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REVIEW ARTICLE

Potential Impact of Autonomous Vehicles on Movement Behavior: A Scoping Review

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Context: This scoping review examines the literature as it relates to autonomous vehicles and impact on movement behavior (i.e., physical activity, sedentary behavior, and sleep) or mode choice (e.g., public transit), beliefs about movement behavior or mode choice, or impact on environments that may influence movement behavior or mode choice.

Evidence acquisition: A search was conducted in June 2018 and updated in August 2019 of numerous databases (e.g., SPORTDiscuss, PubMed, and Scopus) and hand searching using terms such as autonomous cars and walking. Documents were included if they were databased studies, published in English, and related to the research question. They were then coded by 6 reviewers for characteristics of the document, design, sample, autonomous vehicles, movement behavior, and findings. The coding and analysis were conducted between August 2018 and September 2019.

Evidence synthesis: Of 1,262 possible studies, 192 remained after a title and abstract scan, and 70 were included after a full-article scan. Most of the studies were conducted in Europe (42%) or North America (40%), involved simulation modeling (50%) or cross-sectional (34%) designs, and were published mostly in transportation (83%) journals or reports. Of the 252 findings, 61% related to movement behavior or mode choice. Though the findings were equivocal in some cases, impacts included decreased demand for active transportation, increased demand for autonomous vehicles, increased sitting and sleeping, and reduced walking.

Conclusions: Though no experimental or longitudinal studies have been published to date, the available research suggests that autonomous vehicles will impact aspects of mode choice and the built environment of people residing in much of the developed world, resulting in reduced walking and more sitting.
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CONTEXT

Automated vehicle technology is rapidly advancing in sophistication and holds the potential to transform economies, ecologies, and societies in various and yet to be imagined ways, prompting a concentration of interest and scholarly activity from stakeholders from multiple disciplines and sectors. An autonomous vehicle (AV) is one that can detect and navigate its environment with little or no human involvement or guidance. As vehicles increase in their level of automation, they employ more complex systems for navigating, sensing the environment, and communicating with other vehicles. The Society of Automotive Engineers classifies the levels of automation for vehicles by 6 degrees from zero automation to full (Levels 4 and 5).[1] Though estimates of availability and uptake of AVs vary,[2] one study in the

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Netherlands projects them to be commercially available between 2025 and 2045.[3] This same study projects penetration rates reaching 1%−11% in 2030 and 7%−61% by 2050. In fact, low-speed driverless shuttles are already being employed in certain retirement communities, university campuses, and other fixed environments.[4] Furthermore, Waymo has launched a self-driving taxi service in Phoenix, AZ that operates in a 100-square-mile area and travels at a top speed of 45 miles per hour.[5] Evidence also suggests a keen market exists for this technology. For example, when surveyed, 60% of adults sampled in La Rochelle, France, stated they would use AVs if they were available.[6] Thus, within the next 30 years, AVs are likely to account for a significant portion of travel choices in developed countries and urban areas.

As commercial readiness of this technology becomes increasingly imminent, research efforts seek to identify, anticipate, and strategically respond to the vast and inevitable changes that will unfold in response. Much attention and public discourse to date has emphasized AVs' capacity to potentially increase safety and fuel efficiency and to decrease fuel emissions, travel time, and costs.[7−12] Research has also focused on how AV technology will impact land use and has prompted speculations about its potential to increase urban density and transform city centers.[13] Although these issues merit the scholarly momentum surrounding them, Milakis et al.[12] noted, "The implications of automated vehicles for the economy, public health, and social equity are still heavily under researched."

One of the commonly cited benefits of AV technology is its capacity to increase mobility for those currently unable to drive, including young people, the elderly, and individuals experiencing disability.[13] This improved mobility could enhance experiences of personal independence, reduce social isolation, and help individuals connect with communities and services.[14,15] However, a less considered implication of AV technology, but one of great importance to discussions of public health, is the potential it presents for impacting movement behavior (MB; i.e., physical activity, sedentary behavior, and sleep).[16] The extent to which people engage in sufficient levels of physical activity and sleep although avoiding excessive sedentary behavior (i.e., sitting) is an important contributor to health.[17−19] Indeed, the Public Health Agency of Canada recognizes the constellation of these health behaviors as a risk factor for chronic disease and has recently developed a surveillance framework describing how they will be monitored.[20,21] Furthermore, countries such as Australia, Canada, New Zealand, and South Africa and WHO have released 24-hour MB guidelines for preschool-aged children (0−5 years) that make recommendations about the appropriate amounts of daily physical activity, sedentary behavior, and sleep that should be enjoyed for health.[16]

Although many people recognize that they should be physically active, avoid excessive amounts of sedentary behavior, and maintain a balanced sleep regimen,[22] humans seek efficiencies in how they move around daily and their physiology is geared toward limiting energy expenditure relative to energy intake.[23] Thus, the presence of automobiles is associated with lower levels of physical activity in the U.S.,[24] with average daily vehicle miles traveled per person increasing substantially during the latter part of the last century.[25] Consequently, as AVs become increasingly available and accessible, the convenience this technology affords may inhibit incidental physical activity and active commuting and increase opportunities for sedentary behavior (i.e., sitting) and sleep. Indeed, some have speculated that travel mode choice (i.e., how people travel from place to place in their daily routines) will shift dramatically away from public transportation, which has important implications for MB.[7,8,11,26] For instance, a recent review concluded that privately owned AVs will increase vehicle miles traveled and reduce demand for public transport and slower modes such as active transportation.[27] Conversely, the use of shared AVs could reduce the number of vehicles and demand for parking. However, this review only included simulation or modeling studies and focused on travel behavior and land use.

