Automated vehicle Services for People with disabilities – Involved Responsive Engineering
(ASPIRE Center)

Quarterly Progress Report #4

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1. Accomplishments

Aim 1: <u>Systematic Review</u>: We will conduct a comprehensive review of the literature to more clearly understand the current trends and implications for future travel related to accessible automated vehicles and services.

- **Specific Objectives:**
  1. Address reviewer's comments on systematic review journal paper

- **Major Activities:**

Last quarter we successfully completed the Systematic Review (Aim 1) phase of the grant. In response to the call for papers, a manuscript describing the work was submitted to "Special Issue of Neuroscience Letters on Neurological and Cognitive Rehabilitation: New Contributions from Engineering". This received a favorable review.

The manuscript referenced above has now been accepted for publication in Neuroscience Letters and is fully available online:
https://doi.org/10.1016/j.neulet.2021.136103

Dicianno, Brad E., Sivashankar Sivakanthan, S. Andrea Sundaram, Shantanu Satpute, Hailee Kulich, Elizabeth Powers, Nikitha Deepak, Rebecca Russell, Rosemarie Cooper, and Rory A. Cooper. "Systematic Review: Automated Vehicles and Services for People with Disabilities." Neuroscience Letters (2021): 136103.

Please see attached manuscript in appendix for more details.

Aim 2: **<u>Understand the needs of Users and Providers</u>:** We will conduct surveys, focus groups, and journey mapping of stakeholders, including individuals with disabilities, their travel companions and/or caregivers, designers, medical providers, and mobility service experts (e.g., vehicle manufacturers and modifiers, as well as adaptive driving training instructors). The survey will be refined using pilot surveys, focus groups and journey mapping and then distributed broadly to all key stakeholders.

- **Specific Objectives:**
  1. Finalize interview script for focus group & journey mapping
  2. Complete and submit IRB for focus group & journey mapping
  3. Draft survey questions on RedCap
  4. IRB protocol development for survey

- **Major Activities:**

  We will target recruitment of focus groups and surveys to include the following cohorts that will provide input on their experiences with, barriers to, and future needs and capabilities for accessible automated transportation:

  - Person with disability and older adults,
  - Transportation Partner/Caregivers
  - Transportation Provider, Expert or Designer

This quarter, the following documents were finalized based on the research gaps identified in the systematic review and feedback received from our advisory board members:

1. Journey Mapping interview script (Individuals with disabilities & older adults)
2. AV Focus Group script (Individuals with disabilities & older adults)
3. AV Focus Group script (Caregivers/travel partners)

A Pitt IRB has been submitted and is currently under review:
STUDY20090111- ASPIRE Center: Journey Mapping & AV Focus Group

An IRB amendment to include other stakeholders in the AV Focus Group such as designers, medical providers, and mobility service experts will be submitted as soon as the scripts for this cohort has been finalized.

Survey development: A Voice of the Consumer-Provider REDCap survey is currently under development as the survey questions are being drafted. The draft will be shared with the advisory board members for review/comments before it is finalized.

The survey consists of the following sections:

Section 1: Current use of various modes of transportation and barriers and facilitators to travel based on mode
Section 2: Impact of current modes of transportation on community participation
Section 3: Perceived barriers and facilitators of using automated vehicles for transportation and impact on participation
Section 4: Socio-demographic and geographic characteristics (e.g., gender, disability type and onset, age, employment, income, rural/urban living, etc.)

Another Pitt IRB (STUDY20120052) related to the survey is currently under development and will be submitted for review in the next quarter.

2. Changes/Problems

a. Actual Problems or delays and actions to resolve them

Nothing to Report.

b. Anticipated Problems/Issues

Nothing to Report.

3. Collaborations

The ASPIRE Center continues to attract more organizations to engage and partner. We have been continuously engaging advisory board members in project activities at key milestones. This quarter, we collaborated with Virginia Tech Transportation Institute on the Department of Transportation (DOT) National Highway Traffic Safety Administration (NHTSA) Request for Proposal (RFP), title: Additional Considerations for Making ADS Vehicles Accessible for All Road Users.

