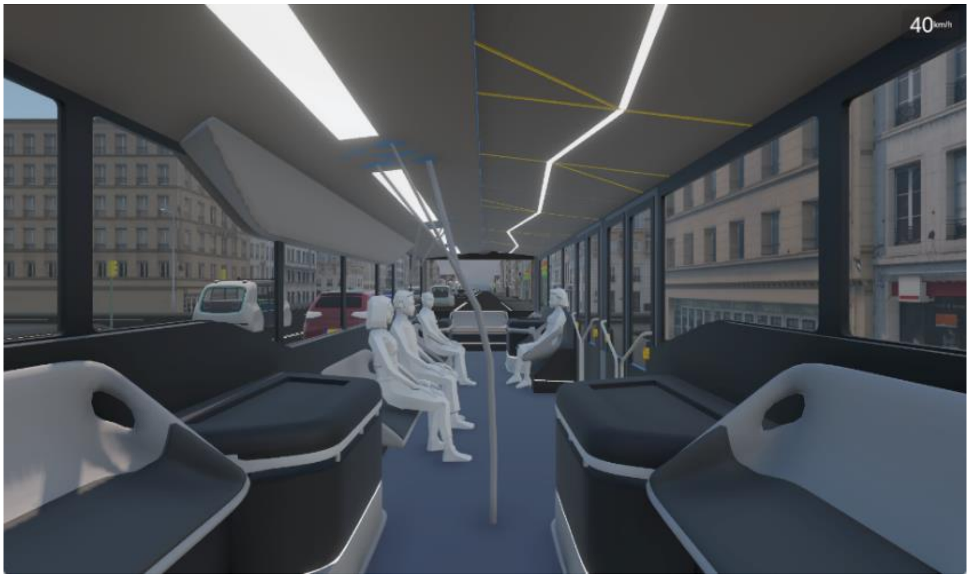

Figure 2: Example of bus scenario. Attribute levels represented: city centre, not crowded, no human assistant, starting to get dark, passengers mind their own business

The selection of attributes put emphasis on personal security issues of travelling in unsupervised public transport, one of main concerns people have expressed about AVs (Salonen, 2018; Launonen *et al*. 2021). Several attributes test aspects that might influence perceived personal security in public transport: landscape (industrial wasteland with derelict industrial buildings); crowding; supervision (no human supervision), time of day (dusk and night-time); and behaviour of other passengers (some acting in anti-social manner, talking loud, listening to music, and putting their feet on the seats).

The attributes are also important for other reasons. Human supervision is important because people are concerned with risk of collision if no human is present to take over vehicle if needed (Liljamo et al. 2018; Islam et al. 2022). Crowding and landscape type are part of the trip's perceived quality and can cause stress, regardless of perceptions of personal security. Time of day and crowding also interact with landscape: it is also more difficult to see the landscape at night and in a crowded bus.

2.2 Autonomous car scenario

The participant enters the vehicle. The vehicle starts moving while participant can see autonomous buses moving faster in the bus lane. At some point mid-journey, the participant is asked to choose what they would prefer doing (e.g., read a book, watch a movie, look outside). The traffic becomes denser progressively, almost reaching a standstill and the trip starts taking longer than expected. The participant is provided with information saying that delayed arrival is expected. Land use also changes (**Table 2**, **Figure 3**). The participant has the possibility, at any moment, of requesting to get off and get on an autonomous bus or walk, at the next bus stop and relevant attributes (cost and travel time), are presented. If the participant chooses to do so, the experiment continues with the bus scenario. If not, the car continues. At the end of minute 9, the car stops. The participant's destination is opposite. The participant is asked to choose between: a) send the vehicle to a nearby parking area to reuse the following day (which has a cost), b) send the vehicle back to the city centre (free, but the following day it will take 20 minutes to pick the passenger again).

Table 2: Car scenario

Attributes	**Stage**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Landscape	City centre			Industrial wasteland	City centre	Industrial wasteland	City centre	Industrial wasteland	Destination
Time of day	Daytime		Gradually starting to get darker					Night-time	
Congestion	No congestion	Gets progressively worse						Starts to ease up	No congestion

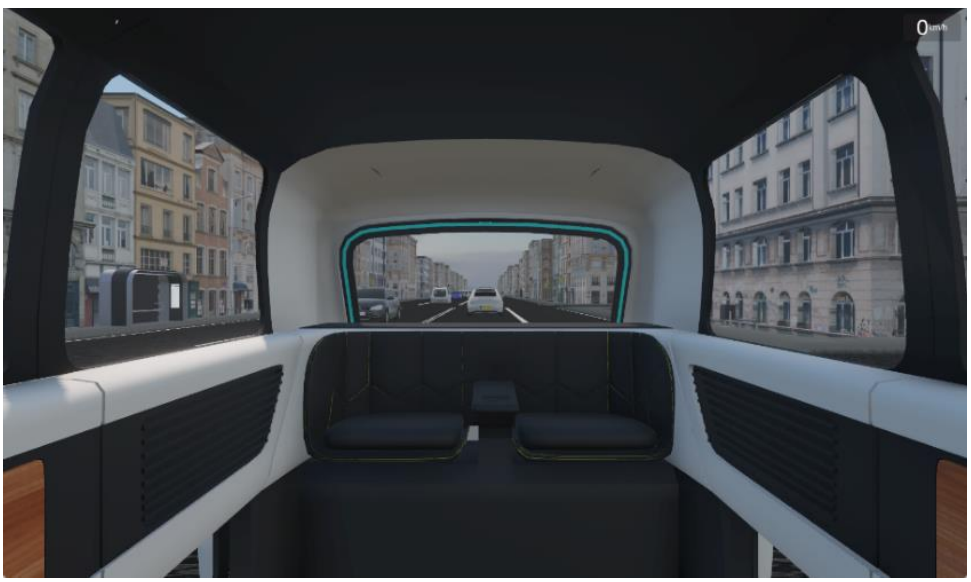

Figure 3: Example of car scenario. Attribute levels represented: city centre, daytime, starting to be congested

In the car scenario, the landscape (e.g., what the car passenger can see from the window) serves as an attribute because in the future, driving will no longer required, so passengers can enjoy the scenery, which becomes more important as a trip quality determinant. Time of day and congestion also prevent people from seeing the landscape. Congestion is an attribute because it is a major determinant of travel mode choice and of traveller stress. In this scenario, we test a situation where buses always move faster than cars, by using dedicated (and uncongested) lanes.