In line with calls for a closer examination of the public health implications of AVs,[12,28] it is clear that a substantial gap exists in understanding of the implications of AVs for MB. Guided by ecologic models of physical activity,[29] sedentary behavior,[30] and active transportation,[31] a scoping review was conducted to explore the state of research on the topic, and the potential impact of AVs on the MB of children and adults. These models suggest that the environments in which people live, work, and play shape beliefs about behavior and subsequent behavior. Thus, 3 questions were asked about whether AVs impact MB or mode choice (e.g., public transit and walking to a destination), beliefs about MB or mode choice, and environments that may influence MB or mode choice (e.g., parking and green space).

Given the nascent AV phenomenon, the scoping review format was thought to be the most suitable approach for summarizing existing research.[32,33] Specifically, though they tend to be very descriptive, a scoping review provides an appropriate methodology for identifying gaps in the literature and may be particularly relevant for addressing research topics with limited or emerging evidence.[33]

EVIDENCE ACQUISITION

Because the International Prospective Register of Systematic Reviews does not currently accept registrations for scoping reviews, literature reviews, or mapping reviews, the protocol for this review was not registered formally. However, procedures incorporated recommendations for scoping reviews[32,33] and followed the PRISMA extension for Scoping Reviews.[34]

An expert librarian who is a member of the research team searched SPORTDiscus, CINAHL, MEDLINE, PubMed, Transport Research International Documentation, Compendex, Scopus, and Web of Science, using terms developed from the research questions (e.g., *autonomous cars, driverless cars, self?driving car*, hands-free car*, self-parking car*, vehicles*, sleep*, walk*, active transportation, physical* activ*, cycling, sedentary behavio?r, sitting time, movement behavio?, transport behavio?r, mobilit**, and *commute*). The search was completed June 14, 2018 and updated on August 6, 2019 (Appendix 1, available online, provides an example of the search strategy for MEDLINE). AVs were defined as being at Level 4 or 5 of automation,[1] and MB included physical activity, sedentary behavior, or sleep.[16] Additional searches were conducted through other sources (e.g., Google) and screening the reference lists of included articles.

Documents were included if they met the following inclusion criteria: (1) related to vehicles at Levels 4 or 5 of automation[1]; (2) involved MB or mode choice, or environments that impact MB or mode choice; (3) was a data-based study (quantitative or qualitative); (4) either published or gray literature; and (5) published in English. The first eligibility screening of titles and abstracts was conducted by 6 reviewers who had expertise in the procedures of systematic reviews (e.g., coding studies) and who had been familiarized with the topic (e.g., definitions of AVs and MB) and the research questions. During this process, each reviewer screened approximately 200 cases independently and recorded whether an article should be included or excluded and the primary reason for the exclusion. A total of 4 reviewers in pairs then assessed the remaining full-text articles for eligibility. Articles were first independently screened and then each pair met to compare results and resolve discrepancies. Any differences of opinion were discussed with a senior member of the research team to reach consensus. These meetings also provided the opportunity to discuss challenges and uncertainties that arose during the study selection. The interrater reliability among reviewers for the full-text screening was fair (Cohen's κ=0.33).

Data extraction was conducted using a codebook developed by the lead author and 2 co-authors and was informed by guiding frameworks.[29−31] The codebook consisted of the following categories: characteristics of the document (i.e., author, year of study, discipline of the journal, and geographic location of the research); characteristics of the studies (i.e., publication status, publication type, and design); characteristics of sample (i.e., age, sex, type of population, and sample size); characteristics of vehicle (i.e., level of automation and nature of vehicle ownership); characteristics of MB, mode choice, beliefs, or environment; subcategories of each research question (i.e., change in MB, mode choice, beliefs, or environments because of AVs); and purpose and findings. For the environment, only those features that have demonstrated associations with MB or mode choice were coded (e.g., land use, parking, and sprawl).[35−39] A total of 6 reviewers in pairs extracted data from the studies; they coded 3 articles at a time independently and then met to compare the results and resolve discrepancies. Each pair reviewed approximately 10−12 documents. Two members of the research team coordinated the reviews and ensured each pair adhered to the review protocol and verified the coding. A senior member of the research team was consulted in cases of unresolved discrepancies. The interrater reliability among reviewers ranged from moderate to perfect agreement (Cohen's κ=0.44−1.0) across 15 categorical variables and excellent reliability (intraclass correlation coefficient=0.98−0.99) across 2 continuous variables.

Frequency counts were calculated for each categorical variable. The main findings were recorded as text and subjected to content analysis. Specifically, the primary meaning of the text was categorized according to the themes derived from the authors' framework: behavior (i.e., MB and mode choice), belief, or environment, and the specific type of behavior, belief, or environment. Direction of change was then noted (i.e., no change, change, decrease, or increase) for MB, mode choice, and environment. For beliefs, the valence of the belief (i.e., positive, negative, or neutral) for the outcome associated with AVs was coded. For instance, if a belief reflected that AVs would lead to more engagement in sleeping in the vehicle, and the respondents thought that was favorable, it would be coded as MB with a positive valence. Similarly, if respondents expressed negative attitudes about AVs' impact on public transportation, that would be coded as mode choice with a negative valence. All documents included for analysis are listed in Appendix 2, available online. The coding and analysis were conducted between August 2018 and September 2019.

