Journal of Transport & Health 15 (2019) 100623

Contents lists available at ScienceDirect

Journal of Transport & Health

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

The potential implications of autonomous vehicles for active transport

Leon Booth[a], Richard Norman[b], Simone Pettigrew[a,*]

[a] School of Psychology, Curtin University, Kent St, Bentley, WA, 6102, Australia
[b] School of Public Health, Curtin University, Kent St, Bentley, WA, 6102, Australia

ARTICLE INFO

Keywords:
Active transport
Walking
Bicycling
Public health
Policy
Environment

ABSTRACT

Introduction: Active transport (e.g., walking, cycling, and public transport) is associated with numerous health benefits and is the most environmentally sustainable means of personal transport. The introduction of autonomous vehicles (AVs) is expected to result in wide-scale changes to active transport behaviors. Assessing the likely extent of these changes is important to inform strategies designed to minimize disruptions to active transport resulting from AVs.
Methods: An online survey was administered to a national sample of 1624 Australians of driving age (16 years and older). Respondents reported their current levels of engagement in walking, cycling, and/or public transport, and how likely they would be to use an AV instead of these activities. Regression models were used to explore how demographic, psychological, and various transport-related factors were associated with the likelihood of substituting AVs for each mode of active transport.
Results: Substantial minorities of respondents indicated that they would be likely to use AVs instead of walking (18%), cycling (32%), and public transport (48%). The examined factors accounted for significant amounts of variance in each regression model. One factor was significant in all three models: a more favorable general attitude to AVs was associated with a greater likelihood of replacing walking, cycling, and public transport with AV use.
Conclusions: Overall, the results suggest that AVs could substantially reduce participation in active transport, with corresponding disbenefits for individuals and society. Policies need to be implemented immediately to promote the use of active transport and minimize the migration from active transport to AVs.

1. Introduction

1.1. Active transport

Transport options that involve physical activity are referred to as active transport (Frank et al., 2010). The primary forms of active transport are walking, cycling, and public transport (Pérez et al., 2017). While public transport itself does not involve physical activity, it is considered to be a form of active transport because journeys undertaken using public transport typically involve walking or cycling for a portion of the trip (Saghapour et al., 2018).

* Corresponding author.
E-mail addresses: Leon.booth@curtin.edu.au (L. Booth), Richard.norman@curtin.edu.au (R. Norman), simone.pettigrew@curtin.edu.au (S. Pettigrew).

https://doi.org/10.1016/j.jth.2019.100623
Received 29 April 2019; Received in revised form 21 August 2019; Accepted 22 August 2019
Available online 31 August 2019
2214-1405/

Active transport has many individual and societal-level benefits, particularly in terms of physical activity and greenhouse gas emissions (Frank et al., 2010; Pérez et al., 2017). Physical inactivity is a substantial health issue that contributes to the development of non-communicable diseases such as type 2 diabetes, cardiovascular disease, and cancer (Wagner and Brath, 2012). Non-communicable diseases resulting from physical inactivity are estimated to cause three million preventable deaths per year worldwide, place a substantial burden on healthcare systems, and reduce productivity (Muka et al., 2015; World Health Organization, 2009). Conversely, the use of active transport increases physical activity, thereby reducing rates of non-communicable diseases (Jarrett et al., 2012). In terms of greenhouse gas emissions, active transport generates fewer emissions per person per mile than private vehicles (Woodcock et al., 2007). In addition, the vehicle manufacturing process is resource intensive and thus further contributes to emissions (Neves and Brand, 2018). Combining both these sources of emissions, the average car produces approximately 10 times more emissions per mile travelled over its lifespan compared to a bicycle (Neves and Brand, 2018). As such, increasing the use of active transport can reduce the significant carbon footprint that is currently created by private vehicles (Ngo et al., 2018).

Governments are increasingly implementing strategies to encourage the use of active transport to improve health outcomes, reduce emissions, and increase the livability of cities (Alvanides, 2014; Decker et al., 2012). Examples of these strategies include urban designs that promote the use of active transport and discourage the use of cars (Wefering et al., 2013), health promotion programs that encourage children and adults to use active transport for their commutes to school/work (Larouche et al., 2018; Merom et al., 2008), and greater expenditure on public transport (Hidalgo and Huizenga, 2013; Jiang et al., 2017). In Australia, the context of the present study, the level of motor vehicle ownership is among the highest in the world at 776 vehicles per 1000 people (Australian Bureau of Statistics, 2018c; Wu et al., 2014). Only 9% of Australians travel to work via public transport, 1% by bicycle, and 4% by foot (Australian Bureau of Statistics, 2017). The Australian government has recognized that Australia's reliance on cars is unsustainable and that there is a need to encourage and facilitate greater use of active transport (Arundel et al., 2017; Infrastructure Australia, 2016).

1.2. Autonomous vehicles

The wide-scale introduction of autonomous vehicles (AVs) is expected to change people's transport behaviors, including those relating to active transport (Soteropoulos et al., 2019). AVs are vehicles that can independently perform the tasks associated with driving, thereby removing the need for a human driver (Milakis, 2019). The replacement of conventional vehicles with AVs is expected to provide many public health benefits, including reduced traffic fatalities, lower emissions, decreased traffic congestion, and increased mobility for people who are unable to drive (Kelley, 2017; Pettigrew, 2017). However, AV use might also have unintended negative consequences, including increased congestion and reduced active transport (Childress et al., 2015; Crayton and Meier, 2017). Compared with active or public transport, AVs offering door-to-door transport will reduce physical activity requirements (Crayton and Meier, 2017), and while AVs are predicted to produce fewer emissions than conventional vehicles due to being electric and more efficient (Milakis et al., 2017), active transport will still remain a more sustainable option (Creger et al., 2019). As such, despite the benefits that AVs will bring, active transport will continue to be the preferred mode of transport across many health and environmental outcomes (Creger et al., 2019).

