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Walking in the Era of Autonomous Vehicles

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Abstract: (1) Background: The emergence of autonomous vehicles (AVs) is likely to have substantial implications for walking behaviours due to the availability of new transport options and altered physical environments within cities. The aim of this exploratory study was to identify AV-related factors that could affect walking at the population level and strategies to ameliorate any negative effects. (2) Methods: A total of 46 Australian expert stakeholders were interviewed about their perceptions of the potential impacts of AVs on walking behaviours. The interviewees represented government departments (state and federal), non-government organisations (NGOs), private sector companies, peak bodies, and academia. (3) Results: Interviewees expected AVs to have different effects on individuals' ability and motivation to engage in planned versus incidental walking. While those with innate motivation to walk as a form of exercise or leisure may experience enhanced participation opportunities, it appears that incidental walking could be adversely impacted through the availability of convenient AV door-to-door transport options and automated home delivery services that reduce walking related to commuting and shopping. (4) Conclusions: Proactive policy actions are needed to optimize the potential positive impacts of AVs on walking and circumvent the potential negative impacts on valuable incidental walking that constitutes a key component of many people's total physical activity.

Keywords: autonomous vehicles; walking; urban planning; transport policy

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1. Introduction

Autonomous vehicles (AVs) (also known as driverless vehicles) are being tested in a wide range of trial applications around the world [1]. These applications include privately owned vehicles, all forms of public transport, on-demand transport, delivery drones and robots, and freight vehicles [2–6]. Once widely implemented, AVs are expected to yield substantial benefits across individual, social, economic, and environmental domains [7]. Specific transport-related benefits include lower prevalence of crash-related injury and death, increased safety for vulnerable road users such as pedestrians and cyclists, enhanced mobility for the elderly and those with disabilities, and increased leisure time due to release from driving [8–15]. Environmental benefits are also anticipated through lower greenhouse gas emissions resulting from outcomes such as electrification, smoother traffic flows, and less idling [11]. Across many applications, AVs are expected to be a highly cost-effective form of transport due to the eradication of driver costs [16], but an associated negative outcome is the loss of jobs for those in driving-related occupations [17]. Overall, AVs represent an important component of the smart cities of the future [1,18].

The emerging nature of AVs means their potential impacts on human behaviours such as walking, cycling, and other forms of active transport are difficult to predict. This complicates urban planning processes, which typically require a long-term orientation due to the lead times involved in designing and implementing transport-related infrastructure [19]. It is understood that well-designed cities are those that provide ample walking opportunities [20–23]. Facilitating walking behaviours has multiple positive outcomes, including (i) enabling active transport to reduce road congestion and minimize emissions [24] and (ii) assisting people to meet their physical activity requirements to achieve positive physical and mental health outcomes [25]. In terms of the latter, there is low compliance with minimum physical activity guidelines in many countries [26], including in Australia, the context of the present study. Just under half of Australian adults (48%) achieve the minimum recommended level of at least 150 min of moderate to vigorous activity per week [27]. This low level of physical activity has substantial adverse health consequences for individuals and at the population level [28].

Concerns have been raised about the potential effects of the emergence of AVs on walking behaviours [29–31]. Modelling studies applying a variety of AV implementation assumptions (e.g., extent of AV penetration in transport systems) have typically concluded that overall levels of physical activity are likely to decrease as a result of the availability of AVs [32,33]. Survey research conducted in Australia found that around one in five participants reported an intention to replace current walking trips with use of AVs once these vehicles are widely available [29]. Such potential outcomes are of considerable relevance to urban planning processes, yet research in this area remains limited and it has been noted that more work is required to understand the likely impacts of AVs on the way people choose to move around cities [13,34].

To move towards addressing this knowledge gap in the Australian context, the aim of the present study was to identify factors that are likely to increase or decrease walking behaviours once AVs are widely available to inform policy development and city design. To achieve this, in-depth interviews with a diverse range of expert stakeholders were used to (i) identify factors that might influence walking in a future where AVs are common and (ii) explore possible strategies to address the potential negative effects of AVs on walking. The approach was novel in accessing the views of relevant representatives from government, non-government, and private sector organisations across diverse sectors to explore the possible impacts of AVs on walking behaviours and how any adverse effects can be ameliorated.