EVIDENCE SYNTHESIS

In accordance with PRISMA extension for Scoping Reviews guidelines, Figure 1 presents a flow chart of the search and selection process. The initial search of databases (*n*=2,730) and manual searches (*n*=26) resulted in 2,756 potential includes. After removal of duplicates, 1,262 were considered for title and abstract screening. A further 1,070 documents were excluded at that stage. The remaining 192 documents were then subjected to full-text review, which resulted in 70 documents and 252 findings being included in the final analysis. Of note, the first included document was published in 2013 and 59% of the documents were published in 2018 (*n*=14) and 2019 (*n*=27).

As presented in Table 1 (and Appendix 3, available online), most of the documents were journal articles (76%) followed by other documents (i.e., conference proceedings and book chapters, 14%) and reports (10%). Most of the publications were in transportation-related outlets (83%) and originated from either Europe (42%) or North America (40%). In study design, most involved simulation modeling (50%) or employed a cross-sectional design (34%). Limited information was available on the age, sex, or type of participants. For level of automation, most of the studies employed a combination of Levels 4 and 5. Finally, most of the findings examined a combination of shared (20%) or mixed (73%) vehicle ownership, whereas smaller proportions focused on public transit (4%) or private vehicles only (3%).

Slightly less than two thirds of the findings (61%) involved the impact of AVs on MB or mode choice, 26%

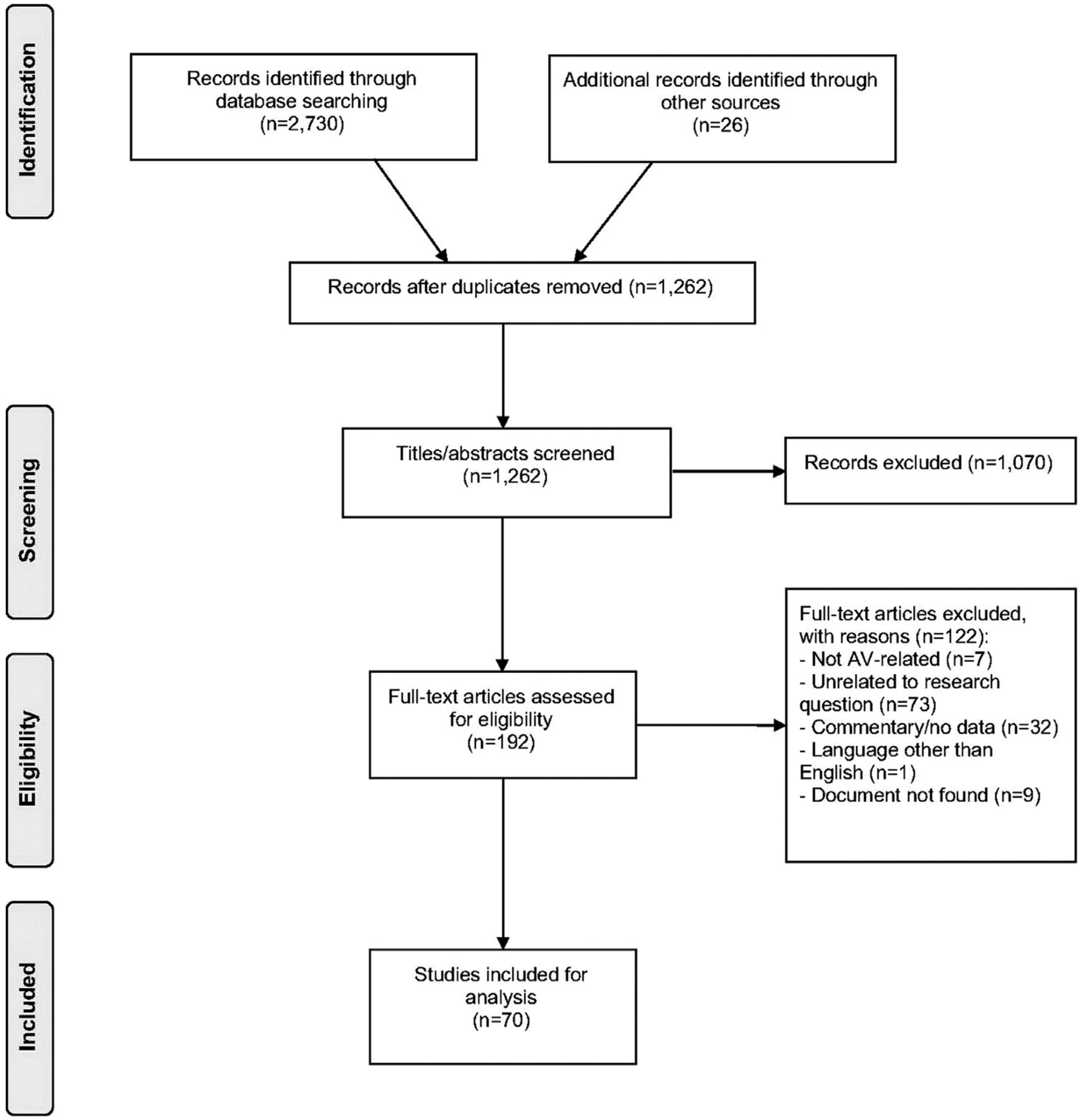

Figure 1. Selection of sources for scoping review.
AV, autonomous vehicle

involved beliefs about MB or mode choice, and 13% involved the impact of AVs on environments that influence MB or mode choice (Table 2). Of those findings examining AV impact on MB or mode choice (n_{findings}=155), most were specific to mode choice (n_{findings}=137; 88%). For the beliefs, most were about mode choice (n_{findings}=38; 58%) and MB (n_{findings}=18; 28%). Finally, impact on the environment was examined primarily in relation to parking (n_{findings}=16; 50%) and sprawl (n_{findings}=9; 28%).

