Transportation Research Interdisciplinary Perspectives 10 (2021) 100380

Contents lists available at ScienceDirect

Transportation Research Interdisciplinary Perspectives

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

Are multimodal travellers going to abandon sustainable travel for L3 automated vehicles?

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ARTICLE INFO

Keywords:
Mode choice
Travel behaviour
Multimodality
Conditionally automated vehicles
Automated vehicle acceptance

ABSTRACT

Reducing car dependency supports the creation of a more sustainable transport system. However, automated vehicles (AVs) are predicted to increase the attractiveness of car travel and decrease the use of public transport and active travel. This current study explored how travellers' intention to use AVs and their current travel behaviour influence their expectations of how they will use public transport and active travel, once conditionally automated (SAE L3) vehicles (L3 AVs) are available.

Survey data (collected during the EU H2020 L3Pilot project) from among current car users from eight European countries (n = 9118) was used. Respondents were asked about their current travel mode usage, intention to use L3 AVs, and expected changes in the use of public transport and active travel once L3 AVs are available. The respondents were divided into nine user segments based on their level of intention to use L3 AVs and multimodality.

Most respondents did not foresee changes in their use of public transport (62%) or active travel (67%). A higher intention to use L3 AVs increased the probability of a traveller expecting to decrease their use of public transport and, to a lesser extent, active travel. Multimodal travellers used public transport and active travel regularly and were also more likely to see a change, either up or down, in their use of public transport and active travel. The results suggest that L3 AVs may pose a challenge to the sustainability by encouraging current users of public transport and active travel to switch to personal AVs.

Introduction

Increasing the sustainability of the transport system is a major challenge. Reducing car dependency is one step that could help create a more sustainable transportation system, especially concerning emissions and land use. Consequently, creating a more multimodal transport system can be seen as a way to reduce car dependency (e.g., European Commission, 2020). Multimodality, in this context, refers to the use of more than one transport mode to satisfy travel needs within a limited amount of time (typically a week) (e.g., Nobis, 2007). Therefore, it is a broader concept than intermodality, which means using multiple modes within the same trip. Existing research on multimodality within Europe and the US has shown that car drivers can be characterized on a continuum from monomodal car users to those who use a mixture of modes in addition to their private car (Buehler and Hamre, 2015; Molin et al., 2016; Nobis, 2007). Multimodality is thus opposite to car dependency.

Meanwhile, automated vehicles (AVs) are expected to change personal mobility in the near future. AVs have been predicted to increase the attractiveness of car travel, because they make it possible for drivers to disengage from driving, increasing travel comfort and enabling other activities while travelling (Milakis et al., 2017; Soteropoulos et al., 2019; Spence et al., 2020). This could potentially decrease the use of public transport and active travel (walking and cycling). In effect, it would decrease the level of multimodality within the transport system and challenge the system's future sustainability.

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https://doi.org/10.1016/j.trip.2021.100380
Received 23 December 2020; Revised 29 March 2021; Accepted 29 April 2021

2590-1982/

The focus of the present study was on conditionally automated (SAE level 3) vehicles (L3 AVs) currently entering the market[1]. L3 AVs are able to handle the driving task within their operational design domain (ODD), defined in terms of road, traffic, weather and other conditions. Within the ODD, the driver functions as a fallback and is required to take control of the car if the car so requests. L3 AVs enable drivers to engage in non-driving-related activities when driving in an automated mode and may increase travel comfort (Metz et al., 2020; Várhelyi et al., 2020). Consequently, the perceived value of travel time among L3 users could decrease compared to manual driving, raising the attractiveness of car travel (Kolarova et al., 2019; Moore et al., 2020; Singleton, 2019) and potentially leading to travel mode changes.

However, the role of the driver is fundamentally different in L3 AVs compared to highly or fully automated (SAE levels 4 and 5) vehicles. With L4 and L5, the driver is not expected to take over control upon request. L4 and L5 AVs can be envisioned to form a fleet of driverless 'robotaxis'. Shared robotaxis could serve the travel demand with a smaller number of vehicles and vehicle-kilometres travelled than manually driven or humanly supervised L3 cars (Fagnant and Kockelman, 2018), creating transport-system-type advantages. However, because L3 AVs can never relocate without a driver, they are unlikely to provide these benefits. Therefore, L3 AVs may have a different overall effect on the sustainability of the transport system than vehicles with higher levels of automation.

Understanding travel mode changes due to AVs

Besides using models and simulations, expected travel mode changes can also be studied using future-oriented stated-preference surveys. Such studies can be especially useful for understanding how respondents' attitudes and other characteristics are linked to potential changes.

Booth et al. (2019) surveyed expectations to replace walking, cycling or public transport trips with fully autonomous AVs. Forty-eight percent of the respondents reported that they could replace public transport trips with AVs, 32% would replace cycling trips and 18% walking trips. The study found that a positive attitude toward AVs predicted expectations to replace these trips with AVs. Intention to use a shared AV predicted a drop in public transport use, and intention to buy an AV decreased walking trips. Intention to use a personal AV was not asked. The study was conducted in Australia, where the mode share of public transport and active travel is lower than in many European countries, thus the results may not be directly transferrable. However, the study suggests that behavioural intention to use L3 AVs once available is likely to be connected not only to the future uptake of L3 AVs (Nordhoff et al., 2020; Venkatesh et al., 2003) but also to changes in the use of public transport and active travel.

Considering the link between intention to use AV and expected changes without taking into account the current travel behaviour of the respondents would miss a major factor influencing the impact potential: current travel behaviour largely determines which travel modes AVs could supplant. For example, if strongly car-dependent persons (i.e., those who currently satisfy most of their travel needs with private cars) start using L3 AVs, changes in their travel behaviour may occur, but the magnitude of changes in the modal share will be relatively minor (i.e., car drivers are still car drivers). However, if travellers who primarily travel with other modes switch to L3 AVs, there may be relatively greater changes in the modal share (e.g., public transport users become car drivers) with implications, for instance, for transport network efficiency. In other words, current multimodal travellers have the greatest potential to decrease the use of public transport and active travel if they so wish.