Australia is a relevant location in which to study this phenomenon due to specific characteristics that will influence how the introduction of AVs will affect walking behaviours. In particular, there is substantial urban sprawl due to the large space available for housing developments on the outskirts of cities. This results in an average work commute of 16.5 km [35], which well exceeds the 'walkable distance' of one kilometre [23]. The availability of convenient public transport is highly variable [36,37] and per capita car ownership is very high by world standards. There are more than 20 million registered motor vehicles in a country of just 25 million people [38], and 79% of the working population commuted to work via car pre-COVID-19 [35]. In comparison, only 14% used public transport and 5% walked or cycled [35]. These national characteristics are likely to influence the demand and supply factors that will determine how the introduction of AVs will affect pedestrian movement within cities.

2. Materials and Methods

Thirty-eight semi-structured interviews were conducted with 46 stakeholders representing a range of entities. Most of the data collection episodes were individual interviews, but five sessions were conducted with multiple stakeholders from the same organisations due to interviewee preferences. The interviews were conducted between August 2021 and April 2022. The stakeholders held relevant positions in government departments (federal: n = 9; states n = 19), non-government organisations (NGOs: n = 3), private sector companies and associated peak bodies (n = 12), and academia (n = 3). The represented organisations had coverage of the following sectors: transport, health, planning and infrastructure, telecommunications, automotives, defence, environment, agriculture, engineering, aviation, and consumer representation.

Reflecting the numerous and diverse areas of expertise relevant to the study, participant recruitment involved accessing the networks of the author team, conducting Internet searches to identify appropriate individuals in key organisations to approach, and asking interviewees to nominate other individuals with relevant expertise (i.e., snowball sampling) [39]. Recruitment continued until no new insights were obtained, indicating that saturation had been reached. Ethical approval for the study was granted by the University of New South Wales Human Research Ethics Committee and all interviewees provided informed consent. A diagram depicting the research process is provided in Supplementary Figure S1.

The participation of individuals with specialized knowledge about particular sectors required an adaptive interviewing approach that involved stakeholders being invited to discuss the implications of the advent of AVs in the context of their specific area of expertise (e.g., transport, urban planning, and health). The approach was exploratory, with broad open-ended questions asked and interviewees being able to steer the conversations in directions they felt were most appropriate within the general subject area. This enabled wide-ranging topics to be covered, resulting in the identification of a highly diverse set of issues relating to the potential effects of AVs. If not raised spontaneously, interviewees were asked to discuss the potential implications of vehicle autonomy for physical activity, including walking. This involved canvassing perceptions of how AVs and pedestrians would interact, the likely responses of community members to the availability of different forms of transport, and the strategies available to policy makers to influence walking outcomes.

The interviews were conducted by three of the authors (SP, VF, LB), with an average interview length of 67 min. The interviews were mainly conducted by teleconference (two were face-to-face) and the sessions were recorded. The transcripts were imported into the NVivo 12 qualitative data management software for coding and thematic analysis. Open and selective coding was undertaken using an inductive process that involved iterative examinations of the coded text and the full transcripts to enhance understanding of the interview content [40]. Conceptual coding 'nodes' were progressively created in NVivo to develop an emergent coding hierarchy based on topics identified in the data. Due to this emergent process, a single coder (SP) undertook the coding task, which is an appropriate analytical approach where the aim is to generate new insights rather than test pre-existing theoretical frameworks [41]. Due to the highly speculative nature of the topic under investigation and the heterogenous profile of the sample, the data analysis process primarily sought to develop typologies of potential walking-related outcomes and seek solutions across the range of issues raised. Interpretations were initially discussed with the researchers who had participated in the interviewing process, followed by consultation with the rest of the author team.