For the impact of AV on MB (n_{findings}=18), increased sitting-related behavior (n_{findings}=6; 33%), increased sleeping (n_{findings}=4; 22%), and decreased walking (n_{findings}=4; 22%) were reported (Table 3) (Appendix 4, available online). For example, "walking can be avoided"[40] using AVs and "the share of walk trips decreases roughly by half,"[41] whereas "relaxing and sleeping options were other activities that a high share of respondents mentioned positively."[42] Though limited in number, the pattern of findings appear to be consistent for MB in that they indicate increased sedentary behavior and less physical activity.

Changes in mode choice (n_{findings}=137) included increased use of AVs (n_{findings}=44; 32%), decreased use of conventional personal vehicles (n_{findings}=19; 14%), decreased use of public transportation (n_{findings}=18; 13%), increased use of public transportation (n_{findings}=18; 13%), and decreased active transportation (n_{findings}=16; 12%).

Table 1. Summary of the Characteristics of the Documents, Studies, and Vehicles ($N_{studies}$=70)

Variable	$N_{studies}$	%
Discipline of the journal		
Transportation	58	83
Urban planning	7	10
Engineering	1	1
Other	4	6
Geographic location		
Europe	29	42
North America	28	40
Australia	4	6
Asia	3	4
Mixed	1	1
Unknown/hypothetical	5	7
Publication status		
Published	63	90
Unpublished	7	10
Publication type		
Journal	53	76
Report	7	10
Other	10	14
Design		
Simulation modeling or scenarios	35	50
Cross-sectional	24	34
Interviews	10	14
Quasi-experimental	1	2
Age of participants		
Mixed	30	43
Seniors	2	3
Not applicable	38	54
Sex of participants		
Mixed	31	44
Not applicable	39	56
Population type		
General public	27	38
Professionals	3	4
Mixed	4	6
Other	2	3
Not applicable	34	49
Level of automation		
Level 4 (e.g., high automation)	1	1
Level 5 (e.g., full automation, driverless)	11	16
Combined (e.g., fully automated)	58	83
Vehicle ownership		
Private	2	3
Shared	14	20
Mixed	51	73
Public transit	3	4

Table 2. Characteristics of Movement Behavior, Mode Choice, Beliefs, and Environment ($N_{findings}$=252)

Variable	$N_{findings}$	% of total findings	% within group
MB or mode choice	155	61	
MB	18	7	12
Mode choice	137	54	88
Beliefs	65	26	
Environment	9	4	14
MB	18	7	28
Mode choice	38	15	58
Environment	32	13	
Land use	7	3	22
Parking	16	6	50
Sprawl	9	4	28

MB, movement behavior.

For instance, “AVs result in a greater number of trips and more time spent inside a vehicle,”[43] “a decrease of the mode shares of non-motorized transport modes on trips under 4 km”[44] will occur, and “one SAV [shared AV] will be able to replace around 14 privately-owned vehicles, or even more when the level of willingness to share is higher.”[45] On the basis of these findings, the introduction of AVs will lead to increased use of AVs, decreased use of conventional personal vehicles, and decreased active transportation. However, the pattern of findings is less clear for how AVs will impact public transportation.

In terms of beliefs ($n_{findings}$=65), most of the findings were positively valenced, suggesting that respondents were positive about how AVs will influence mode choice ($n_{findings}$=23; 35%) and MB ($n_{findings}$=9; 14%), whereas fewer indicated negative beliefs about mode choice ($n_{findings}$=16; 25%) and MB ($n_{findings}$=3; 5%). No real pattern was observed for beliefs about impact on the environment. Thus, people thought “AVs would enable them to spend their travel times performing both recreational and productive activities”[46] but are “concerned that resources may be diverted from public transportation or other more affordable options into AVs.”[47] Overall, though generally positive beliefs were expressed about the impact of AVs, the findings varied and probably reflect the lack of experience that respondents have with the vehicles.

For impact on the environment ($n_{findings}$=32), decreased demand or need for parking ($n_{findings}$=10; 31%), impacts/changes on land use ($n_{findings}$=7; 22%), increased need for parking ($n_{findings}$=6; 19%), and the potential for increased sprawl ($n_{findings}$=5; 16%) were noted. For instance, “the introduction of AVs might boost a new wave of urban sprawl,”[48] “the land-use impacts of autonomous vehicles will be substantial,”[49] and “AVs can drive to places further away from the city center, where the social cost of parking can be negligible.”[40] Overall, the findings for parking demand and sprawl were somewhat

Table 3. Impact of Autonomous Vehicles on Movement Behavior, Mode Choice, Beliefs, and Environment ($N_{findings}$=252)

Variable	$N_{findings}$	% within group
Impact on MB	18	
Sitting-related behavior − increase	6	33
Sitting-related behavior − no change	1	6
Sleeping − increase	4	22
Walking − decrease	4	22
Walking − increase	1	6
Walking − no change	2	11
Impact on mode choice	137	
Active transportation − increase	6	4
Active transportation − decrease	16	12
Active transportation − no change	1	1
AV − increase	44	32
AV − decrease	4	3
Conventional personal vehicles − increase	2	1
Conventional personal vehicles − decrease	19	14
Conventional personal vehicles − no change	5	4
Public transportation − increase	18	13
Public transportation − decrease	18	13
Public transportation − no change	4	3
Impact on beliefs	65	
Environment − positive	4	6
Environment − negative	3	5
Environment − neutral	2	3
MB − positive	9	14
MB − negative	3	5
MB − neutral	1	1
Mode choice − positive	23	35
Mode choice − negative	16	25
Mode choice − neutral	4	6
Impact on environment	32	
Land-use − changes	7	22
Parking − increase	6	19
Parking − decrease	10	31
Sprawl − increase	5	16
Sprawl − decrease	3	9
Sprawl − no change	1	3

AV, autonomous vehicle; MB, movement behavior.

equivocal and these differences are most likely owing to whether the AV is shared or privately owned. The most consistent findings appeared to be for impacts or changes on land use.