Interestingly, multimodal travel behaviour has been linked to a greater intention to use shared AVs (Krueger et al., 2016). It is possible that multimodal travellers' greater familiarity with car sharing in general could make them more willing to use shared AVs (Kopp et al., 2015; Krueger et al., 2016). However, this link has not yet been definitively established.

On the other hand, multimodal travel behaviour can be related to sociodemographic factors, which may influence willingness to use AVs. Younger age has also been associated with a higher willingness to use AVs in general (Krueger et al., 2016; Liljamo et al., 2018; Molin et al., 2016; Nordhoff et al., 2020). Young adults are often multimodal, but once they enter working life and start a family, this tends to decrease (Nobis, 2007; Scheiner et al., 2016). At the other end, exiting working life and a child moving out of the family home tends to bring a return to multimodality. It has been found that multimodal travellers have on average smaller households and are less often employed full time compared to monomodal car users (Buehler and Hamre, 2015; Molin et al., 2016).

Also other factors may influence multimodal travellers' travel mode changes regardless of their intention to use L3 AVs. Multimodal travellers have been found to be more likely to switch travel modes than are monomodal travellers (Diana and Mokhtarian, 2009; Kroesen, 2014; Molin et al., 2016). This can be explained by multimodal travellers' greater familiarity with different modes: users of a specific travel mode have a more realistic picture of it and have more positive attitudes towards it than non-users (Diana and Mokhtarian, 2009; Pedersen et al., 2011; Ton et al., 2020). In contrast, car users often do not have a strong intention to use public transport or bicycles (Eriksson and Forward, 2011). This suggests that multimodal travellers are flexible in selecting the travel mode which is most appropriate at the time.

For current monomodal car users, savings in the perceived value of travel time due to the ability to engage in other activities while travelling by car could make automated driving appealing. Among multimodal travellers, L3 AVs must compete with other travel modes and address the motivations to use alternative modes. Anable and Gatersleben (2005) compared motivations to use a car, public transport and/or active travel. Compared to public transport, car use was seen as more flexible and convenient. L3 AVs could further strengthen these aspects by enabling other activities, which could also entice current public transport users to switch modes. On the other hand, active travel was considered to provide physical exercise and relaxation with minimal environmental impact and low costs. L3 AVs may not address these motivations.

In summary, there is a knowledge gap in understanding the relationship between the willingness to use AVs, multimodality and travel mode changes. Understanding how these two are related would also help to understand the potential implications of AV use on the use of sustainable travel modes, in particular public transport and active travel.

Aim of the study

L3 AVs may increase the attractiveness of personal cars over public transport and active travel. This would pose a challenge to sustainability of the transport system and require policy countermeasures. The aim of this study was to understand potential travel mode changes due to the introduction of L3 AVs. Travel mode changes were investigated based on survey data. The respondents were asked whether they expected an increase or decrease in their personal use of public transport or active travel once L3 AVs are available. The expected changes were investigated relative to the behavioural intention to use L3 AVs and current multimodality. The analysis focused on two research questions:

[1] In March 2021, the Honda Motor Co. announced that it would start selling vehicles with the L3 Traffic Jam Pilot automated driving function in Japan: https://global.honda/newsroom/news/2021/4210304eng-legend.html

1) Is a higher behavioural intention to use L3 AVs associated with an expectation to decrease the use of public transport and active travel?
2) Previous studies have suggested that multimodal travellers might be more willing to use AVs and switch travel modes in general. If multimodal travellers abandoned sustainable travel modes for L3 AVs, then L3 AVs could increase car dependency.

Therefore, the links between intention to use L3 AVs, multimodality and expected changes were investigated. In particular, the role of younger age was examined as a confounding factor linking intention to use and multimodality.

Methods

Data

The current study is part of the EU H2020-funded L3Pilot project (www.l3pilot.eu), which is conducting large-scale pilots of L3 AVs in Europe to investigate their technical abilities, user experience and acceptance, and their potential socioeconomic impacts. As a part of the project, an online survey questionnaire was collected in eight European countries: the United Kingdom, Finland, Sweden, Germany, Italy, France, Spain and Hungary. These countries were selected based on the size of their car market and geographical representation within Europe. Haustein and Nielsen (2016) have segmented EU countries into six segments according to their mobility culture, and our sample covered five out of six clusters, the missing cluster being Ireland, Malta and Cyprus.

The primary aim of the survey was to investigate the acceptance of L3 AVs among European car drivers. The results were published by Nordhoff et al. (2020). The survey contained questions about the respondents' travel behaviour, sociodemographics, familiarity with advanced driving assistance systems, their understanding of the concept of conditionally automated cars, and attitudes toward L3 AVs.

The respondents were informed that an L3 AV could handle longitudinal and lateral control (including lane changes) within its operational design domains (ODDs):

> "There are different terms to define the capabilities of automated cars, such as self-driving, autonomous, automated, pilotless, driverless, and conditionally automated. With this questionnaire, we would like to get your opinion on conditionally automated cars.
>
> Conditionally automated cars can drive under limited conditions, such as driving on motorways, on congested motorways, in urban traffic, and in parking situations. They will not operate beyond these conditions.
>
> Conditionally automated cars do the steering, acceleration and braking. They will stay in the lane and maintain a safe distance to the vehicle in front. They will also overtake slower moving vehicles or change lanes. These cars still have gas and brake pedals and a steering wheel."

The role of the driver in L3 AVs was also explained to the respondents, highlighting that in automated mode they could engage in other activities than driving, but that they would need to be ready to take control:

> "You are not driving when the car is in conditionally automated mode — even if you are seated in the driver's seat. This will allow you to engage in other activities, such as emailing or watching videos. However, the car might ask you to resume vehicle control anytime, e.g., when approaching a construction site, which means you might have to stop what you are doing and resume control of the car."

In addition, the respondent received a more detailed description of one of the ADFs before answering questions focusing on it. The study also included questions on the respondents' gender, age, income level and kilometres/miles driven annually, and the number of children living in their household.