3. Results

The interviewees expressed wide-ranging beliefs about how and when AVs are likely to come into common use in Australia, ranging up to several decades. However, there was a consensus that new cars have increasing numbers of autonomous features that, if enabled by drivers, can substantially enhance the safety of both drivers and vulnerable road users, such as pedestrians and cyclists. These features include adaptive cruise control, lane keeping, and on-coming crash detection, among others. It was also generally understood that there will be a long period during which AVs will co-exist with human-driven vehicles, with a mixed fleet presenting challenges for road users, including pedestrians, as they attempt to adapt their reactions according to vehicle type. A further area of agreement was that, although migration to an electric fleet is occurring slowly in Australia compared to many other countries, ultimately almost all vehicles will be electric.

In the context of these impending changes, interviewees nominated various factors associated with the advent of AVs that they believe are likely to affect walking, with distinctions made between planned and incidental walking. The term 'planned walking', as emerged in this analysis, encompassed where walking is the main focus of the activity, such as where it is undertaken for either exercise and/or leisure. By comparison, incidental walking was described as being where another activity is the primary focus, such as when walking occurs on a work commute or during shopping.

There were similarities and differences in anticipated consequences for the two types of walking that stemmed from the motivations underlying each form of activity. These similarities and differences were considered to have the potential to further polarize people in terms of their daily step counts: those motivated to walk could be enabled to engage in more activity through the opportunities provided by AVs, while those whose walking is mainly incidental could have their activity levels suppressed through access to affordable and convenient door-to-door transport:

> *Maybe it will actually separate people. People who are inclined away from physical activity will be like well, "That's (using AVs) an easy option". For people who are inclined to want it (physical activity), it will be more pleasant. So you'll actually get some people getting much more and some people getting much less.*
>
> (auto industry representative)

The identified factors and their anticipated outcomes are summarized in the typologies presented in Tables 1 and 2 and described below in terms of either their positive (+ve) or negative (−ve) effects on walking. Illustrative quotes from the interviewees are provided throughout. The identified themes represent the most commonly articulated views of direct relevance to the phenomenon under investigation (the effects of AVs on walking behaviours) to provide a coherent analysis with actionable outcomes. There was a general consensus among the interviewees on these themes.

Table 1. Factors nominated as influencing planned walking when AVs are in common use.

	Expected Effect on Walking	Example
Physical characteristics of the walking environment		
Traffic proximity	Encourage/Suppress	Development of walking precincts vs. walking paths adjacent to busy roads
Size of walking path	Encourage/suppress	Walking paths larger due to precise AVs or smaller due to additional road lanes
Mixed use paths	Suppress	Pedestrians share with cyclists, scooter riders, street bots, etc.
Psychosocial outcomes		
Safety concerns	Suprpess	Lack of trust in AVs
Time availability	Encourage	Reduced time burden of driving
Access to new walking environments	Encourage	Enhanced transport options

Table 2. Factors nominated as influencing incidental walking when AVs are in common use.

	Expected Effect on Walking	Example
Physical characteristics of the walking environment		
Traffic proximity	Encourage/Suppress	Development of walking precincts vs. walking paths adjacent to busy roads
Size of walking path	Encourage/Suppress	Walking paths larger due to AVs' within-lane precision vs. smaller due to installation of additional road lanes
Mixed use paths	Supress	Pedestrians share paths with cyclists, scooter riders, street bots, etc.
Convenience outcomes		
Door-to-door transportation	Supress	Private and ride-share AVs reduce walking to/from carparks
'First mile last mile' transit options	Supress	AV transit options reduce walking to/from public transport junctions
Home deliveries	Supress	Shopping conducted from home and delivered by AV vans, bots, and drones

3.1. Planned Walking

As shown in Table 1, two main categories of factors were nominated by interviewees as being likely to impact how people who walk for exercise and/or leisure would adapt their behaviours to accommodate or capitalize on the availability of AVs. These factors related to the physical characteristics of the walking environment and psychosocial outcomes associated with the benefits of AVs for walking-related activities.

The physical nature of walking paths in the future was described by the interviewees as being contingent on numerous AV-related planning decisions. These included: where paths are located (e.g., adjacent to busy roads (−ve effect on walking) or separated into walking precincts (+ve)); path size (e.g., whether footpaths can be made larger because of AVs needing less road space due to their precision driving (+ve) or whether they will be made smaller because of the need for more segregated roads that provide separate lanes for different kinds of vehicles (−ve)), and allocated usage patterns (e.g., separate paths (+ve) or mixed use paths that are shared with other users including cyclists, micro-mobility devices such as e-scooters, and street bots delivering goods (−ve)).