Over the quarter, Dr. Cooper and team have presented in the below virtual events:

- 2021 American Council of Engineering Companies of Pennsylvania Spring Conference
- Automated Road Transportation Symposium (ARTS21)

4. **Education and Workforce Development**

In this quarter, we continued to engage PhD students in the ‘systematic review’ manuscript (Aim 1) activities. The ASPIRE Center had also allocated funds to support additional students to participate in the Research Experience for Undergraduates (REU) which is HERL’s primary summer internship program. Through this program, we were able to hire and integrate a student from UC Berkely into our research team to work on Aim 2 activities. At the culmination of the program, the student presented oral and written presentations of their work in a professional symposium and poster session. The REU provides an exemplary mentoring and resourceful environment that enables undergraduate students to transition from dependent to independent thinkers, develop a sense of excitement about entering an engineering or technical field, and be well prepared for their future careers.

5. **Performance metrics**

Manuscript related to Aim 1 has been accepted for publication in Neuroscience Letters and is fully available online:
https://doi.org/10.1016/j.neulet.2021.136103

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APPENDIX

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Systematic review: Automated vehicles and services for people with disabilities

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ABSTRACT

People with disabilities face many travel barriers. Autonomous vehicles and services may be one solution. The purpose of this project was to conduct a systematic review of the grey and scientific literature on autonomous vehicles for people with disabilities. Scientific evidence (n = 35) was limited to four observational studies with a very low level of evidence, qualitative studies, reviews, design and model reports, and policy proposals. Literature on older adults was most prevalent. Grey literature (n = 37) spanned a variety of media and sources and focuses on a variety of disability and impairment types. Results highlight opportunities and barriers to accessible and usable AVs and services, outline research gaps to set a future research agenda, and identify implications for policy and knowledge translation. People with disabilities are a diverse group, and accessible and usable design solutions will therefore need to be tailored to each group's needs, circumstances, and preferences. Future research in diverse disability groups should include more participatory action design and engineering studies and higher quality, prospective experimental studies to evaluate outcomes of accessible and usable AV technology. Studies will need to address not only all vehicle features but also the entire travel journey.

1. Introduction

Disability affects more than 57 million people in the U.S. [1], and over a billion people globally [2]. Compared to people without disabilities, people with disabilities (PwD) are less likely to be vehicle owners, have access to a vehicle, and be employed, and are more likely to be in lower-income households. Over 40% of PwD rely on others for transportation, and over 70% limit their travel altogether. About 3.6

Abbreviations: AAM, Alliance of Automobile Manufacturers; ADA, Americans with Disabilities Act; ADAS, advanced driving assistance systems; ADS, Automated Driving Systems; ATLAS, Accessible Technology Leveraged for Autonomous vehicles System; AV, automated vehicle; GRADE, Grading of Recommendations Assessment, Development, and Evaluation; HMI, human–machine interface; IVIS, in-vehicle information systems; NHTSA, National Highway Traffic Safety Administration; PICO, Problem/Population, Intervention, Comparison, Outcome; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; PwD, people with disabilities; SAE, Society of Automotive Engineers; TNC, Transportation Network Companies.

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million Americans with travel-limiting disabilities do not leave home regularly. The most recent government transport survey reported that six million PwD have difficulty getting the transportation they need [3]. Transportation barriers for PwD are often due to a lack of accessible transportation [4], lack of awareness and limited information on available services [5], scheduling complications [6], high costs of transportation [4,6], limited availability of transportation for non-medical purposes, and lack of funding in various insurance models [7,8].

In a prior survey study of 1022 PwD who use mobility devices, 93.6% stated that technology-supported travel around the home, to work, and in their neighborhood was critical or important to them, and 91.2% noted that technology-supported travel on buses, taxis, airlines, and trains was critical or important [9]. They also voiced a need for alternative controls that use their voice or faces and devices that assist with transfers of people or mobility devices into and out of vehicles.