The data was collected between April and June 2019 (UK, Finland, Sweden, Germany, Italy, France and Hungary) and in March 2020 (Spain[2]). In each country, a sample that was representative of age, gender and income of its country population was selected. For each country, the aim was to collect a sample of at least 1000 respondents representative of the country (age, gender, income). The quoting criteria are described in detail in Supplementary Material 3 of Nordhoff et al. (2020).

Measures

The current study analysed the questions pertaining to the intention to use L3 AVs, current travel behaviour, expected changes in the use of public transport and active travel, along with sociodemographic variables.

Respondents were asked to rate how frequently they used different transport modes. The available modes were 1) walking (more than 500 m), 2) private personal bicycle, 3) shared bicycle (incl. rental bicycle), 4) motorcycle, 5) private car as a driver, 6) shared car as a driver (incl. rental), 7) car as a passenger, 8) short-distance public transport (<50 km per direction), and 9) long-distance public transport (more than 50 km per direction). Responses were given on a six-point scale: (almost) daily, 4–5 times per week, 1–3 times per week, 1–3 days per month, less than once per month, (almost) never). It was also possible to not answer.

The number of modes used at least weekly was calculated based on the frequency of transport mode responses. The alternative mode use score was calculated by converting the mode usage-specific responses into numbers: 6 = (almost) daily, 5 = 4–5 times per week, 4 = 1–3 times per week, 3 = 1–3 days per month, 2 = less than once per month, 1 = (almost) never). An average was then taken.

Because the focus of the study was to investigate multimodality by contrasting it to car-based monomodality, alternative mode use was considered a more appropriate measure of multimodality than number of modes used weekly. As the survey was targeted at European car users, a great majority of the respondents used a personal car at least weekly, and those who were multimodal without driving a passenger car were excluded to begin with. Walking more than 500 m was also highly common among all the respondents, which makes it less informative regarding travel behaviour.

The decision to favour the alternative mode use score over the number of modes used weekly was confirmed when we analysed the correlations between multimodality measures and mode use indicators (Fig. 1). The alternative mode use score was negatively correlated with using a personal car as a driver (rho = −0.14), but positively correlated with all other modes (walking rho = 0.17, others from rho = 0.49 to rho = 0.70). In contrast, the number of modes used weekly was positively correlated with the use of a personal car, even though the correlation was very weak (rho = 0.06). Similarly to the alternative mode use score, it was positively correlated with the use of all other modes (with walking rho = 0.29, with others from rho = 0.42 to rho = 0.62).

Travellers were split into three groups (Low, Medium, High) based on their alternative mode use score by using 33% and 67% percentiles. The Low group had a score of less than two, indicating that they almost never used any of the alternative modes, whereas the High group scored above 2.71. The results show that the Low group used other

[2] The Covid-19 pandemic influenced daily mobility across Europe from the beginning of 2020. During the data collection in Spain in March 2020, some restrictions on personal mobility were already imposed. However, our Spanish data did not stand out from the rest in terms of travel mode use. We interpreted it to mean that the respondents had based their answers on their 'normal' pre-Covid-19 situation.

Fig. 1. Pearson correlations between the frequency of travel mode use and multimodality measure (alternative mode use and modes used weekly).

modes than a car as a driver and seldom walked more than 500 m (Table 1). The use of other modes increased in the Medium group and further in the High group. The share of weekly users of a personal car as a driver dropped from the Low to the Medium group, but not much from Medium to High.

For the expected changes in the use of sustainable travel modes, respondents were asked how they thought conditionally automated cars would affect their personal use of public transport and active travel modes. The leading question was, "How do you think conditionally automated cars will affect your personal mobility?" The answers were given on a five-point scale: Large decrease, Decrease, No change, Increase, Large increase.

To identify those users who are most likely to start using L3 AVs, it is possible to use the intention to use construct of the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003, 2012). The intention to use L3 AVs was measured by loading two items on the UTAUT behavioural intention construct, modified by Nordhoff et al. (2020). The questions used were, "I intend to use a conditionally automated car in the future" and "I plan to buy a conditionally automated car once it is available". The responses to the questions on intention to use and intention to buy were given on a five-point scale but converted to numbers (Strongly disagree = 1, Disagree = 2, Neutral = 3, Agree = 4, Strongly agree = 5). An average of responses was taken. The two items had a Pearson correlation of rho = 0.70. The Cronbach alpha for the construct was 0.82, indicating good reliability.

Analysis

During collection, data was screened for inconsistent sociodemographic responses and for respondents not answering the questions measuring their understanding of the description of L3 AVs. Respondents who indicated that they "almost never" used a passenger car (defined as private or car-sharing/rental) or did not provide that information were excluded from the survey, because the original target group of the survey were European car drivers. The original data contained 9118 responses.

Table 1
Percentages of weekly users by multimodality group. Modes sorted by the percentage of users in the Low multimodality group.

Travel mode	Multimodality		
	Low	Medium	High
Personal car as a driver	91	78	76
Walking more than 500 m	73	85	87
Car as a passenger	22	43	68
Shared car as a driver	11	37	63
Personal bicycle	9	34	65
Public transport, < 50 km	6	29	68
Public transport, > 50 km	1	8	49
Motorcycle	1	6	35
Shared bicycle	0	2	32

Data from the respondents who had not provided an answer to the UTAUT-related questions and/or had not reported their current travel mode use or their expectations regarding the future use of public transport and active travel was removed from the dataset. This filtering resulted in 8322 responses.

To illustrate the relationships between multimodality, intention to use L3 AVs, and intention to change the use of public transport and active travel, the respondents were divided into nine segments with:

i) The level of intention to use L3 AVs coded in to three levels: sceptics: 1.0–2.0, neutrals: 2.1–3.9, and enthusiastics: 4.0–5.0.
ii) The level of multimodality was coded as Low, Medium and High as defined in 2.2.

Low- and medium multimodal neutral segments were the largest (Table 2). The segments 'High multimodal AV sceptics' and 'Low multimodal AV enthusiastics' were the smallest.

The dependent variable was recoded as 'decrease', 'no change' or 'increase'. The effects of multimodality and the intention to use L3

Table 2
Size of traveller segments and their average intention to use L3 AVs and alternative mode use score. Standard deviation in parentheses.