DISCUSSION

This scoping review summarizes the characteristics of studies examining AVs and MB and describes the potential impact of AVs on MB. For the latter, 3 questions were asked about whether AVs impact MB or mode choice (e.g., public transit), beliefs about MB or mode choice, and impact on environments that may influence MB or mode choice (e.g., parking and green space). Because fully automated vehicles have yet to be introduced on any major scale,[3] research on AVs is still in its infancy. Thus, in the context of the first objective, most studies are cross-sectional or employ simulation modeling and no experimental or longitudinal designs have been published. Furthermore, most research originates from North America and Europe and is published in transportation-related outlets. Perhaps the most striking feature of these studies is the absence of specific information about demographics of participants in most of cases. This was primarily because upward of 50% of the studies employed simulation modeling and assumed a generic population group as their participants. Finally, since the first publication in 2013, a rapid growth has occurred on the topic with the number of relevant publications doubling during the past 2 years, suggesting this is an emerging field of study that warrants further attention.

On the question of impact, this review found that the availability of AVs will potentially influence MB, mode choice, and the environment as it relates to MB or mode choice. Most of the effects would be considered negative from a public health perspective in that they will lead to decreased walking, increased sitting, increased use of AVs, and shifts in mode choice away from active transportation. This is not surprising given that humans seek efficiencies in energy expenditure,[19] and the attractiveness and convenience of AVs in this regard will be powerful. Consistent with ecologic models,[29−31] if AVs are readily available and the environment supports automotive travel over active forms, then people will be more likely to use these vehicles. Conversely, the reduced demand for parking may provide an opportunity to retrofit many of the parking lots that dominate urban centers and perhaps turn them into green spaces that will facilitate recreation.[50,51] As parking spaces are estimated to account for as much as 30%−40% of the district area in major cities, this would be a substantial increase in available space.[52]

Not surprisingly, most of the findings in this review involved mode choice ($n_{findings}$=137). Many of the studies examined the role of AVs in shared versus public or mixed ownership. Although 25% of the mode choice findings suggest decreased use of public and active transportation, another 17% suggest increased demand for public and active transportation, along with 14% linked to decreased use of conventional personal vehicles. Much of this variation is dependent on whether the AV will be shared or privately owned. The shared scenarios tend to suggest fewer vehicles on the road, reduced demand for parking, and more efficient public transport systems.[27] Thus, it is possible that the availability of AVs will lead to increased demand for ride sharing, which may then entail some subsequent engagement in public and active transportation beyond what a person would experience in a private conventional vehicle scenario. This notion of total mobility needs to be further explored as an outcome of the onset of AVs.[53] However, if it entails door-to-door service, then it is unlikely that it will lead to positive impacts on MB.

Only a small minority of the findings were on MB specifically (n_{findings}=18). An obvious implication is that more research should be conducted on how AVs may impact physical activity, sedentary behavior, and sleep of passengers directly. These findings suggest that MB will be impacted in a negative way with less walking and more sedentary behavior (e.g., sitting) as AVs become available. However, this effect may not be universal. For instance, there is some thought that AVs will increase mobility for young people, the elderly, and those living with a disability.[13] Thus, because of those individuals getting out in their communities, they may increase their levels of physical activity. This is a line of research that warrants further attention.

Importantly, more than 80% of the reviewed documents were published or available in transportation-related outlets (e.g., journals and websites). Therefore, the implications for public health have received less attention.[3,9,28,54] This is somewhat surprising given that the determinants of physical activity, sedentary behavior, and sleep are of critical interest to public health researchers and practitioners[55,56] and that transportation is a significant determinant of health.[57] As mentioned previously, if AVs have an impact on MB, then it will be important for stakeholders from multiple disciplines and sectors to pay attention to this matter.[58,59] For instance, the costs and logistic challenges for the available AV technologies to detect pedestrians are deemed prohibitive[58] and safety frameworks to identify potential risks posed by AVs are lacking.[60,61] Furthermore, if the advent of AVs results in more vehicles on the road, the risk of collisions with pedestrians and cyclists will likely increase.[62] To avoid such collisions, jurisdictions may decide to grant right-of-way on the streets to AVs instead of pedestrians. This would be problematic from a public health perspective that advocates for pedestrian-friendly environments[63] and ethically justifiable regulations.[9] Thus, in the absence of smart public policy and dialogue among the various stakeholders,[60,61] decisions about pedestrian safety and avoidance of liability costs may result in barriers to physical activity and active transportation (e.g., no crossing zones at certain intersections).[28]

Limitations

This review is limited by the nature of the included studies. Given the early stages of research on AVs, no interventions or longitudinal studies were available. Therefore, although study quality is not necessarily considered in scoping reviews,[32] the reviewed studies were of low quality in terms of internal validity and other traditional metrics of research design.[64] Second, most studies employed either simulation study or cross-sectional designs (e.g., stated preference approaches). These designs are quite different from one another and, as such, may have contributed to some of the observed variation in findings (e.g., parking and public transportation). Third, given that the vast majority of documents reported on research based in Europe, North America, or Australia, the findings of this review may not be relevant to developing countries, and more research needs to be done in that regard. Finally, scoping reviews are not suitable for determining effectiveness of interventions and magnitude of effect. However, they are systematic in that they clearly describe a search strategy, inclusion criteria, and a process for charting the data.[32,65] Thus, they are useful for describing a body of research and identifying potential gaps.