> *If you use the examples of some of the best active transport areas like the Netherlands or Sweden, they're successful for active transport because they have dedicated infrastructure and separate infrastructure.*
>
> (federal government representative)

> *That interaction between AVs and active transport is going to be a challenge for a long time in urban environments … the opportunity is that if AVs result in less road space need, and if there is less congestion, we can start getting rid of some of the space that we've allocated to dual carriageway roads, and start allocating that more towards providing a shared path, or providing a principal shared path or a wider footpath.*
>
> (transport engineer)

> *There's quite a bit of concern from the elderly pedestrian community as well as from the cyclists about those (street delivery bots), but the engineers are quite keen on these ideas of little things that might be able to do deliveries at less cost.*
>
> (academic)

> *The scooters are already becoming a bit of an issue where they are riding too fast and because it's shared paths. Where they are leaving them as well, it's a bit of a trip hazard. If you have these little autonomous food delivery options, they take up even more space. I think we are going to start to see struggles with this space.*
>
> (federal government representative)

In the absence of proactive regulatory efforts, it was considered likely that traffic congestion would increase due to a proliferation of 'ghost rides' (where empty vehicles traverse roads on the way to and from picking up their owners) (−ve) and the languishing of public transport due to the convenience of door-to-door transport offered by personal or on-demand AVs (−ve).

> *Empty running is where, unless you've got some other incentive, once the vehicle has driven you somewhere you may as well just send it home again to avoid parking costs. That gets a fairly diabolical congestion outcome. It also means that you've got some potentially quite poor active transport and incidental exercise outcomes.*
>
> (state government representative)

> *They've done all this work to try and get people onto active transport and public transport, and that AVs could actually undo a lot of that work.*
>
> (federal government representative)

> *If we have an autonomous vehicle in which I can actually do my emails on the way to work, then some of the negative aspects of driving are then taken away, and so maybe I would be less likely to catch public transport.*
>
> (academic)

The second category of factors identified by interviewees as being likely to influence whether people choose to engage in planned walking encompassed psychosocial variables relating to the walking experience that could be leveraged to enhance walking outcomes. These variables included safety concerns, time availability, and access to more varied walking environments.

To address safety concerns among those engaging in planned walking, interviewees recommended addressing the path sharing and proximity to heavy traffic issues noted above, enabling two-way communication between vulnerable road users and AVs, and overcoming potential problems associated with the lack of sound from electric vehicles. The layering of different types of onboard sensors was explained by interviewees to be a key element of how objective (actual) safety is being optimized, which will reduce accidents and in turn increase perceived safety.

> *When you have a fusion between lidar, radar, and cameras, they're very accurate, they're very, very good. That is the reason you have the multi-sensor approach, so you have redundancies all over the place.*
>
> (state government representative)

Similarly, it was noted that efforts are being made to develop communication technologies that enable some form of interaction between different types of road users to overcome the increased vulnerability that can be perceived when pedestrians are unable to make eye contact with drivers to assure them they have been seen.

> *(There is) some work starting to come in terms of how will the autonomous vehicle communicate to the vulnerable road user that they have actually been detected and therefore the vulnerable road user can feel more confident that they're not actually going to be just squashed?*.
>
> (academic)

Issues relating to a lack of noise were considered to be less well-resolved at this point in time.

> *Having low- and zero-emission vehicles that are quieter causes some issues around how people are alerted to the fact that a vehicle's coming. So that sort of stuff really needs to be in place— you're not going to be able to hear these things coming. How are you actually going to make people aware?*.
>
> (peak body representative)

There were two aspects to the potential for AVs to provide more time for planned walking. The first was time-savings from greater traffic efficiency and the second was the ability to use commute time for productive activities that could leave more time in the day for physical activity (+ve).