As AVs are not yet widely available, there is limited understanding as to how they will affect the use of active transport (Hall et al., 2018). It is possible that AVs will complement active transport by increasing pedestrian/cyclist safety and providing a convenient ‘first and last mile’ service for public transport (Combs et al., 2019; Creger et al., 2019). Alternatively, AVs could provide a more appealing transport option that results in many people replacing active transport altogether (Childress et al., 2015). Younger people, males, and those with longer commutes have been found to be more willing to use AV technology (Becker and Axhausen, 2017), making it likely that these population sub-groups will be more predisposed to substituting active transport with AVs. Research is needed to provide policy makers with insights into how the use of active transport is likely to change with the advent of AVs across the population and for specific sub-groups to enable the formulation of appropriate strategic responses (Crayton and Meier, 2017; Fagnant and Kockelman, 2015; Taeihagh and Lim, 2019).

1.3. Insights from modelling research

Due to the lack of empirical evidence available to assess how AVs are likely to affect transport choices (Hall et al., 2018), simulation models are commonly used to investigate different hypothetical AV scenarios. Soteropoulos et al. (2019) reviewed 37 AV computational modelling studies, 10 of which simulated the effect that AVs would have on public transport, five on walking, and three on cycling. The results of these studies varied considerably, especially in terms of public transport outcomes. Usage levels of public transport were predicted to change by −75% to +138%. The simulations that predicted an increase in the use of public transport hypothesized that AVs would be integrated into public transport networks, thereby increasing the efficiency and range of public transport (Gelauff et al., 2017). By comparison, those that predicted a decrease assumed that AVs would offer a more comfortable and faster option than public transport at a competitive price (De Almeida Correia and Van Arem, 2016). Most of the AV simulations that projected changes to walking and cycling predicted declines (change in walking: −56% to +7%; change in cycling; −45% to −2%). The only study predicting an increase in walking assumed that all conventional vehicles (cars, motorcycles, taxis, and buses) were no longer available, which resulted in the simulated users switching to AVs, public transport, and walking, with walking demonstrating the smallest increase (Martinez and Viegas, 2017).

Decreases in the use of all modes of active transport were particularly pronounced in simulations that assumed AVs would be privately owned rather than being a part of a shared fleet (Childress et al., 2015). Private AVs were expected to be preferred over shared AVs and active transport due to their added comfort, time efficiency, and ease of use (Childress et al., 2015; Soteropoulos et al., 2019). AVs were also predicted to reduce the 'cost' of travel time, as it was expected that they will allow passengers to engage in activities such as socializing, working, or relaxing while travelling (De Almeida Correia and Van Arem, 2016; Soteropoulos et al., 2019).

Simulation studies are limited by the restricted scope of the factors they investigate and the values that are assigned to these factors. Estimated variables commonly incorporated into simulation models include the level of AV market penetration, the cost of using AVs to the passenger, whether AVs are shared or private, and the cost of travel time. The large differences in values assigned to these variables produced substantial variations in the predicted changes to active transport (Soteropoulos et al., 2019). Due to their nature, the simulations did not attempt to examine human factors that have previously been shown in survey studies to affect intentions to use AVs, such as age, gender, knowledge of AVs, and attitude to AVs (Becker and Axhausen, 2017; Haboucha et al., 2017). Theoretical frameworks such as the Theory of Planned Behavior, the Unified Theory of Acceptance and Use of Technology, and the Technology Acceptance Model note the potential importance of these variables in influencing behavioral intentions (Ajzen, 1991; Venkatesh and Davis, 2000; Viswanath et al., 2003), highlighting the importance of including these variables in future analyses.

1.4. The present study

An exploratory study was undertaken to (i) assess the extent to which AVs are likely to be used in place of active transport and (ii) examine the potential role of factors that may influence substitution intentions. Individuals who currently use active transport were directly asked about their replacement intentions, thus extending the understanding of this issue beyond the results of previous simulation studies. The factors assessed in the present study that have not been included in AV simulation research were age, gender, location (metropolitan vs. non-metropolitan), knowledge of AVs, attitude to AVs, likelihood of buying an AV, likelihood of using an AV ride-share, overall physical activity, and current hours spent using each form of active transport. These factors have been examined in previous general AV research and active transport research (Becker and Axhausen, 2017; Haboucha et al., 2017; Merom et al., 2008; Nordhoff et al., 2018), but to date do not appear to have been investigated in the context of intentions to replace active transport with AV use.

2. Method

2.1. Sample

The data for this study were gathered as part of a larger research project examining the potential social implications of the advent of AVs. An online survey was administered to a national sample of Australians of legal driving age (16 years and older, $n = 1621$) by PureProfile, a large web panel provider that has been accredited by the International Organization for Standardization (ISO). Respondents received a small financial reward for participating in the survey. Quotas were applied to the sample to ensure an equal gender split and an even representation across three age categories (33% 16–30 years, 33% 31–50 years, 34% 51+ years). Table 1 compares the demographic characteristics of the sample to national demographic distributions. The project was approved by the

Table 1
Sample profile (n = 1621).

Demographic Attribute	*n*	Present Study (%)	Australian Population [a] (%)
Gender			
Female	811	50	51
Male	810	50	49
Age			
Mean (*SD*)		42.9 (17.6)	N/A
16–30 years	530	33	24
31–50 years	543	34	34
51+ years	548	34	42
Socioeconomic status [b]			
Low	481	30	34
Mid	758	47	41
High	376	23	25
Missing [c]	6	0.4	N/A
Education			
Tertiary	586	36	31
Non-tertiary	1035	64	69

Note: Proportions may not add up to 100% due to rounding. N/A = not available.