CONCLUSIONS

Though no experimental or longitudinal studies have been published to date, the available research suggests that AVs will impact aspects of mode choice and the built environment of people residing in much of the developed world, resulting in reduced walking and more sitting and sleeping. However, impacts on the demand for public transportation and parking are somewhat equivocal. Current projections suggest that fully automated vehicles may account for much of the local travel choices in urban areas by 2050.[3] During the next few decades, research should examine the factors that contribute to acceptability of these vehicles on the part of the public and how they can best be integrated in a transportation system that facilitates both mobility and active transportation.

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and provided input on the manuscript; JAS assisted with coding and provided input on the manuscript; BW assisted with coding and provided input on the manuscript; AS helped develop the search strategy and ran the various searches; MIC advised on the content analysis and provided input on the manuscript.

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SUPPLEMENTAL MATERIAL

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REFERENCES

1. SAE International. Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles. www.sae.org/standards/content/j3016_201806/. Updated June 15, 2018. Accessed January 27, 2020.
2. Litman T. *Autonomous vehicle implementation predictions: implications for transport planning*. Victoria Transport Policy Institute. www.vtpi.org/avip.pdf. Published 2020. Accessed January 27, 2020.
3. Milakis D, Snelder M, van Arem B, van Wee B, Correia G. Development and transport implications of automated vehicles in the Netherlands: scenarios for 2030 and 2050. *Eur J Transp Infrastruct Res.* 2017;17(1):63–85. https://doi.org/10.18757/ejtir.2017.17.1.3180.
4. Lee TB. How startups are building driverless cars without Google's billions: driverless shuttles may be the first step toward fully self-driving cars. *arsTechnica.* https://arstechnica.com/cars/2018/06/how-startups-are-building-driverless-cars-without-googles-billions/. Published 2018. Accessed January 27, 2020.
5. Boudway I, Bloomberg. Waymo, Alphabet's self-driving taxi service, takes the slow lane to customer acquisition. http://fortune.com/2019/05/08/waymo-alphabet-self-driving-taxi-phoenix-arizona/. Published 2019. Accessed January 27, 2020.
6. Piao J, McDonald M, Hounsell N, Graindorge M, Graindorge T, Malhene N. Public views towards implementation of automated vehicles in urban areas. *Transp Res Procedia.* 2016;14:2168–2177. https://doi.org/10.1016/j.trpro.2016.05.232.
7. Fagnant DJ, Kockelman KM. Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transp Res A.* 2015;77:167–181. https://doi.org/10.1016/j.tra.2015.04.003.
8. Fagnant DJ, Kockelman KM. Dynamic ride-sharing and fleet sizing for a system of shared autonomous vehicles in Austin, Texas. *Transportation.* 2018;45(1):143–158. https://doi.org/10.1007/s11116-016-9729-z.
9. Fleetwood J. Public health, ethics, and autonomous vehicles. *Am J Public Health.* 2017;107(4):532–537. https://doi.org/10.2105/AJPH.2016.303628.
10. Hoogendoorn R, van Ārerm B, Hoogendoom S. Automated driving, traffic flow efficiency and human factors: literature review. *Transp Res Rec.* 2014;2422(1):113–120. https://doi.org/10.3141/2422-13.
11. Levin MW, Boyles SD. Effects of autonomous vehicle ownership on trip, mode, and route choice. *Transp Res Rec.* 2015;2493(1):29–38. https://doi.org/10.3141/2493-04.
12. Milakis D, van Arem B, van Wee B. Policy and society related implications of automated driving: a review of literature and directions for future research. *J Intell Transp Syst.* 2017;21(4):324–348. https://doi.org/10.1080/15472450.2017.1291351.
13. Anderson JM, Kalra N, Stanley KD, et al. *Autonomous Vehicle Technology: A Guide for Policymakers*. Santa Monica, CA: RAND Corporation, 2016.
14. Harrison A, Ragland DR. Consequences of driving reduction or cessation for older adults. *Transp Res Rec.* 2003;1843(1):96–104. https://doi.org/10.3141/1843-12.