> *It gives them more time to do physical activity because you should be getting from A to B quicker. You spend less time commuting, less time sitting around doing nothing*.
>
> (telecommunications specialist)

> *If I spent fewer hours at work because I've done an hour in each direction, I would probably use that for physical activity, take the dog for a walk*.
>
> (transport software specialist)

Access to more varied walking environments was suggested to be provided by AVs through their drop-off and pick-up functionality that could free people to experience a broader range of contexts, thereby increasing walking enjoyment (+ve).

> *At the moment, if you want to go for a walk along the coast, you can only walk half as far because you've got to turn around and walk back to the vehicle. If you could set up either your own vehicle or a robotaxi to drop you off and then go and park 10 km up the road and you can go and walk your 10 km, that might be an opportunity in terms of a health*

benefit because it's much more interesting to see something for the first time than it is to see something for the second time.

(state government representative)

3.2. Incidental Walking

The factors relating to the physical walking environment that were expected to affect planned walking were also considered to be relevant to incidental walking. These included the nature of walking paths (locations, size, and usage demarcations), traffic congestion, and perceived safety. However, some of the more positive outcomes for planned walking expected from AVs were not relevant for incidental walking (e.g., productivity benefits and access to new walking environments), and instead some of the operational benefits of AVs were considered to be disadvantageous for people's walking activity. This was largely due to AVs being expected to intensify existing trends involving the use of mobility- and transport-related technologies to enhance commuter and consumer convenience and resulting increases in sedentarism. This was anticipated to occur via three main mechanisms: (i) the door-to-door transport provided by personal AVs, (ii) 'first mile last mile' solutions, and (iii) the further proliferation of automated home delivery services (summarized in Table 2).

Private ownership of AVs to the same extent as current private ownership of existing cars was recognized as a suboptimal outcome in terms of incidental walking. The heightened convenience of personal AVs was predicted to lead to the ghost rides and increased traffic congestion mentioned above (−ve), along with the potential for public transport systems to be cannibalized (−ve).

The worst-case scenario would be that everybody has their own private autonomous vehicle because we'll obviously have a lot of people travelling around in vehicles and a lot of empty vehicle kilometers travelled. We'll see probably a worsening of congestion because of the volume of vehicles on the roads. We'll see a de-prioritization of people in our streets. We'll probably see a lot less people walking, cycling, and using public transport because the car is so convenient. They just get it to drop them off door to door and then it goes home and they call it back when they want it.

(insurance provider representative)

The use of AVs for 'first mile last mile' transport options for segments that would otherwise be walked (e.g., AVs that are used to get to and from public transport hubs) were described as having the potential to reduce levels of physical activity by replacing walking. Such services were understood by interviewees to have many benefits, especially for the elderly and those with disabilities whose mobility could be greatly enhanced through the availability of door-to-door transport services. However, for able-bodied individuals who rely on commuting for at least part of their weekly physical activity, the evolution of AVs that replace walking for first mile last mile trip segments is likely to result in substantial reductions in walking at the population level.

The last mile, first mile is very often the difference between using public transport or not. So, if a person can grab the smartphone, hop on the computer, whatever, call in an AV and it takes them to the railway station which is 400/500 m away, game changer.

(state government representative)

First mile last mile is interesting because if you are going to get all this connectivity and these systems talking to systems where you're not going to even walk that last mile or that first mile. That's going to have a bit of an effect of people's exercise regime.

(automation consultant)

Some interviewees discussed the large increases in home deliveries that have resulted from the combined effects of the rapidly growing gig economy (supply) and the behavioural changes induced by the COVID-19 pandemic (demand). Vehicle autonomy was viewed as an additional factor that will consolidate and amplify this trend towards shopping from home. An anticipated outcome of greater online shopping and reduced in-store shopping was lower daily walking levels, which in turn were expected to have negative health and social outcomes.

> *I think that's (vehicle autonomy) going to exacerbate a lot of that (fast food availability). You already you see with Uber Eats, people aren't having to leave their house, so again they're not getting any of that incidental exercise in order to at least get the food.*
>
> (academic)

3.3. Implications for Policy and Practice

The interviewees suggested a range of strategies to address the potential negative effects of AVs on planned and incidental walking, some of which involved regulation and some involving investment in infrastructure and incentives. Development and implementation of a comprehensive road use charging or taxing system was one of the recommended regulatory strategies to reduce road congestion by increasing the walkability of neighbourhoods, incentivizing the use of various forms of active transport, and discouraging ghost rides. This approach would provide financial disincentives for personal vehicle use by introducing a per kilometre charge, ideally supplemented by the affordable pricing of public transport options to encourage individuals to choose public transport for longer distances and walking and other forms of active transport for shorter distances.