	Multimodality	Intention to use AVs		
		Sceptics	Neutrals	Enthusiastics
Share (%)	Low	11	16	5
	Medium	9	20	9
	High	3	13	13
N	Low	924	1299	403
	Medium	780	1643	786
	High	261	1107	1119
Intention to use L3 AVs, M (SD)	Low	1.40 (0.44)	3.00 (0.37)	4.25 (0.38)
	Medium	1.51 (0.44)	3.03 (0.37)	4.25 (0.37)
	High	1.56 (0.43)	3.13 (0.36)	4.34 (0.40)
Alternative mode use score, M (SD)	Low	1.50 (0.27)	1.55 (0.27)	1.56 (0.26)
	Medium	3.28 (0.23)	2.34 (0.24)	2.37 (0.24)
	High	3.37 (0.59)	3.51 (0.61)	3.72 (0.69)

AVs on the expected changes in the use of public transport and active travel modes were modelled with multinomial logistic regressions. Multinomial models were used because the dependent variable had three levels, and the proportional odds assumption of the ordinal logistic regression appeared to be violated. The models were fitted with the R package nnet (version 7.3–15).

Three different multinomial logistic regression models were compared: The first included only the intention to use, the second added multimodality and the third their interaction. Based on the Akaike Information Criteria (AIC), the third model was used.

The relationship between the intention to use L3 AVs, multimodality, and age were analysed with a path model. Using a path model makes it possible to analyse the indirect effect (mediation) of age on the intention to use L3 AVs via multimodality and compare it with the direct effect of age on the intention to use L3. In the model, multimodality and age directly predicted the intention to use L3 AVs. In addition, age was set to predict multimodality, which meant that it could have an indirect effect on the intention to use via multimodality. The model was fitted with the R package lavaan (version 0.6–7) using maximum likelihood estimation.

Sociodemographic characteristics of the nine segments were compared using multinomial regression models. The dependent variable had always two levels (e.g., male vs. not male). Thus, the models reduced to the binary logistic regression. The main effects and their interaction were included. The reference levels were Neutral for intention to use and Medium for multimodality.

Results

Expected changes in sustainable travel mode usage

Most of the respondents expected no change in their use of public transport (62%) or active travel (67%). Of the respondents, 26% expected a decrease and 12% an increase in their use of public transport. For active travel the shares were 17% expecting a decrease and 16% an increase.

The share of those expecting no change in their use of public transport or active travel was highest among Low multimodal segments and decreased for Medium multimodality and further for High multimodality segments (Figs. 2 and 3). At the same time, the share of those expecting a change in either direction increased from Low to High multimodality. Having a higher intention to use L3 AVs increased the share of those expecting a decrease in their use of public transport.

Multinomial logistic regressions were used to model the effects of multimodality and intention to use L3 AVs on the probability of expecting a certain type of change (Table 3). A higher degree of multimodality increased the probability of expecting a change in either direction. A higher intention to use L3 AVs increased the probability of expecting a 'decrease' in the personal use of public transport and active travel modes. At the same time, the probability of answering 'no change' became smaller. In addition, high intention to use L3 AVs together when occurring with a High multimodality increased the probability of expecting an 'increase' slightly more than expecting a 'decrease'.

It is important to consider multimodality in addition to the intention to use L3 AV alone, because if the changes were investigated solely with the intention to use L3 AVs, the results would be somewhat unintuitive: a higher intention to use L3 AVs would suggest a higher probability to expect either an increase or a decrease (see Supplementary Material). The reason behind this is that there is a medium size positive correlation between multimodality and intention to use L3 AVs (rho = 0.35, 95% CI [0.33, 0.36]).

The expectations alone do not show the full impact potential, because it also depends on the current use of public transport and active travel. Regular users of public transport or active travel who expected to decrease their use represented 12% and 15% of the respondents, respectively. These groups outnumbered the irregular users expecting an increase (public transport 6%, active travel 2%).

Fig. 4 highlights that a net decrease in the use of public transport largely depends on Medium to High multimodal travellers, who are also neutral to enthusiastic toward L3 AVs. The survey did not ask what public transport trips the travellers would replace with L3 AVs. However, regular public transport users might consider e.g., commuting or shopping using L3 AVs instead of public transport. Among irregular public transport users, L3 AVs might replace e.g., less frequently occurring long-distance travel.

For active travel (Fig. 5), expectations to increase or decrease it appeared more balanced among regular users. However, the overall effect of L3 AVs may still be declining. It is plausible that travellers who are neutral or enthusiastic toward L3 AVs might replace existing active travel trips with L3 AVs. On the other hand, expectations to increase active travel may reflect a more general positive attitude toward them, and their realization may depend on other factors such as the availability of an active travel infrastructure.

Sociodemographic factors

Traveller segments' sociodemographic indicators are shown in Table 4. Table 5 reports which between-segment differences were statistically significant: Males were overrepresented in all the enthusiastic segments, and females among the sceptics. Males were also more present in the high multimodality segments. Having children was positively associated with being enthusiastic and high in multimodality, and negatively associated with being sceptical and low in multimodality. The same applied to being in working life. The effects were even stronger when the respondents belonged to the high multimodal