Automated vehicles (AVs) may be a solution to the unmet travel needs of PwD. The U.S. Department of Transportation defines AVs as vehicles "in which at least some aspect of a safety–critical control function (e.g., steering, throttle, or braking) occurs without direct driver input. Automated vehicles may be autonomous (i.e., use only vehicle sensors) or may be connected (i.e., use communications systems such as connected vehicle technology, in which cars and roadside infrastructure communicate wirelessly)" [10]. Ford, Toyota, Mercedes-Benz, Tesla, Google, and Uber among others are developing AVs that are either currently being tested on American roadways or will be within the next 5-years [11,12]. In addition, the U.S. Department of Defense is funding research into a variety of AVs and robotic technologies [13]. The combined investment is in the billions of dollars [14,15]. Despite these advances in technology, no overarching federal laws in the U.S. specifically govern AVs.

Each year, the number of states considering legislation related to AVs has gradually increased, but the needs of PwD have not been sufficiently addressed in such legislation [16]. The National Highway Traffic Safety Administration (NHTSA) published several documents, including the "Vehicle Performance Guidance for Automated Vehicles Policy," which was replaced by "Automated Driving Systems 2.0: A Vision for Safety," which called for the public, industry, state and local governments, and safety and mobility advocates to promote AV development and implementation but did not provide guidance on accessibility [17,18]. This was followed by "Preparing for the Future of Transportation: Automated Vehicles 3.0 (AV 3.0)," which expands the scope to all surface on-road transportation systems and was developed through the input from a diverse set of stakeholders [19]. In January 2020, "Ensuring American Leadership in Automated Vehicle Technologies (AV 4.0)" was released [20], followed by an "Automated Vehicles Comprehensive Plan" which builds upon AV 4.0 and defines goals to promote collaboration and transparency, modernize the regulatory environment, and prepare the transportation system [21]. While AV 3.0, AV 4.0, and the comprehensive plan explicitly discuss the need for accessible design and announced an inclusive design challenge [22], they do not provide guidance on the accessible design of AVs or policy. The NHTSA also released guidance for companies to voluntarily report how they are addressing safety, but safety issues relevant to PwD are lacking in reporting criteria and in the reports themselves [23,24].

Frameworks and taxonomy for AV design also lack detail about disability needs. The World Forum for Harmonization of Vehicle Regulations published a framework document on AVs, but it does not address disability or accessible design [25]. The National Council on Disability in its report entitled "Self-Driving Cars: Mapping Access to a Technology Revolution" [26] provided several recommendations, including (a) that any products resulting from research and development of AVs incorporate accessibility of people with diverse disabilities and comply with Section 508 of the Rehabilitation Act; (b) guidelines are needed for how PwD can safely interact with and use AVs in the environment where they need to use them; and (c) all types of common and public use AVs must be fully accessible. The Society of Automotive Engineers (SAE) international standard J3016 provides a common taxonomy and definitions for automated driving [27]. Unfortunately, it fails to define any key terms or unique issues related to the usability or accessibility for PwD.

As a first step to creating a roadmap for the accessible and usable design of AVs and services for PwD, a comprehensive review of the grey and scientific literature is needed and is the primary aim of this project. The secondary aim is to summarize research gaps and implications for policy and knowledge translation to inform future work.

2. Materials and methods

This project was registered in the International Prospective Register of Systematic Reviews (CRD42017055658). The following databases were used: Ovid MEDLINE ALL, Web of Science Core Collection, PubMed, PsycINFO, and REHABDATA. Grey literature was identified by our Advisory Board, by investigators, and through a Google search. A search strategy was devised in consultation with our Advisory Board and with a research librarian and tailored for each database with consideration of available operations, incides, and subject indexing (Supplementary Appendix). The Institute of Electrical and Electronics Engineers taxonomy and Problem/Population, Intervention, Comparison, and Outcome (PICO) framework [28] were used to inform search terms related to AVs. The concept of PwD was operationalized at broad and narrow levels, as recommended by Ioerger, et al. [29], and included older adults experiencing the effects of aging. The concept of AV was also broad and included any vehicle type (e.g. car, shuttle, air taxi, ridesharing, etc).