> *Things like what London have done with the congestion charge, what Singapore does with their congestion charge, what Singapore does with the auctioning of licenses for new vehicles to restrict or tamper back some of that unconstrained private vehicle ownership and use. That needs to be looked at more.*
>
> (transport engineer)

> *Road user charging could be an interesting one because people might be deterred from using their own vehicles on the road and then may find it attractive to use public transport. So it could actually have the effect that governments may want in terms of potentially reducing congestion and emissions, and getting people onto public transport.*
>
> (automation consultant)

Interviewees also suggested the potential to regulate AV use on footpaths, such as by limiting the use of street bots for deliveries to address footpath congestion.

> *You add delivery bots into the mix and do you have dedicated bot paths instead of footpaths? So I think really clever, proactive regulation of space is important.*
>
> (state government representative)

Investment in constructing and maintaining safe and appealing paths was also considered an important element of a comprehensive approach to ensuring cities are structured in a manner that promotes walking once AVs are in common use. This approach recognizes the substantial cost-effectiveness of providing appropriate paths for active transport.

> *We're developing an active transport health model where we cost the benefits of active transport as a new way of costing business cases for investing in walking paths and cycling paths.*
>
> (state government representative)

At a broader level, the process of adapting the physical environment to be more conducive to walking in the AV era represents an opportunity to reconsider urban design more generally. The ideal design was described as one where infrastructure supports liveable local communities with ready access to amenities.

> *Best-case scenario could be that we have redesigned our communities to support this new way of transport, which will take a lot of shifting to do ... It's almost going back to village styles where you've got schools and shops and places to commute within a fairly*

> *small radius of travel. Those would be most accessible by walking and cycling because they'll be nice and treed and green, and it'll be just a really beautiful space to be.*
>
> (state government representative)

However, some interviewees noted the challenges that will be associated with making substantial infrastructure changes before AVs become commonplace. These challenges were seen to be exacerbated by the sprawling nature of Australia's suburban cities.

> *(We need) infrastructure and systems that make people feel safe to ride their bikes and to walk. So, that all needs to be thought through and does relate to density again—it's going to be difficult to come up with walkable outer suburbs with huge blocks.*
>
> (federal government representative)

As noted above, overcoming issues associated with the noiselessness of electric vehicles was described as challenging. A potential benefit of AVs could be the ability of two-way communication between pedestrians and vehicles to prevent collisions; however, it was noted that the introduction of such a system would require community members to be willing to share their location data, which may not be considered an acceptable solution by some. Others may be willing to do so provided they see a clear benefit.

> *I can see a future where you wear a thing, that a lot of people would do, embedded in their clothing or their watch or something like that to make it easier to detect.*
>
> (state government representative)

> *(There can be a) data exchange trade off—I'm happy to share my data but this is what I would like to get back . . . you know, I want to get safety alerts when I'm on the road. I'm going to share out information about where I am so that others get to see me and there'll be a broadcast from my device.*
>
> (peak body representative)

The lure of convenient, affordable unhealthy foods and beverages was recognized to be a likely driver of the mass availability of autonomous home delivery services. The strength of the relevant market forces was such that taxing unhealthy products distributed in this manner was raised as a potential method of discouraging the delivery of unhealthy foods via autonomous delivery options.

> *It's going to come down to taxing the goods, isn't it? That's where it sits. If there's things that have significant health consequences, then that's the biggest lever—you make those things more expensive.*
>
> (transport infrastructure provider representative)

4. Discussion

This study of the potential impacts of AVs on walking behaviours identified various positive and negative factors that could be the focus of planning activities designed to optimize walking in the future. The findings highlight the importance of understanding the different drivers of planned and incidental walking and addressing the factors relevant to each to produce the most favourable outcomes for walking once AVs are widely available. As noted in the literature, potential solutions for successful AV introduction cover the broad areas of technological innovation, appropriate policy and legislation, investment in infrastructure, and efforts to enhance consumer acceptance [42,43].