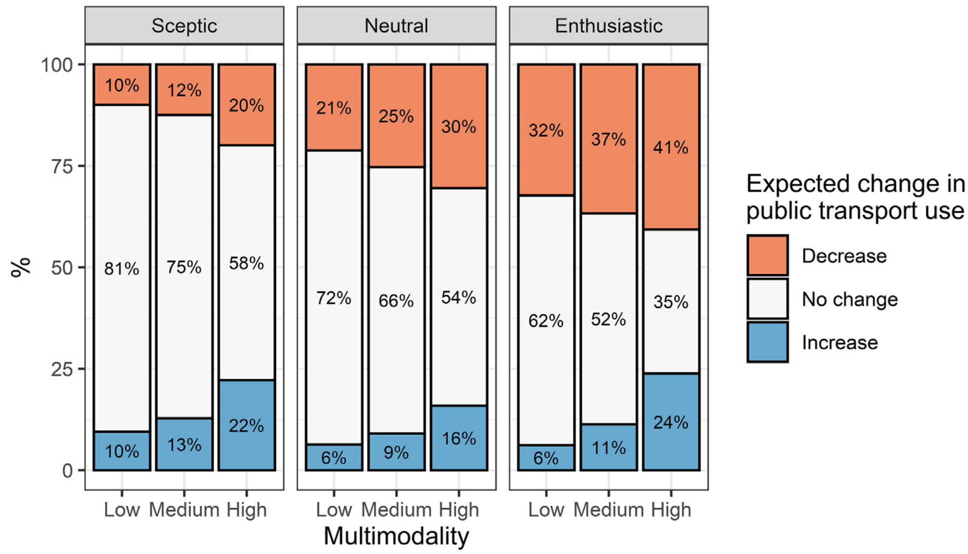

Fig. 2. Share of respondents expecting a decrease, no change, or an increase in their use of public transport by traveller segment.

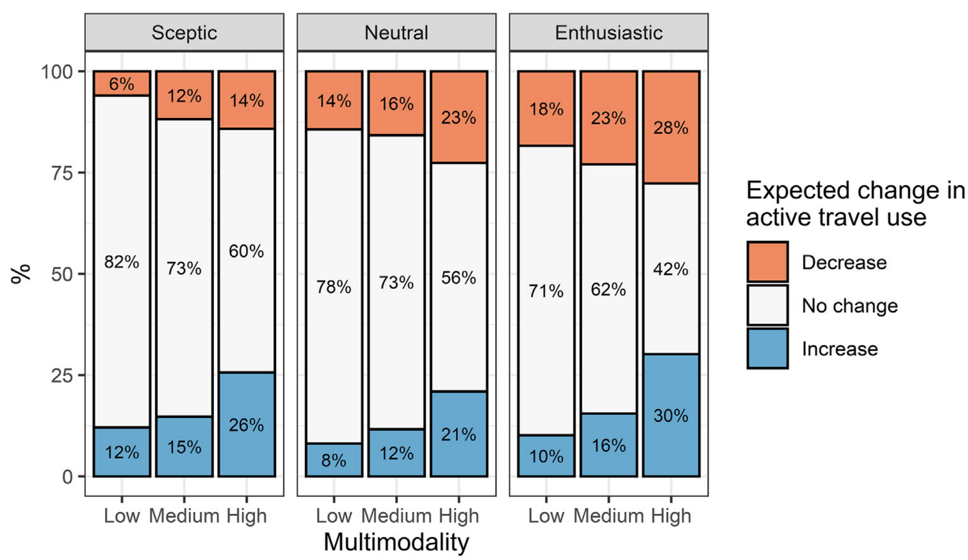

Fig. 3. Share of respondents expecting a decrease, no change, or an increase in their use of active travel by traveller segment.

Table 3
Multinomial logistic regression models for expected changes in the use of public transport and active travel. Logit coefficients and 95% confidence errors. Statistical significance calculated using standard normal distribution.

	Dependent variable:			
	Public transport		Active travel	
	Decrease	Increase	Decrease	Increase
Intention to use	**0.603****	−0.170	**0.355****	−0.152
	[0.445, 0.761]	[−0.357, 0.017]	[0.182, 0.529]	[−0.322, 0.018]
Multimodality	**0.453****	**0.337****	**0.383****	**0.340****
	[0.234, 0.672]	[0.101, 0.574]	[0.143, 0.622]	[0.122, 0.559]
Intention to use × multimodality	−0.041	**0.098****	0.00003	**0.089****
	[−0.102, 0.020]	[0.030, 0.166]	[−0.066, 0.066]	[0.027, 0.152]
Constant	**−3.560****	**−2.743****	**−3.416****	**−2.565****
	[−4.101, −3.020]	[−3.341, −2.144]	[−4.011, −2.821]	[−3.115, −2.014]
AIC	14,214		13,756	
Note:	**p < 0.01			

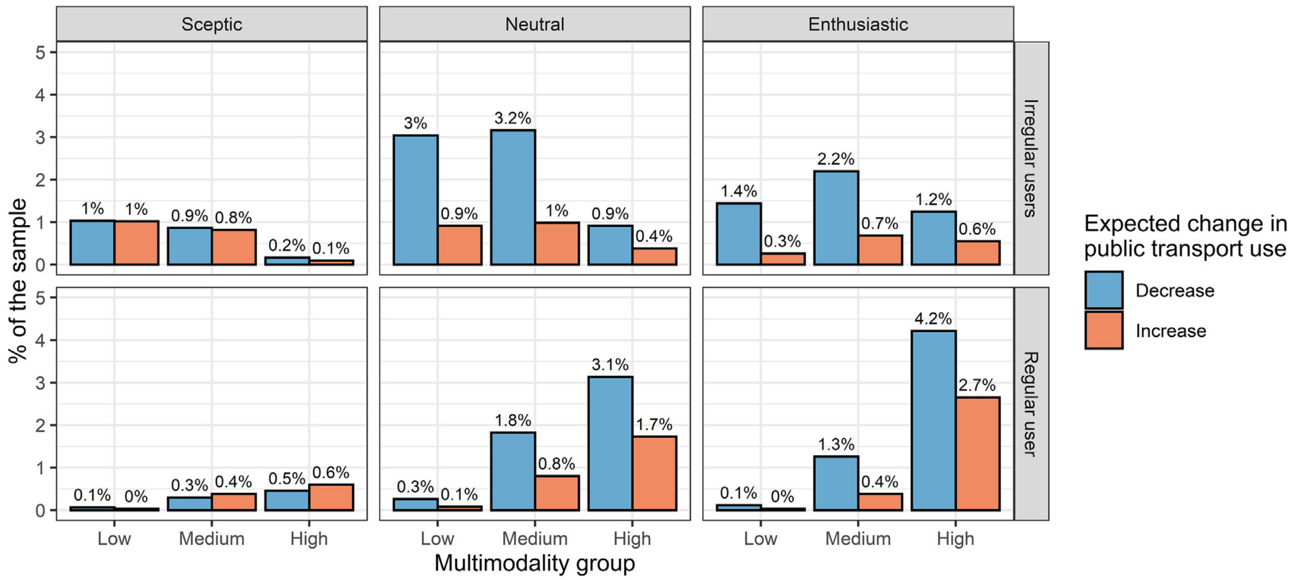

Fig. 4. Share of respondents who expect a change in public transport use relative to the total sample size by segment. Regular (at least weekly) users of public transport at the bottom, irregular users on top.