[a] Percentages for age and gender are from the Australian Bureau of Statistics (2016) census data. Percentages for education are based on the Australian Bureau of Statistics (2018b) Education and Work data cubes for persons aged 20–64 years.

[b] Socio-Economic Indexes for Areas (SEIFA) classification (Australian Bureau of Statistics, 2018a).

[c] Treated listwise.

Curtin University Human Research Ethics Committee.

2.2. Survey instrument

Consistent with the theoretical frameworks mentioned above, the survey incorporated items relating to sociodemographic, attitudinal, and behavioral intentions variables. Respondents reported their demographic characteristics (age, gender, postcode) and the average number of hours per week they spent walking, cycling, and on public transport. General attitude to AVs was explored by asking "*How do you feel about fully autonomous vehicles being widely used in the future?*" (response options: 1 (Very negative) to 5 (Very positive)). To examine self-perceived knowledge of AVs, respondents were asked *"How much do you know about fully autonomous vehicles?"* (response options: 1 (Nothing at all) to 4 (A large amount)). Intention to use private or shared AVs was assessed by asking whether they would "*Ever buy a fully autonomous vehicle?"* and "*Use an autonomous vehicle ride sharing service (like Uber) if it was available?"* (response options: 1 (Very unlikely) to 5 (Very likely)). Reflecting the expectation that AVs and non-AVs will share the roads in the coming decades (Taeihagh and Lim, 2019), respondents were then told to "imagine a scenario in which both conventional driver-operated cars and autonomous vehicles are available". Respondents were asked how likely they would be to replace their existing forms of active transport with an AV. For example, "*How likely would you be to use an autonomous vehicle for trips that you currently walk?"* (response options: 1 (Very unlikely) to 5 (Very likely) and 'Don't know/Not applicable').

2.3. Data analysis

Data were analyzed using SPSS version 24. Three ordinary least squares multiple regression models were used to determine whether the assessed factors (age, gender, location (determined via postcode), knowledge of AVs, attitude to AVs, intentions to use AVs, engagement in physical activity, and current use of active transport) were associated with intentions to use AVs in place of walking, cycling, or public transport. The factors were simultaneously entered into each regression model to estimate the variance accounted for by each factor. Respondents were only included in each regression analysis if they currently engaged in that form of active transport. Additionally, respondents who answered 'Don't know/Not applicable' for the likelihood of using an AV in place of a mode of active transport were excluded from the respective regression model. To assess the robustness of the resulting models, ordinal regressions were also conducted. These analyses revealed a comparable pattern of findings (results not shown).

3. Results

Table 2 presents the results for respondents' intentions to use an AV in place of each active transport option. Among those reporting regular walking ($n = 1528$), 18% indicated being somewhat/very likely to use an AV instead. In terms of regular cycling ($n = 362$) and public transport use ($n = 625$), replacement rates were higher at 32% and 48% respectively.

The assessed factors accounted for a significant amount of variance in the likelihood of substituting walking with an AV (adjusted $R^2 = 0.15$, F (9, 1309) = 25.68, $p < 0.001$), cycling (adjusted $R^2 = 0.14$, F (9, 307) = 5.38, $p < 0.001$), and public transport (adjusted $R^2 = 0.33$, F (9, 550) = 29.41, $p < 0.001$). Fig. 1 illustrates the significant predictors identified across the three modes of active transport and the complete results of the regression models are presented in Table 3. Just one factor, a more favorable attitude to AVs, was significantly positively associated with substitution in all cases. Age was negatively associated with two active transport mode replacements: older respondents were less likely to report using AVs in place of walking and public transport, but not cycling. The numbers of hours spent walking and on public transport were also positively associated with the likelihood of replacing those modes of active transport.

4. Discussion

Consistent with the findings of simulation studies (Chen and Kockelman, 2016; Kröger et al., 2018; Soteropoulos et al., 2019), the results of the present study suggest that AVs have the potential to significantly reduce participation in all three primary forms of active transport. This was found to be especially the case for public transport, which is likely to reflect the fact that this form of transport is primarily used for commuting, whereas walking and cycling are also often undertaken for exercise or leisure, the benefits of which cannot be replicated by AV use (Redman et al., 2013; Xia et al., 2017). The results highlight the need to proactively develop strategies to optimize the use of active transport before, during, and after the wide-scale introduction of AVs. Ideally these strategies would be designed to minimize the number of people who choose to substitute their current use of active transport with AVs, while also encouraging more people to engage in active transport to increase population-level participation.

The only factor that was significant in all three regression models was a positive attitude to AVs, indicating that this variable will be an especially important consideration in the development of strategies to lessen the impact that AVs are likely to have on active transport. The two other factors that were significant in at least two models were age and existing time spent engaging in the relevant transport mode. In line with previous research predicting more rapid AV adoption rates among younger people, younger respondents reported higher levels of replacing walking and public transport with AVs than older respondents (Becker and Axhausen, 2017; Kyriakidis et al., 2015). Respondents who spent more rather than less time walking and using public transport demonstrated a greater likelihood of substituting these forms of active transport with AV use, which is congruent with previous research finding that people with longer commute times tend to be more willing to adopt AV technology (Becker and Axhausen, 2017).

Table 2
Likelihood of using an AV in place of current active transport behaviors.

Behavior	Median score	Very/Somewhat unlikely (%)	Neither likely nor unlikely (%)	Very/Somewhat likely (%)	Don't know/Not applicable (%)
Use an autonomous vehicle for trips that you currently walk (n = 1528)	2	58	19	18	5
Use an autonomous vehicle for trips that you currently make using a bicycle (n = 362)	3	44	19	32	6
Use an autonomous vehicle for trips that you currently make using public transport (n = 625)	4	30	18	48	5

Note: Median score calculated on a scale of 1 (Very unlikely) to 5 (Very likely). The n value for each behavior represents the number of respondents who reported engaging in that mode of active transport.