3 Data Collection

3.1 Data Specification

The VR headset records participants' choices during the VR experiment, i.e., the initial choice of car or bus, if/when they change from one to another, what they choose to do during the trip, and what they choose to do with the vehicle (at the end of the car trip). The headset will also record head movements, i.e., if the participant is looking at the outside or inside of the vehicle in each moment. Physiological data (brain activity) is also recorded using non-invasive electroencephalography (EEG) earbuds (EMOTIV MN8).

Three additional data collection instruments are used:

- A pre-questionnaire, filled online ahead of the experiments. This collects data on participant characteristics, such as demographics, travel context, travel behaviour, and general travel attitudes.
- A post-experiment questionnaire, filled online or in paper immediately after the experiment, probing for participants' reasons for choices, awareness of the scenario stages, and opinions about the quality, realism, and plausibility of the scenarios.
- A debrief session during which participants will watch video versions of the two scenarios and asked about their opinions, generating a dataset with statements, linked to each stage of the scenarios.

3.2 Participant recruitment

Experiments are scheduled to take place in December 2023 at 3 locations: Helmond (Netherlands), Katowice (Poland), and Mytilene (Greece). In each location, the sample will be balanced across gender and age groups (18-34, 35-64, 65+). For the Helmond experiment, participants will also participate in an AV demonstration. Differences will be analysed between participants who joined the demonstration first, then experienced the VR, and those that experienced the VR first and then joined the demonstration.

Participants will be provided with an information sheet and will sign a consent form before the event. Participants will be informed by researchers and by a message at the start of the game that they can opt-out at any moment during the experiment. They will be provided clear instructions on how they can themselves wear and calibrate the devices, but male and female researchers will be present to assist participants if needed. The devices will be disinfected after each use. Participants will receive a small compensation for their time.

4 Analysis

With the completion of the data collection experiments, the EEG raw data will be processed to derive frequency bands, the strength of which will be used to estimate indicators of emotional states: stress and attention. The participant choices, emotional states, head movements, and comments will be combined into one dataset, based on time-stamp matching. This is matched with the attributes of the corresponding scenarios stages and participants’ awareness of changes in those stages. This will finally be matched with the participant characteristics, attitudes, and questionnaire responses. Descriptive quantitative and qualitative analyses will be conducted on the dataset with the participants’ reasons for choices and opinions about the scenarios. Table 3 outlines the models that are planned to be estimated to analyse the resulting dataset.

Table 3: Models

Dependent variable	**n**	**Specification**	**Explanatory variables**					
			Scenario stages	**Awareness of scenario change**	**Choice of travel time use**	**Emotional states**	**Head movement**	**Participant characteristics and attitudes**
Initial choice (car vs bus)	90	Binomial						Yes
Travel time use	90	Multinomial						Yes
Switch car to bus	<730	Mixed logit	Yes	Yes	Yes	Yes	Yes	Yes
Switch bus to car	<730	Mixed logit	Yes	Yes	Yes	Yes	Yes	Yes
Parking choice	<90	Multinomial						Yes
Emotional states	32,400	Non-parametric	Yes	Yes	Yes			Yes
Awareness of scenario change	720	Binomial	Yes		Yes			Yes

5 Conclusions

The outlined experiment design and setting presents an opportunity to generate an understanding on commonly neglected aspects of widespread AV deployment, such as mode-choice, mode-switching and travel-time-use, while at the same time investigating the use of innovative data collection methods. The envisaged analysis will also support the testing of advanced travel behaviour models that would integrate a range of exploratory variables which are scarcely evaluated.

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References

Djavadian S., Farooq B., Vasquez R., Yip G. (2019) Virtual immersive reality based analysis of behavioural responses in connected and autonomous vehicle environment., in K G Goulias and A W Davis (Eds.) *Mapping the Travel Behavior Genome*, Elsevier, Amsterdam., pp. 543-559.

Helgath J., Braun P., Pritschet A., Schubert M., Böhm P., Isemann D. (2018) Investigating the effect of different autonomy levels on user acceptance and user experience in self-driving cars with a VR driving simulator. *Lecture Notes in Computer Science* 10920, 247-256.

Launonen P., Salonen A.O., Liimatainen H. (2021) Icy roads and urban environments. Passenger experiences in autonomous vehicles in Finland. *Transportation Research Part F: Traffic Psychology and Behaviour*, 80, 34-48.

Liljamo, T., Liimatainen H., Pöllänen M. (2018) Attitudes and concerns on automated vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour* 59, 24-44.

Salonen A O. (2018) Passenger's subjective traffic safety, in-vehicle security and emergency management in the driverless shuttle bus in Finland. *Transport Policy*, 61, 106-110.

Woldeamanuel Faber K., van Lierop D. (2020) How will older adults use automated vehicles? Assessing the role of AVs in overcoming perceived mobility barriers. *Transportation Research Part A: Policy and Practice* 133, 353-363.