There is little prior research on the predicted nature of the impacts of AVs on walking with which to compare the findings of this study. However, the results are consistent with the limited existing studies examining the likely effects of AVs on walking in particular [29,30] and active transport overall [31,32]. Together, these bodies of work, along with the general observation that new transport technologies are not designed with the intention of increasing the physical exertion of users, underscore the ongoing trend towards more convenient and sedentary forms of transport. An added outcome suggested by the present study is increasing reliance on home deliveries of consumer goods once automated delivery options increase the affordability and convenience of this form of product access. This would be an adverse outcome given shopping can comprise a substantial proportion of individuals' physical activity [44], and there are already low levels of compliance with physical activity guidelines [27]. The advent of AVs could therefore produce an environment in which people who are inclined to be sedentary are enabled to further reduce their activity levels across multiple behavioural domains, resulting in minimal daily walking and increased risk of chronic disease.

While the expected impacts of AVs on planned walking appear to be less intense than those on incidental walking, the interviewees also stressed the importance of ensuring that appropriate infrastructure is in place to provide conducive opportunities for walking for exercise and other leisure pastimes. Such investments could potentially encourage greater levels of planned walking to compensate for reductions in incidental walking to some degree. In addition, they noted the need to improve pedestrians' perceptions of the safety of AVs to encourage planned walking, which could include the dissemination of information to the general public about the absolute and relative safety of AVs compared to human-driven vehicles [45].

Consistent with recommendations reported in some previous work [29,30,46,47], fiscal policy levers were considered by interviewees to be key elements of effective strategies to promote walking in the era of AVs. Road charging systems and highly affordable public transport options were proposed as methods of steering people towards forms of transport that include incidental walking. Such systems need to be carefully developed to ensure those with mobility limitations (e.g., the elderly and those living with a disability) can benefit from the mobility-enhancing aspects of AVs without incurring unmanageable costs [48].

Across the factors identified in this study, it seems clear that a comprehensive approach involving intersectoral collaboration will be required to effectively implement the suite of policies and strategies needed to optimize walking once AVs are readily available [8,17,49,50]. However, the traditionally siloed nature of government and industry could make such collaboration challenging. Relevant entities are likely to include urban planners, transport planners, engineers, physiologists, health economists, fiscal policy specialists, and disability representatives, among others. Entities with commercial interests (e.g., vehicle manufacturers, fleet managers, and consumer goods retailers) would ideally be involved in the implementation aspects of policies developed by those prioritizing social and health benefit outcomes.

Limitations and Future Research Directions

This exploratory study involved collecting interview data from a range of experts based in Australia. The qualitative approach combined with convenience sampling means the outcomes cannot be considered confirmatory and additional research is needed with a broader range of participants to assess the generalizability of the findings. Such future research should also include members of the general public to complement the focus in this study on topic area experts. The confinement of data collection to a single country represents an additional limitation, which could be addressed through more international research on this issue. Quantitative studies conducted with experts and communities across multiple countries would be useful for the further explication of the likely impacts of AVs on walking and the range of strategies that could be applied to optimize outcomes for individuals, cities, and nations. It should also be recognized that both experts' and lay individuals' response to the advent of AVs and their use is largely uncertain. Similar to the introduction of the motor vehicle, it will be only long after AVs are introduced that the true nature of their social, health, and environmental effects—positive and/or negative—will be realized. Finally, this analysis was focused on just one form of activity: walking. Future research could assess the extent to which the findings are of relevance to other behaviours that also represent both active transport and leisure activity, and that are also likely to be substantially impacted by the advent of AVs (e.g., cycling [51]).

In conclusion, the findings of the present study highlight the importance of a proactive approach to walking optimization in the AV era. To avoid the mistakes made when cities were designed around motor vehicles, it will be necessary to anticipate the potential impacts of the evolution of AVs and introduce structural and policy changes designed to amplify the positive outcomes and circumvent the negative consequences that could result in reduced walking among future generations.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su141710509/s1, Figure S1: The research process.

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