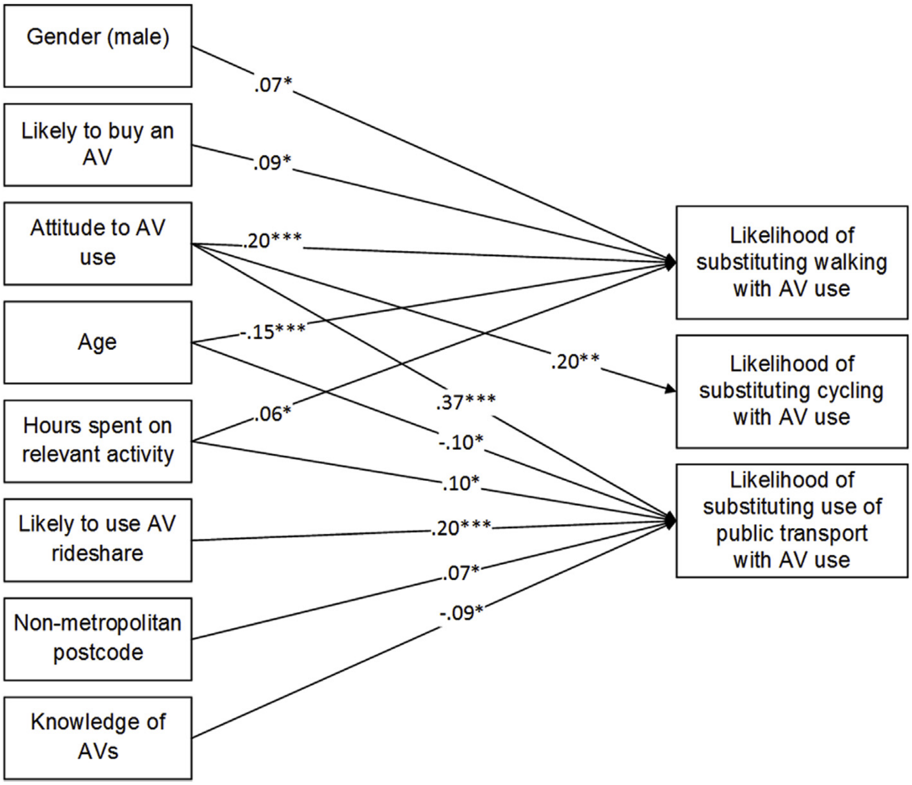

Fig. 1. Significant predictors identified in each regression model. The standardized β coefficients are reported for each predictor. Negative values indicate a negative relationship between the predictor and criterion variables. *$P < 0.05$. **$P < 0.01$. ***$P < 0.001$.

Table 3
Results of three active transport regression models, including unstandardized (B) and standardized (β) regression coefficients for each predictor.

Variable	Walking		Cycling		Public Transport	
	B [95% CI]	*β*	*B* [95% CI]	*β*	*B* [95% CI]	*β*
Gender (male)	.17 [−.30, −.04]	.07*	−.09 [−.21, .39]	.03	.14 [−.05, .33]	.05
Age	−.01 [−.01, −.01]	−.15***	−.01 [−.02, .01]	−.08	−.01 [−.01, −.00]	−.10*
Metro (non-metropolitan)	−.05 [−.20, .01]	−.02	−.11 [−.49, .27]	-.03	.35 [−.02, .69]	.07*
Knowledge about AVs	< .01 [−.01, .01]	< .01	.18 [−.04, .39]	.09	−.17 [−.31, −.03]	−.09*
Attitude to AVs	.23 [.16, .31]	.20***	.26 [.07, .44]	.20**	.48 [.36, .60]	.37***
Likely to ever buy an AV	−.08 [.01, .15]	.09*	.14 [−.02, .31]	.14	−.04 [−.07, .15]	.04
Likely to use AV rideshare	.07 [< .01, .13]	.07	−.03 [−.19, .14]	−.03	.21 [.11, .31]	.20***
Engagement in physical activity	< .01 [−.01, .01]	.02	< −.01 [−.02, .01]	−.04	< .01 [−.01, .011]	.03
Hours spent on relevant activity	.01 [< .01, .03]	.06*	.04 [−.01, .08]	.11	.03 [.01, .06]	.10*

Note: Hours spent on relevant activity refers to the hours per week that the person engaged in that form of transport (e.g. hours spent walking per week). β regression coefficients are standardized in terms of the units of measurement.
*$P < 0.05$. **$P < 0.01$. ***$P < 0.001$.

4.1. Strategies to encourage active transport

The anticipated reduction in active transport associated with more favorable attitudes to AVs presents a particular dilemma for policy makers because these positive attitudes need to be fostered to achieve the many expected public health benefits of conversion from traditional vehicles (Pettigrew et al., 2018), while also encouraging the prioritization of active transport. To achieve this difficult task, potential strategies will need to be multifactorial in nature to take into account the numerous external and psychological factors that shape transport choices (Bouscasse et al., 2018; Lanzini and Khan, 2017).

Relevant external factors include the relative cost, convenience, safety, and comfort of transport options (Xia et al., 2017). Cost is a particularly important determinant of transport use (Buehler, 2011), making pricing strategies a critical means of encouraging the continued and increased use of active transport during the introduction of AVs. For example, it is expected that road user charges will be applied on a cost-per-mile basis to enable governments to fund road and transport systems once license, registration, and fuel excise revenues cease being viable funding sources (Simoni et al., 2019). This will provide the opportunity to apply variable charges according to the type of transport (e.g., shared vs private vehicles) and route (e.g., whether public transport is available along the same travel corridor: Creger et al., 2019) to encourage the use of more socially beneficial forms of transport. Cycling could be promoted through free bike-sharing programs, with research indicating that people are receptive to this idea as a means to support active transport (Fishman et al., 2015; Xia et al., 2017).