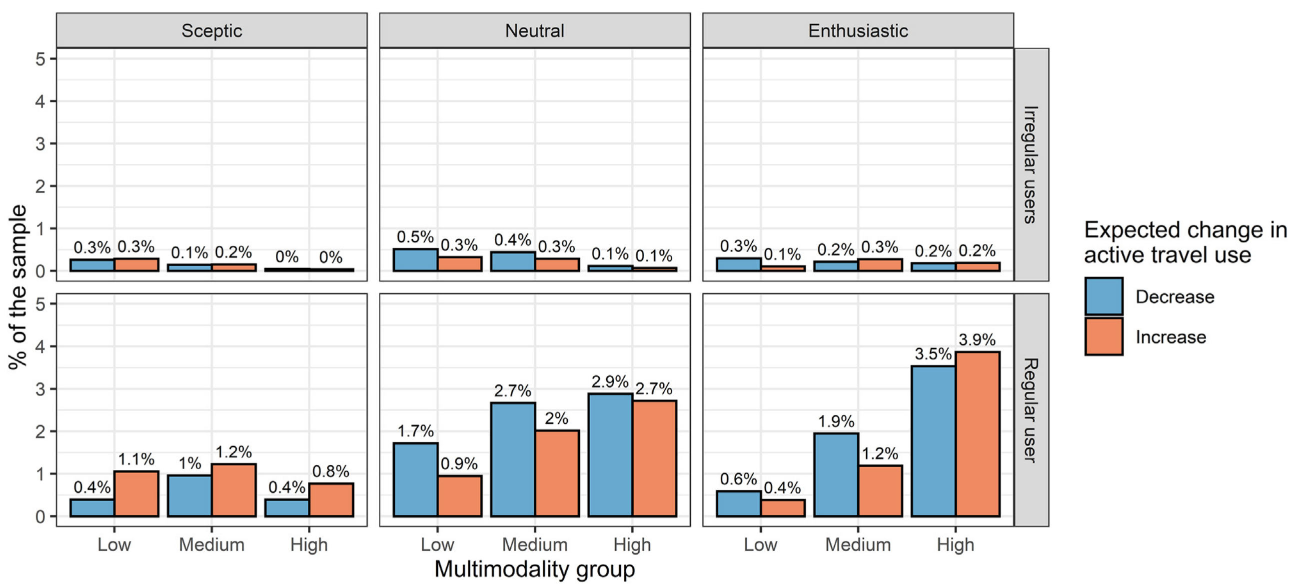

Fig. 5. Share of respondents who expect a change in active travel use relative to the total sample size by segment. Regular (at least weekly) users of active travel at the bottom, irregular users on top.

enthusiastic segment, as shown by the significant interaction. Those who had a higher income were less often sceptical or low in multimodality.

As noted earlier (3.1), multimodality and the intention to use L3 AVs were positively correlated. Age was negatively correlated both with multimodality (rho = -0.37, 95% CI [−0.38, −0.35]) and the intention to use L3 AVs (rho = −0.22, 95% CI [−0.24, −0.20]). The correlation is also visible in the segment averages (Table 4). Enthusiastic segments were on average 3–5 years younger than their sceptic counterparts and high multimodal traveller segments on average 9 to 12 years younger than their low multimodal counterparts.

This suggested that the association between multimodality and the intention to use L3 AVs could be partially explained by the younger age of multimodal travellers. A path model was used to test the mediation of age via multimodality to the intention to use L3 AVs (Table 6). Age was significantly negatively associated with the alternative mode use score. The alternative mode score was significantly positively associated with the intention to use L3 AVs. The strength of the indirect effect of age on the intention to use L3 AVs was roughly equal to that of the direct effect of age. Still, it should be noted that age explained only a small portion of the variance in multimodality (R^2 = 0.138). Similarly, age and multimodality together explained only a small portion of the variance in the intention to use L3 AVs (R^2 = 0.135).

Discussion

The current study investigated the links between multimodal travel behaviour, intention to use L3 AVs, and expectations to change the use of public transport and active travel once L3 AVs are available. The

Table 4
Traveller segment sociodemographic indicators. Average age and standard deviation. Percentage of males, females, those with multiple children, being in working life, and belonging to the group with higher income.

Dimension	Multimodality	Intention to use AVs		
		Sceptics	Neutrals	Enthusiastic
Age, M (SD)	Low	51 (13)	48 (13)	47 (12)
	Medium	47 (14)	43 (14)	42 (13)
	High	40 (14)	36 (12)	37 (12)
Males (%)	Low	47	51	59
	Medium	44	50	55
	High	46	54	56
Females (%)	Low	52	49	41
	Medium	56	50	45
	High	54	45	43
Households with children (%)	Low	23	32	34
	Medium	27	40	45
	High	41	53	65
In working life (%)	Low	62	66	72
	Medium	67	74	76
	High	77	78	85
Students (%)	Low	2	3	3
	Medium	7	7	6
	High	9	11	6
Retired (%)	Low	21	16	9
	Medium	14	9	8
	High	7	3	2
Higher income (%)	Low	42	44	52
	Medium	45	50	53
	High	47	47	54

Table 5
Multinomial logistic regression models comparing traveller segments in terms of sociodemographic variables. Logit coefficients with 95% confidence intervals. Reference categories are Neutral and Medium multimodality.