15. Lollar DJ. Public health and disability: emerging opportunities. *Public Health Rep.* 2002;117(2):131–136. https://doi.org/10.1016/S0033-3549(04)50119-X.
16. Tremblay MS. Introducing 24-hour movement guidelines for the early years: a new paradigm gaining momentum. *J Phys Act Health.* 2020;17(1):92–95. https://doi.org/10.1123/jpah.2019-0401.
17. Chastin SFM, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined effects of time spent in physical activity, sedentary behaviors and sleep on obesity and cardio-metabolic health markers: a novel compositional data analysis approach. *PLoS One.* 2015;10(10):e0139984. https://doi.org/10.1371/journal.pone.0139984.
18. Gupta N, Hallman DM, Dumuid D, et al. Movement behavior profiles and obesity: a latent profile analysis of 24-h time-use composition among Danish workers. *Int J Obes.* 2020;44(2):409–417. https://doi.org/10.1038/s41366-019-0419-8.
19. Lee EY, Carson V, Jeon JY, Spence JC, Tremblay MS. Levels and correlates of 24-hour movement behaviors among South Koreans: results from the Korea National Health and Nutrition Examination Surveys, 2014 and 2015. *J Sport Health Sci.* 2019;8(4):376–385. https://doi.org/10.1016/j.jshs.2018.11.007.
20. Butler GP, Roberts KC, Kropac E, et al. At-a-glance - conceptualizing a framework for the surveillance of physical activity, sedentary behaviour and sleep in Canada. *Health Promot Chronic Dis Prev Can.* 2019;39(5):201–204. https://doi.org/10.24095/hpcdp.39.5.04.
21. Roberts KC, Butler G, Branchard B, et al. The physical activity, sedentary behaviour and sleep (PASS) indicator framework. *Health Promot Chronic Dis Prev Can.* 2017;37(8):252–256. https://doi.org/10.24095/hpcdp.37.8.04.
22. Yun L, Vanderloo L, Berry TR, et al. Assessing the social climate of physical (in)activity in Canada. *BMC Public Health.* 2018;18(1):1301. https://doi.org/10.1186/s12889-018-6166-2.
23. Pontzer H. Constrained total energy expenditure and the evolutionary biology of energy balance. *Exer Sport Sci Rev.* 2015;43(3):110–116. https://doi.org/10.1249/JES.0000000000000048.
24. Shoham DA, Dugas LR, Bovet P, et al. Association of car ownership and physical activity across the spectrum of human development: Modeling the Epidemiologic Transition Study (METS). *BMC Public Health.* 2015;15:173. https://doi.org/10.1186/s12889-015-1435-9.
25. Brownson RC, Boehmer TK, Luke DA. Declining rates of physical activity in the United States: what are the contributors? *Annu Rev Public Health.* 2005;26:421–443. https://doi.org/10.1146/annurev.publhealth.26.021304.144437.
26. Childress S, Nichols B, Charlton B, Coe S. Using an activity-based model to explore possible impacts of automated vehicles. *Transp Res Rec.* 2015;2493(1):99–106. https://doi.org/10.3141/2493-11.
27. Soteropoulos A, Berger M, Ciari F. Impacts of automated vehicles on travel behaviour and land use: an international review of modelling studies. *Transp Reviews.* 2019;39(1):29–49. https://doi.org/10.1080/01441647.2018.1523253.
28. Crayton TJ, Meier BM. Autonomous vehicles: developing a public health research agenda to frame the future of transportation policy. *J Transp Health.* 2017;6:245–252. https://doi.org/10.1016/j.jth.2017.04.004.
29. Spence JC, Lee RE. Toward a comprehensive model of physical activity. *Psychol Sport Exer.* 2003;4(1):7–24. https://doi.org/10.1016/S1469-0292(02)00014-6.
30. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior determinants and interventions. *Am J Prev Med.* 2011;41(2):189–196. https://doi.org/10.1016/j.amepre.2011.05.013.
31. Panter JR, Jones AP, van Sluijs EM. Environmental determinants of active travel in youth: a review and framework for future research. *Int J Behav Nutr Phys Act.* 2008;5:34. https://doi.org/10.1186/1479-5868-5-34.
32. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res Methodol.* 2005;8(1):19–32. https://doi.org/10.1080/1364557032000119616.
33. Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. *Implement Sci.* 2010;5:69. https://doi.org/10.1186/1748-5908-5-69.

34. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med.* 2018;169(7):467–473. https://doi.org/10.7326/M18-0850.
35. Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth a review. *Am J Prev Med.* 2011;41(4):442–455. https://doi.org/10.1016/j.amepre.2011.06.036.
36. Fraser SDS, Lock K. Cycling for transport and public health: a systematic review of the effect of the environment on cycling. *Eur J Public Health.* 2011;21(6):738–743. https://doi.org/10.1093/eurpub/ckq145.
37. Herrmann T, Boisjoly G, Ross NA, El-Geneidy AM. The missing middle: filling the gap between walkability and observed walking behavior. *Transp Res Rec.* 2017;2661(1):103–110. https://doi.org/10.3141/2661-12.
38. McCormack GR, Shiell A. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. *Int J Behav Nutr Phys Act.* 2011;8:125. https://doi.org/10.1186/1479-5868-8-125.
39. Rosso AL, Auchincloss AH, Michael YL. The urban built environment and mobility in older adults: a comprehensive review. *J Aging Res.* 2011;2011:816106. https://doi.org/10.4061/2011/816106.
40. Liu W. An equilibrium analysis of commuter parking in the era of autonomous vehicles. *Transp Res C Emerg Technol.* 2018;92:191–207. https://doi.org/10.1016/j.trc.2018.04.024.
41. Hörl S, Erath A, Axhausen KW. Simulation of autonomous taxis in a multi-modal traffic scenario with dynamic demand. *Arbeitsberichte Verkehrs-und Raumplanung.* 2016:1184. https://doi.org/10.3929/ethz-b-000118794.
42. Fraedrich E, Cyganski R, Wolf I, Lenz B. *User perspectives on autonomous driving: a use-case-driven study in Germany. Arbeitsberichte 187.* Berlin, Germany: Geographisches Institut, Humboldt-Universität. www.geographie.hu-berlin.de/de/institut/publikationsreihen/arbeitsberichte/download/Arbeitsberichte_Heft_187.pdf. Published 2016. Accessed January 27, 2020.
43. Correia GHdA, van Arem B. 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 B Methodol.* 2016;87:64–88. https://doi.org/10.1016/j.trb.2016.03.002.
44. Kröger L, Kuhnimhof T, Trommer S. Does context matter? A comparative study modelling autonomous vehicle impact on travel behaviour for Germany and the USA. *Transp Res A Policy Pract.* 2019;122:146–161. https://doi.org/10.1016/j.tra.2018.03.033.
45. Zhang W, Guhathakurta S, Fang J, Zhang G. Exploring the impact of shared autonomous vehicles on urban parking demand: an agent-based simulation approach. In: Paper presented at: International Conference on Computers in Urban Planning and Urban Management; July 7−10; 2015 http://web.mit.edu/cron/project/CUPUM2015/proceedings/Content/modeling/205_zhang_h.pdf. Accessed January 27, 2020.
46. Acheampong RA, Cugurullo F. Capturing the behavioural determinants behind the adoption of autonomous vehicles: conceptual frameworks and measurement models to predict public transport, sharing and ownership trends of self-driving cars. *Transp Res F Traffic Psychol Behav.* 2019;62:349–375. https://doi.org/10.1016/j.trf.2019.01.009.
47. Lu Z, Du R, Dunham-Jones E, Park H, Crittenden J. Data-enabled public preferences inform integration of autonomous vehicles with transit-oriented development in Atlanta. *Cities.* 2017;63:118–127. https://doi.org/10.1016/j.cities.2017.01.004.
48. Carrese S, Nigro M, Patella SM, Toniolo E. A preliminary study of the potential impact of autonomous vehicles on residential location in Rome. *Res Transp Econ.* 2019;75:55–61. https://doi.org/10.1016/j.retrec.2019.02.005.
49. Meyer J, Becker H, Bösch PM, Axhausen KW. Autonomous vehicles: the next jump in accessibilities? *Res Transp Econ.* 2017;62:80–91. https://doi.org/10.1016/j.retrec.2017.03.005.
50. Gruel W, Stanford JM. Assessing the long-term effects of autonomous vehicles: a speculative approach. *Transp Res Procedia.* 2016;13:18–29. https://doi.org/10.1016/j.trpro.2016.05.003.
51. Appleyard B, Riggs W. 10 Principles toward more sharing and less sprawl: a manifesto for street livability, health, and humanity in the era of driverless cars. *Planetizen.* www.planetizen.com/node/96769. Published 2018. Accessed January 27, 2020.
52. Shoup DC. *The High Cost of Free Parking.* Chicago, IL: Planners Press, 2005.
53. Watkins SJ. Driverless cars − advantages of not owning them: car share, active travel and total mobility. *Proc Inst Civ Eng Munic Eng.* 2018;171(1):26–30. https://doi.org/10.1680/jmuen.16.00067.
54. Pettigrew S. Why public health should embrace the autonomous car. *Aust N Z J Public Health.* 2017;41(1):5–7. https://doi.org/10.1111/1753-6405.12588.
55. Spence JC, Rhodes RE, Carson V. Challenging the dual-hinge approach to intervening on sedentary behavior. *Am J Prev Med.* 2017;52(3):403–406. https://doi.org/10.1016/j.amepre.2016.10.019.
56. Xiao C, Goryakin Y, Cecchini M. Physical activity levels and new public transit: a systematic review and meta-analysis. *Am J Prev Med.* 2019;56(3):464–473. https://doi.org/10.1016/j.amepre.2018.10.022.
57. Litman T. Transportation and public health. *Annu Rev Public Health.* 2013;34:217–233. https://doi.org/10.1146/annurev-publhealth-031912-114502.
58. Combs TS, Sandt LS, Clamann MP, McDonald NC. Automated vehicles and pedestrian safety: exploring the promise and limits of pedestrian detection. *Am J Prev Med.* 2019;56(1):1–7. https://doi.org/10.1016/j.amepre.2018.06.024.
59. Synder R. Public health and equity considerations of AVs in California. Transpo Group. https://ww3.arb.ca.gov/cc/ab32publichealth/meetings/071817/snyder.pdf. Accessed January 27, 2020.
60. Ryerson MS, Miller JE, Winston FK. Edge conditions and crash-avoidance roles: the future of traffic safety in the world of autonomous vehicles. *Inj Prev.* 2019;25(2):76–79. https://doi.org/10.1136/injuryprev-2017-042567.
61. Koopman P, Wagner M. Autonomous vehicle safety: an interdisciplinary challenge. *IEEE Intell Transp Syst Mag.* 2017;9(1):90–96. https://doi.org/10.1109/MITS.2016.2583491.
62. Dumbaugh E, Li W. Designing for the safety of pedestrians, cyclists, and motorists in urban environments. *J Am Plann Assoc.* 2010;77(1):69–88. https://doi.org/10.1080/01944363.2011.536101.
63. Raine KD, Muhajarine N, Spence JC, Neary NE, Nykiforuk CIJ. Coming to consensus on policy to create supportive built environments and community design. *Can J Public Health.* 2012;103(9 suppl 3):eS5–eS8. https://doi.org/10.1007/bf03403828.
64. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health.* 1998;52(6):377–384. https://doi.org/10.1136/jech.52.6.377.
65. Peters MDJ, Godfrey CM, Khalil H, McInerney P, Parker D, Soares CB. Guidance for conducting systematic scoping reviews. *Int J Evid Based Healthc.* 2015;13(3):141–146. https://doi.org/10.1097/XEB.0000000000000050.