Inclusion criteria were: must include data from or about individuals with disabilities, caregivers, or service animals; be in the English language; be published on or after July 1990 (the year that the Americans with Disabilities Act (ADA) was passed); involve accessible or inaccessible travel options, estimates or trends; and must be an empirical, peer-reviewed study, a peer-reviewed literature review article, an article published in a scholarly journal, or grey literature of high quality. Exclusion criteria were anecdotal or opinion articles, unless they were written by experts in the field of AV.

Manuscripts identified in the search were screened in two stages: title and abstract screening and full-text screening. In both stages, each manuscript was evaluated by two independently trained reviewers. When a manuscript was excluded, reviewers listed a reason. When conflicts arose, the two reviewers and an independently trained reviewer met to resolve the disagreement. The references cited in the included full-text manuscripts were also screened for potential inclusion.

Publications that involved an intervention evaluated observationally with measures were critically appraised by two trained members of the research team and scored using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) methodology [30–32]. A third senior investigator resolved disagreements in GRADE scoring. Results were reported using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The initial draft of the manuscript was reviewed by the Advisory Board and revised according to feedback.

3. Results

3.1. Overview

A PRISMA Flow Diagram (Fig. 1) displays the article count at each stage of the review and reasons for exclusion.

3.2. Grey literature

Grey literature results (n = 37) included: 1 book, 1 checklist, 2 conference papers, 1 edited transcript of a conference presentation, 1