The external environment can also be modified to support active transport via infrastructure changes that prioritize the use of active transport over personal car ownership (Cavoli and Cohen, 2019; Legacy et al., 2019). Urban densification is being pursued by numerous cities to improve various outcomes, including greater use of active transport (Arundel et al., 2017; Fan et al., 2014; Hawkins, 2013). Participation in walking and cycling can be promoted by developing networks of connected walkways/cycle paths (Brown et al., 2017; Tribby et al., 2017). Creating drop-off and pick-up zones for AVs could also further facilitate the use of walking (Creger et al., 2019; Vanwolleghem et al., 2014), although door-to-door AV services would need to be provided for people with reduced mobility given this is a key anticipated social benefit of AVs (Pettigrew et al., 2018).

In terms of psychological factors, transport habits are likely to be crucial in determining people's choices once AVs are a viable transport option (Lanzini and Khan, 2017). Transport habits involve the same mode of transport being used continually without alternatives being considered (Gardner and Abraham, 2008; Lanzini and Khan, 2017). People are more open to initiating the use of alternative modes of transport when the context around their habitual transport choice changes (Thomas et al., 2016; Verplanken and Wood, 2006). The impending advent of AVs represents one such disruptive change that is likely to cause individuals to reconsider their preferred mode(s) of transportation. Preemptive interventions will therefore be needed to prevent habitual active transport users from changing their current habits, and also to potentially encourage more people to adopt habitual active transport use during this phase of transport disruption. There is some evidence that interventions involving the provision of free public transport for a limited time can successfully persuade habitual car users to start using public transport, however the likelihood of long-term behavior change remains unclear (Abou-Zeid and Fujii, 2016; Lieberoth et al., 2018; Taniguchi et al., 2014).

4.2. Limitations and future research

The present study was exploratory in nature and had a number of limitations. While substantial minorities of respondents indicated that they would likely use AVs in place of the assessed forms of active transport, this may not translate into actual behavioral change due to the intentions-behavior gap (Sheeran, 2002) and the difficulty associated with envisaging a world in which AVs are common place. People might be more likely to use AVs instead of active transport when they can better appreciate the level of convenience that AVs will offer, with trial data indicating that Australians are more accepting of AVs after personally experiencing one (Royal Automobile Club, 2017). In addition, as the questions for active transport replacement intentions related to a possible future scenario, hypothetical bias may have resulted in respondents being overoptimistic in their intentions to continue using active transport once more convenient AVs are available (Burgess et al., 2010). The results of the present study may therefore underestimate the actual substitution rates once AVs are widely available. However, it is also possible that people will be more inclined to use active transport when AVs are available due to greater demonstrated safety for pedestrians and cyclists, which could ultimately make walking and cycling more appealing (Pettigrew et al., 2018).

Another limitation is the use of a web panel for respondent recruitment, which may have resulted in sampling bias. Although this was minimized through the use of quotas, the sample was somewhat younger than the national population. Future research could apply alternative sampling and data collection methods to provide comparison points. In addition, work is needed in other geographical locations to assess the extent of substitution that is likely to occur in other physical and cultural contexts.

The availability of measures investigating AV-related behaviors is limited due to this being a new areas of research, and as such the measures employed in the present study have not been previously validated. Furthermore, the present study did not directly ask respondents about replacement intentions for conventional vehicles, therefore the predicted reductions in active transport participation cannot be compared to potential reductions in conventional car use. Investigating whether replacement intentions for conventional cars differ to active transport is an important avenue for future research.

5. Conclusion

Both active transport and autonomous vehicles present numerous benefits for individuals and society. The introduction of AVs is likely to affect the number of people who use active transport, but until AVs are widely available the scale of this impact will be unknown. The present findings suggest that many people may replace their existing active transport behaviors with AV use, and that this is likely to be especially pronounced among those with more positive attitudes to AVs, younger people, and those exhibiting higher current levels of active transport use. To minimize the substitution of active transport with AVs, policy makers need to be proactive in implementing a range of strategies addressing relevant psychological and external factors to encourage the use of active transport prior to, during, and after the introduction of AVs (Legacy et al., 2019). AVs are set to fundamentally change transport in a way that will force extensive policy and infrastructure change (Fagnant and Kockelman, 2015). This represents an opportunity to consider the implications for active transport and ensure proactive efforts are made to both prepare for AVs and prioritize the use of active transport.

Funding statement

This work was supported by the Bankwest Curtin Economics Centre (BCEC). BCEC had no involvement in the design of the study; the collection, analysis, and reporting of the data; the writing of the manuscript; and the decision to submit the manuscript for publication.

References

Abou-Zeid, M., Fujii, S., 2016. Travel satisfaction effects of changes in public transport usage. Transportation 43 (2), 301–314. https://doi.org/10.1007/s11116-015-9576-3.

Ajzen, I., 1991. The theory of planned behavior. Organ. Behav. Hum. Decis. Process. 50 (2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-T.

Alvanides, S., 2014. Active transport: why and where do people (not) walk or cycle? J. Transp. Health 1 (4), 211–213. https://doi.org/10.1016/j.jth.2014.11.002.

Arundel, J., Lowe, M., Hooper, P., Roberts, R., Rozek, J., Higgs, C., Giles-Corti, B., 2017. Creating Liveable Cities in Australia: Mapping Urban Policy Implementation and Evidence-Based National Liveability Indicators. Centre for Urban Research RMIT University, Melbourne VIC Retrieved from: http://cur.org.au.