	Dependent variable:					
	Males	Children in household	In working life	Students	Retired	Higher income
Sceptics	**−0.232****	**−0.582****	**−0.308****	−0.040	**0.469****	**−0.175***
	[−0.403, −0.060]	[−0.769, −0.396]	[−0.494, −0.123]	[−0.374, 0.294]	[0.210, 0.728]	[−0.347, −0.003]
Enthusiastic	**0.200***	**0.232****	0.140	−0.266	−0.203	0.113
	[0.029, 0.370]	[0.061, 0.404]	[−0.058, 0.337]	[−0.623, 0.091]	[−0.510, 0.104]	[−0.057, 0.284]
Low multimodality	0.054	**−0.326****	**−0.366****	**−0.815****	**0.563****	**−0.207****
	[−0.091, 0.200]	[−0.479, −0.173]	[−0.525, −0.207]	[−1.173, −0.458]	[0.340, 0.786]	[−0.354, −0.060]
High multimodality	**0.192***	**0.519****	**0.255****	**0.498****	**−1.229****	−0.139
	[0.039, 0.344]	[0.365, 0.673]	[0.075, 0.435]	[0.234, 0.762]	[−1.612, −0.845]	[−0.292, 0.014]
Sceptics × Low multimodality	0.089	0.131	0.121	−0.563	−0.089	0.082
	[−0.151, 0.330]	[−0.136, 0.399]	[−0.134, 0.376]	[−1.222, 0.096]	[−0.428, 0.250]	[−0.161, 0.325]
Enthusiastic × Low multimodality	0.128	−0.143	0.144	0.067	−0.367	0.197
	[−0.155, 0.412]	[−0.435, 0.149]	[−0.171, 0.459]	[−0.694, 0.828]	[−0.845, 0.111]	[−0.086, 0.480]
Sceptics × High multimodality	−0.121	0.131	0.217	−0.236	0.350	0.179
	[−0.441, 0.200]	[−0.200, 0.462]	[−0.153, 0.587]	[−0.810, 0.338]	[−0.305, 1.005]	[−0.142, 0.500]
Enthusiastic × High multimodality	−0.122	**0.267***	**0.301***	−0.380	−0.270	0.159
	[−0.361, 0.117]	[0.025, 0.508]	[0.008, 0.594]	[−0.850, 0.090]	[−0.904, 0.363]	[−0.080, 0.397]
Constant	−0.016	**−0.416****	**1.025****	**−2.559****	**−2.255****	0.012
	[−0.113, 0.081]	[−0.515, −0.317]	[0.915, 1.134]	[−2.746, −2.372]	[−2.420, −2.090]	[−0.085, 0.109]
Note:	*p < 0.05; **p < 0.01					

Table 6
Path model for the effects of age and multimodality on the intention to use L3 AVs.

Path	Standardized		Unstandardized		
	Estimate	95% CI	Estimate	Std.err.	Z
Age → Multimodality	−0.365	[−0.383, −0.347]	−0.024	0.001	−35.768**
Multimodality → Intention to use	0.307	[0.287, 0.328]	0.366	0.013	27.952**
Age → Intention to use (direct)	−0.105	[−0.126, −0.083]	−0.008	0.001	−9.537**
Age → Multimodality → Intention to use (indirect)	−0.112	[−0.122, −0.103]	−0.009	0.0004	−22.025**
Total age → Intention to use (direct + indirect)	−0.217	[−0.237, −0.197]	−0.017	0.001	−20.273**
Note:					**p < 0.01

analysis was based on a survey among car drivers from eight European countries. Nine traveller segments were formed to demonstrate their inter-relationships and explore their relationships with sociodemographic variables. The segments were formed by dividing the respondents into sceptics, neutrals, and enthusiastics based on their intention to use L3 AVs, and low, medium, and high based on their level of multimodality.

Among the respondents, use of a personal car as a driver and walking more than 500 m were the most commonly used transport modes. Their use was typically at least weekly both among those who used and did not use alternative modes, such as public transport and active travel. This observation is in line with earlier studies, which have recognized that travel behaviour can be characterized on a continuum from car-based monomodality to multimodality (Molin et al., 2016; Nobis, 2007). Consequently, a score based on the frequency of alternative use mode, excluding driving a personal car and walking, was used to quantify multimodality in this study.

The majority of respondents did not expect a change in their use of public transport and active travel based on the introduction of L3 AVs; 26% expected a decrease and 12% an increase in their use of public transport. For active travel, the shares of those expecting a decrease (17%) and an increase (16%) were in balance. A large share of the respondents expected a decrease in public transport or active travel and were currently using these regularly (public transport 12%, active travel 15%). There were only a few travellers expecting an increase and not regularly using them (public transport 6%, active travel 2%).

The current results suggest that L3 AVs could pose a challenge to the sustainability of the future transport system by encouraging current users of public transport and active travel to switch to AVs. Public transport may be more susceptible than active travel. The possibility to multitask while travelling could be a motivation to choose public transport over a personal car, but L3 AVs could facilitate engagement in non-driving related activities. L3 AVs are unlikely to address some motivations to use active travel modes, such as physical exercise, low environmental impact and low cost (Anable and Gatersleben, 2005).

A higher intention to use L3 AVs was associated with a higher probability to expect a decrease in the use of public transport and active travel. To our knowledge, the link between the behavioural intention to use L3 AVs and a drop in the use of public transport or active travel has not been reported before. A higher behavioural intention is motivated e.g. by positive expectations of the technology (Nordhoff et al., 2020; Venkatesh et al., 2003, 2012). Thus, the finding is in line a previous finding that a positive attitude towards AVs decreases the use of public transport and active travel (Booth et al., 2019).

Multimodality increased the probability of expecting a change in the use of public transport and active travel in either direction. This is in line with previous studies, which have suggested that multimodal travellers are more likely to change their travel modes and to use shared AVs (Diana and Mokhtarian, 2009; Kopp et al., 2015; Kroesen, 2014; Krueger et al., 2016; Molin et al., 2016).

Multimodality and intention to use L3 AVs were positively correlated. Mediation analysis suggested that multimodal travellers' younger age could partially explain the positive correlation between multimodality and intention to use L3 AVs, as younger people typically hold more positive views towards AVs (Liljamo et al., 2018; Nordhoff et al., 2020).