Australian Bureau of Statistics, 2016. A Snapshot of Australia on Census Night. Australian Bureau of Statistics, Canberra, ACT Retrieved from: http://www.censusdata.abs.gov.au.

Australian Bureau of Statistics, 2017. More than Two in Three Drive to Work, Census Reveals. Australian Bureau of Statistics, Canberra, ACT Retrieved from: https://www.abs.gov.au.

Australian Bureau of Statistics, 2018a. Census of Population and Housing: Socio-Economic Indexes for Areas (SEIFA), Australia, 2016. Australian Bureau of Statistics, Canberra, ACT Retrieved from: https://www.abs.gov.au.

Australian Bureau of Statistics, 2018b. Education and Work, Australia. May 2018 Australian Bureau of Statistics, Canberra, ACT Retrieved from: https://www.abs.gov.au.

Australian Bureau of Statistics, 2018c. Motor Vehicle Census. Australian Bureau of Statistics, Canberra, ACT Retrieved from: https://www.abs.gov.au.

Becker, F., Axhausen, K.W., 2017. Literature review on surveys investigating the acceptance of automated vehicles. Transportation 44 (6), 1293–1306. https://doi.org/10.1007/s11116-017-9808-9.

Bouscasse, H., Joly, I., Bonnel, P., 2018. How does environmental concern influence mode choice habits? A mediation analysis. Transp. Res. D Transp. Environ. 59, 205–222. https://doi.org/10.1016/j.trd.2018.01.007.

Brown, V., Moodie, M., Carter, R., 2017. Evidence for associations between traffic calming and safety and active transport or obesity: a scoping review. J. Transp. Health 7, 23–37. https://doi.org/10.1016/j.jth.2017.02.011.

Buehler, R., 2011. Determinants of transport mode choice: a comparison of Germany and the USA. J. Transp. Geogr. 19 (4), 644–657. https://doi.org/10.1016/j.jtrangeo.2010.07.005.

Burgess, J.A., Spence, J.C., Cameron Wild, T., 2010. Reducing overestimated intentions and expectations for physical activity: the effect of a corrective entreaty. Psychol. Health 25 (3), 383–400. https://doi.org/10.1080/08870440802491629.

Cavoli, C., Cohen, T., 2019. Automated vehicles: exploring possible consequences of government (non)intervention for congestion and accessibility. Transp. Rev. 39 (1), 129–151. https://doi.org/10.1080/01441647.2018.1524401.

Chen, T.D., Kockelman, K.M., 2016. Management of a shared autonomous electric vehicle fleet: implications of pricing schemes. Transp. Res. Rec. 2572 (1), 37–46. https://doi.org/10.3141/2572-05.

Childress, S., Nichols, B., Charlton, B., Coe, S., 2015. Using an activity-based model to explore the potential impacts of automated vehicles. Transp. Res. Rec. 2493, 99–106. https://doi.org/10.3141/2493-11.

Combs, T.S., Sandt, L.S., Clamann, M.P., McDonald, N.C., 2019. Automated vehicles and pedestrian safety: exploring the promise and limits of pedestrian detection. Am. J. Prev. Med. 56 (1), 1–7. https://doi.org/10.1016/j.amepre.2018.06.024.

Crayton, T.J., Meier, B.M., 2017. Autonomous vehicles: developing a public health research agenda to frame the future of transportation policy. J. Transp. Health 6, 245–252. https://doi.org/10.1016/j.jth.2017.04.004.

Creger, H., Espino, J., Sanchez, A.S., 2019. Autonomous Vehicle Heaven or Hell? Creating a Transportation Revolution that Benefits All. Greenlining Institute, Oakland, CA Retrieved from: http://greenlining.org.

De Almeida Correia, G.H., Van Arem, B., 2016. Solving the user optimum privately owned automated vehicles assignment problem (UO-POAVAP): a model to explore the impacts of self-driving vehicles on urban mobility. Transp. Res. Part B. Policy. Method. 87, 64–88. https://doi.org/10.1016/j.trb.2016.03.002.

Decker, B., Hećimović, H., Wołek, M., 2012. Sustainable urban mobility planning in central eastern europe: case examples from Poland and Croatia. Procedia. Soc. Behav. Sci. 48, 2748–2757. https://doi.org/10.1016/j.sbspro.2012.06.1244.

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

Fan, J.X., Wen, M., Kowaleski-Jones, L., 2014. An ecological analysis of environmental correlates of active commuting in urban U.S. Health Place 30, 242–250. https://doi.org/10.1016/j.healthplace.2014.09.014.

Fishman, E., Washington, S., Haworth, N., 2015. Bikeshare's impact on active travel: evidence from the United States, Great Britain, and Australia. J. Transp. Health 2 (2), 135–142. https://doi.org/10.1016/j.jth.2015.03.004.

Frank, L.D., Greenwald, M.J., Winkelman, S., Chapman, J., Kavage, S., 2010. Carbonless footprints: promoting health and climate stabilization through active transportation. Prev. Med. 50, S99–S105. https://doi.org/10.1016/j.ypmed.2009.09.025.

Gardner, B., Abraham, C., 2008. Psychological correlates of car use: a meta-analysis. Transp. Res. F Traffic Psychol. Behav. 11 (4), 300–311. https://doi.org/10.1016/j.trf.2008.01.004.

Gelauff, G., Ossokina, I., Teulings, C., 2017. Spatial Effects of Automated Driving: Dispersion, Concentration or Both? Netherlands Institute for Transport Policy Analysis, The Hague. https://doi.org/10.13140/RG.2.2.32766.48965.