It should also be noted that age may directly influence expected changes in travel mode. For example, younger persons who do not own a car may look forward to having one in the future regardless of whether it is automated. When asked how L3 AVs would change respondents' personal mobility, their answer could have something to do with their view of the future in general.

Besides younger age, sociodemographic factors may also contribute to the correlation between multimodality and willingness to use AVs. Multimodal travel behaviour is more common in urban environments (Molin et al., 2016; Nobis, 2007) and those who live there tend to be more willing to use AVs (Liljamo et al., 2018). On the other hand, increased availability of public transport options and reduced parking possibilities in cities (Scheiner et al., 2016) may make the use of public transport more feasible. In the current sample, high multimodal individuals were slightly more often males than females, and males typically have a higher willingness to use AVs (Liljamo et al., 2018; Nordhoff et al., 2020). Higher multimodality was associated with a higher participation in working life and having children in the household. Both were also positively associated with being enthusiastic about L3 AVs (i.e., higher intention to use). In contrast, lower income level was associated with being sceptical and less multimodal. This suggests that L3 AVs may address the needs of travellers who are trying to balance work and family. Many of them also actively use different modes to meet their travel needs. This is in contrast to previous research, which has linked multimodality with smaller households (Buehler and Hamre, 2015; Molin et al., 2016) and being young or retired (Nobis, 2007; Scheiner et al., 2016). Possibly, the disparity in results is due to the current sample being limited to the age range 18–70 years and not having included people who do not use a personal car daily.

Limitations

The current study has its limitations. The goal was to have a representative sample of car users in each country, but the topic of the questionnaire and the use of Internet panels may have skewed the sample towards participants who were generally more interested in technology.

The current data did not contain data on attitudes towards travel modes, nor motives for or barriers to travel mode choices, which could help explain the expected changes. Respondents were given detailed descriptions of L3 AVs, but vehicle automation is likely to change personal mobility in ways that they could not foresee. The obvious limitation of future-oriented stated-preference studies is that they can suggest possible outcomes but not confirm them.

Intention to use L3 AVs was measured with the behavioural intention construct based on Nordhoff et al. (2020). The measure used only two items, which may not cover all the aspects of intention to use.

Policy implications

Increasing the sustainability of transport is a global challenge and strategic goal, also for the EU (European Commission, 2020). Shifting towards a multimodal transport system as opposed to car-based monomodality is often seen as a way to achieve a more sustainable transport system (European Commission, 2020). The current results suggest that L3 AVs may attract users of public transport and active travel to switch to car-travel. The intention to use is highest among current multimodal travellers, and their behaviour is likely to have the greatest impact on the modal share of public transport and active travel.

An increase in car travel would create more congestion and emissions, including exhaust fumes, microplastics from tires and CO_2 if vehicles run on fossil fuels. Worsening congestion could limit the growth of car travel but could also encourage greater investments in road infrastructure.

Looking at future trends, urbanization may further worsen problems with congestion. Shared L3 AVs could also provide a more private and convenient alternative to public transport, attracting also those who do not own a car. On the other hand, mobility-as-a-service (MaaS), new forms of micromobility, and innovations in automated public transportation may also decrease car dependency in unforeseen ways. Regardless of the above, it should be noted that L3 AVs may also have positive impacts, such as increased safety and efficiency of transport.

Personal car use is attractive due to its relatively high speed and convenience compared to alternative modes. Automated driving may further increase the convenience and reduce the value of travel time. However, the speed and convenience of cars is largely due to the infrastructure supporting or even necessitating car use. Infrastructure has been found to influence travel patterns: When moving to a city which supports multimodal travelling, people are more likely to become multimodal than when moving to a more car-dependent city (Klinger and Lanzendorf, 2016; Klinger et al., 2013).

Creating environments where multimodal travel is feasible could help nudge travellers to move away from car-based monomodality towards multimodal travelling. Compact form and prioritizing public transport and active travel, as in the eco-city concept (Kenworthy, 2006), could help achieve this. Use of L3 AVs in urban areas can also be reduced with conventional measures such as congestion charging (Börjesson and Kristoffersson, 2018) and controlling the price and availability of parking (Christiansen et al., 2017; Lehner and Peer, 2019).

Conclusions

The current results show that among car drivers a higher intention to use L3 AVs was associated with a greater probability to reduce the use of public transport and active travel, once L3 AVs are available. Multimodal travel behaviour increases the probability of expecting a change in general, either an increase or decrease. Overall, multimodal travellers who regularly use public transport could be those with the greatest potential to use public transport less once L3 AVs become available.

Future research needs to investigate why multimodal travellers are keen on using L3 AVs and what kind of trips L3 AVs could replace. Research on motives for change is needed: For example, to what extent is a shift to L3 AVs motivated by current barriers to non-automated car driving, and to what extent by the possibility to engage in non-driving related activities? Understanding these motivations could help create policy countermeasures. It would also be valuable to investigate how experience with automated driving influences the expected impacts once L3 AVs are in use.

Supporting multimodal travel has been envisioned as a way to increase the sustainability of the transport system. The current results suggest that L3 AVs can pose a serious challenge to sustainability by attracting current multimodal public transport and active travel users to switch to personal AVs. AV-related changes in personal mobility need to be monitored in the future.

CRediT authorship contribution statement

Esko Lehtonen: Conceptualization, Methodology, Software, Validation, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. **Fanny Malin:** Conceptualization, Writing - review & editing. **Satu Innamaa:** Conceptualization, Writing - review & editing. **Sina Nordhoff:** Investigation, Data curation, Writing - review & editing. **Tyron Louw:** Writing - review & editing. **Afsaneh Bjorvatn:** Writing - review & editing. **Natasha Merat:** Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The research leading to these results received funding from the European Commission Horizon 2020 program under the project L3Pilot, grant agreement number 723051. The information and views set out in this publication are the sole responsibility of the authors. The authors would like to thank the partners within L3Pilot for their cooperation and valuable contribution. We thank Adelaide Lönnberg (MapleMountain Editing) for revising the language of the text.

Data availability

Available from the corresponding author upon reasonable request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2021.100380.

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