Haboucha, C.J., Ishaq, R., Shiftan, Y., 2017. User preferences regarding autonomous vehicles. Transp. Res. C Emerg. Technol. 78, 37–49. https://doi.org/10.1016/j.trc.2017.01.010.

Hall, J.D., Palsson, C., Price, J., 2018. Is Uber a substitute or complement for public transit? J. Urban Econ. 108, 36–50. https://doi.org/10.1016/j.jue.2018.09.003.

Hawkins, C., 2013. Competing interests and the political market for smart growth policy. Urban Stud. 51 (12), 2503–2522. https://doi.org/10.1177/0042098013512875.

Hidalgo, D., Huizenga, C., 2013. Implementation of sustainable urban transport in Latin America. Res. Transp. Econ. 40 (1), 66–77. https://doi.org/10.1016/j.retrec.2012.06.034.

Infrastructure Australia, 2016. Australian Infrastructure Plan: Priorities and Reforms for Our Nation's Future. Infrastructure Australia, Sydney NSW Retrieved from: https://infrastructureaustralia.gov.au.

Jarrett, J., Woodcock, J., Griffiths, U.K., Chalabi, Z., Edwards, P., Roberts, I., Haines, A., 2012. Effect of increasing active travel in urban England and Wales on costs to the national health service. The Lancet 379 (9832), 2198–2205. https://doi.org/10.1016/S0140-6736(12)60766-1.

Jiang, B., Liang, S., Peng, Z.-R., Cong, H., Levy, M., Cheng, Q., ... Remais, J.V., 2017. Transport and public health in China: the road to a healthy future. The Lancet 390 (10104), 1781–1791. https://doi.org/10.1016/S0140-6736(17)31958-X.

Kelley, B., 2017. Public health, autonomous automobiles, and the rush to market. J. Public Health Policy 38 (2), 167–184. https://doi.org/10.1057/s41271-016-0060-x.

Kröger, L., Kuhnimhof, T., Trommer, S., 2018. Does context matter? A comparative study modelling autonomous vehicle impact on travel behaviour for Germany and

the USA. Transp. Res. A Policy Pract. https://doi.org/10.1016/j.tra.2018.03.033.
Kyriakidis, M., Happee, R., de Winter, J.C.F., 2015. Public opinion on automated driving: results of an international questionnaire among 5000 respondents. Transp. Res. F Traffic Psychol. Behav. 32, 127–140. https://doi.org/10.1016/j.trf.2015.04.014.
Lanzini, P., Khan, S.A., 2017. Shedding light on the psychological and behavioral determinants of travel mode choice: a meta-analysis. Transp. Res. F Traffic Psychol. Behav. 48, 13–27. https://doi.org/10.1016/j.trf.2017.04.020.
Larouche, R., Mammen, G., Rowe, D., Faulkner, G., 2018. Effectiveness of active school transport interventions: a systematic review and update. BMC Public Health 18 (1). https://doi.org/10.1186/s12889-017-5005-1.
Legacy, C., Ashmore, D., Scheurer, J., Stone, J., Curtis, C., 2019. Planning the driverless city. Transp. Rev. 39 (1), 84–102. https://doi.org/10.1080/01441647.2018.1466835.
Lieberoth, A., Holm Jensen, N., Bredahl, T., 2018. Selective psychological effects of nudging, gamification and rational information in converting commuters from cars to buses: a controlled field experiment. Transp. Res. F Traffic Psychol. Behav. 55, 246–261. https://doi.org/10.1016/j.trf.2018.02.016.
Martinez, L.M., Viegas, J.M., 2017. Assessing the impacts of deploying a shared self-driving urban mobility system: an agent-based model applied to the city of Lisbon, Portugal. Int. J. Transp. Sci. Technol. 6 (1), 13–27. https://doi.org/10.1016/j.ijtst.2017.05.005.
Merom, D., Miller, Y.D., van der Ploeg, H.P., Bauman, A., 2008. Predictors of initiating and maintaining active commuting to work using transport and public health perspectives in Australia. Prev. Med. 47 (3), 342–346. https://doi.org/10.1016/j.ypmed.2008.03.014.
Milakis, D., 2019. Long-term implications of automated vehicles: an introduction. Transp. Rev. 39 (1), 1–8. https://doi.org/10.1080/01441647.2019.1545286.
Milakis, D., van Arem, B., van Wee, B., 2017. Policy and society related implications of automated driving: a review of literature and directions for future research. J. Intell. Transp. Syst. 21 (4), 324–348. https://doi.org/10.1080/15472450.2017.1291351.
Muka, T., Imo, D., Jaspers, L., Colpani, V., Chaker, L., van der Lee, S.J., ... Franco, O.H., 2015. The global impact of non-communicable diseases on healthcare spending and national income: a systematic review. Eur. J. Epidemiol. 30 (4), 251–277. https://doi.org/10.1007/s10654-014-9984-2.
Neves, A., Brand, C., 2018. Assessing the potential for carbon emissions savings from replacing short car trips with walking and cycling using a mixed GPS-travel diary approach. Transp. Res. A Policy Pract. https://doi.org/10.1016/j.tra.2018.08.022.
Ngo, V.D., Frank, L.D., Bigazzi, A.Y., 2018. Effects of new urban greenways on transportation energy use and greenhouse gas emissions: a longitudinal study from Vancouver, Canada. Transp. Res. D Transp. Environ. 62, 715–725. https://doi.org/10.1016/j.trd.2018.04.013.
Nordhoff, S., de Winter, J., Kyriakidis, M., van Arem, B., Happee, R., 2018. Acceptance of driverless vehicles: results from a large cross-national questionnaire study. J. Adv. Transp. 22 2018. https://doi.org/10.1155/2018/5382192.
Pérez, K., Olabarria, M., Rojas-Rueda, D., Santamariña-Rubio, E., Borrell, C., Nieuwenhuijsen, M., 2017. The health and economic benefits of active transport policies in Barcelona. J. Transp. Health 4, 316–324. https://doi.org/10.1016/j.jth.2017.01.001.
Pettigrew, S., 2017. Why public health should embrace the autonomous car. Aust. N. Z. J. Public Health 41 (1), 5–7. https://doi.org/10.1111/1753-6405.12588.
Pettigrew, S., Talati, Z., Norman, R., 2018. The health benefits of autonomous vehicles: public awareness and receptivity in Australia. Aust. N. Z. J. Public Health 42 (5), 480–483. https://doi.org/10.1111/1753-6405.12805.
Redman, L., Friman, M., Gärling, T., Hartig, T., 2013. Quality attributes of public transport that attract car users: a research review. Transp. Policy 25, 119–127. https://doi.org/10.1016/j.tranpol.2012.11.005.
Royal Automobile Club, 2017. Social Issues Relating to Land-Based Driverless Vehicles in Australia. Submission to the Standing Committee on Industry, Innovation, Science and Resources. Royal Automobule Club, Perth, WA Retrieved from: https://rac.com.au.
Saghapour, T., Moridpour, S., Thompson, R.G., 2018. Enhancing active transport demand modelling by incorporating accessibility measures. Cities 78, 206–215. https://doi.org/10.1016/j.cities.2018.02.015.
Sheeran, P., 2002. Intention-behavior relations: a conceptual and empirical review. Eur. Rev. Soc. Psychol. 12 (1), 1–36. https://doi.org/10.1080/14792772143000003.
Simoni, M.D., Kockelman, K.M., Gurumurthy, K.M., Bischoff, J., 2019. Congestion pricing in a world of self-driving vehicles: an analysis of different strategies in alternative future scenarios. Transp. Res. C Emerg. Technol. 98, 167–185. https://doi.org/10.1016/j.trc.2018.11.002.
Soteropoulos, A., Berger, M., Ciari, F., 2019. Impacts of automated vehicles on travel behaviour and land use: an international review of modelling studies. Transp. Rev. 39 (1), 29–49. https://doi.org/10.1080/01441647.2018.1523253.
Taeihagh, A., Lim, H.S.M., 2019. Governing autonomous vehicles: emerging responses for safety, liability, privacy, cybersecurity, and industry risks. Transp. Rev. 39 (1), 103–128. https://doi.org/10.1080/01441647.2018.1494640.
Taniguchi, A., Gräås, C., Friman, M., 2014. Satisfaction with travel, goal achievement, and voluntary behavioral change. Transp. Res. F Traffic Psychol. Behav. 26, 10–17. https://doi.org/10.1016/j.trf.2014.06.004.
Thomas, G.O., Poortinga, W., Sautkina, E., 2016. Habit discontinuity, self-activation, and the diminishing influence of context change: evidence from the UK Understanding Society survey. PLoS One 11 (4), e0153490. https://doi.org/10.1371/journal.pone.0153490.
Tribby, C.P., Miller, H.J., Brown, B.B., Smith, K.R., Werner, C.M., 2017. Geographic regions for assessing built environmental correlates with walking trips: a comparison using different metrics and model designs. Health Place 45, 1–9. https://doi.org/10.1016/j.healthplace.2017.02.004.
Vanwolleghem, G., D'Haese, S., Van Dyck, D., De Bourdeaudhuij, I., Cardon, G., 2014. Feasibility and effectiveness of drop-off spots to promote walking to school. Int. J. Behav. Nutr. Phys. Act. 11 (1), 136. https://doi.org/10.1186/s12966-014-0136-6.
Venkatesh, V., Davis, F., 2000. A theoretical extension of the technology acceptance model: four longitudinal field studies. Manag. Sci. 46 (2), 186–204. https://doi.org/10.1287/mnsc.46.2.186.11926.
Verplanken, B., Wood, W., 2006. Interventions to break and create consumer habits. J. Public Policy Mark. 25 (1), 90–103. https://doi.org/10.1509/jppm.25.1.90.
Viswanath, V., Morris, M., Davis, G., Davis, F., 2003. User acceptance of information technology: toward a unified view. MIS Q. 27 (3), 425–478. https://doi.org/10.2307/30036540.
Wagner, K.-H., Brath, H., 2012. A global view on the development of non communicable diseases. Prev. Med. 54, S38–S41. https://doi.org/10.1016/j.ypmed.2011.11.012.
Wefering, F., Rupprecht, S., Bührmann, S., Böhler-Baedeker, S., 2013. Guidelines: Developing and Implementing a Sustainable Urban Mobility Plan. Rupprecht Consult – Forschung und Beratung GmbH, Brussels Retrieved from: https://sutp.org.
Woodcock, J., Banister, D., Edwards, P., Prentice, A.M., Roberts, I., 2007. Energy and transport. The Lancet 370 (9592), 1078–1088. https://doi.org/10.1016/S0140-6736(07)61254-9.
World Health Organization, 2009. Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks. World Health Organization, Geneva Switzerland Retrieved from: https://www.who.int.
Wu, T., Zhao, H., Ou, X., 2014. Vehicle ownership analysis based on GDP per capita in China: 1963-2050. Sustainability 6 (8), 4877–4899. https://doi.org/10.3390/su6084877.
Xia, T., Zhang, Y., Braunack-Mayer, A., Crabb, S., 2017. Public attitudes toward encouraging sustainable transportation: an Australian case study. Int. J. Sustain. Transp. 11 (8), 593–601. https://doi.org/10.1080/15568318.2017.1287316.