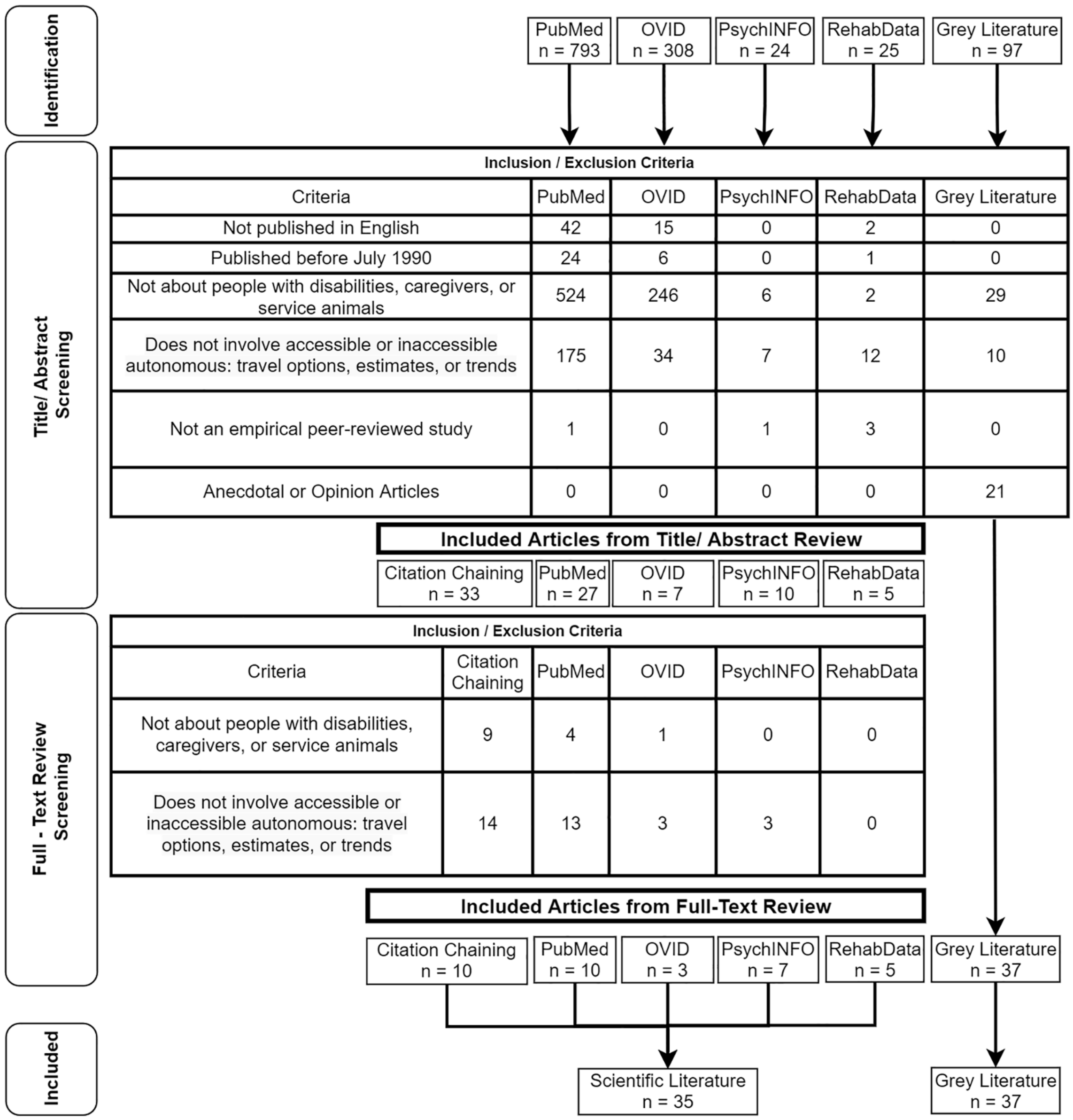

Fig. 1. PRISMA Flow Diagram.

letter addressing proposed regulations, 2 newspaper articles, 1 podcast, 20 reports, 1 video, and 7 websites. Twenty-eight sources dealt, at least in part, with AVs; other sources were concerned with public transit, paratransit, conventional rideshare, or a combination of these. Twelve sources discussed disability generally, but others referred to individuals with specific disabilities or impairments: individuals with mobility impairments (n = 18), individuals who are blind or who have visual impairments (n = 17), individuals with cognitive impairments or intellectual disabilities (n = 12), individuals who are deaf or who have a hearing impairment (n = 11), and older adults (n = 10).

A few of the reports focused on statistics that frame the opportunity for AVs. Estimates of the number of Americans with travel limiting disabilities range from 18.5 to 25.5 million [33,34]. The largest of these estimates include 13.4 million individuals age 18–64 and 11.2 million individuals age 65 or older [33]. People with disabilities travel less than similarly situated individuals across age, economic status, employment status, and household vehicle ownership [33,34]. Taking into account a variety of economic, social, and travel pattern factors, des Cognets, et al estimated that the travel-limited population could support a rideshare fleet of 2 million accessible AVs and that millions more might be purchased for private use [34].

Amongst the potential benefits of AVs for PwD, about one-third of the sources specifically mention the ease in commuting to medical appointments, greater access to employment, or both. One white paper notes that, on an annual basis, problems with transportation cause 11.2 million missed medical appointments, and that $19 billion could be saved — mostly by state and federal programs — through improved access to medical care [35]. Only one-fifth of individuals age 18–64 with travel limiting disabilities are employed, compared with three-quarters of individuals without travel limiting disabilities in the same age group [33]. Experts expect accessible AVs to increase access to employment for as many as 2 million PwD [35,36]. There is evidence that access to transportation increases a sense of well-being for PwD [37].

Grey literature sources highlighted some of the current transportation barriers for PwD. For individuals who could operate an adapted vehicle, common complaints are that modifications to purchased vehicles must be done by a third party, and these modifications are expensive — at times equaling or exceeding the cost of the vehicle [38,39]. Currently, individuals who cannot operate an adapted or non-adapted vehicle rely on walking or wheelchair mobility, public transit, paratransit, taxis, ridesharing, or friends or family members to transport them [33,40]. Although public transit is required by the ADA to accommodate riders with disabilities, including those using wheelchairs, limited routes and fixed schedules constrain travel options for all who must rely on it [41]. In addition, physical barriers en route to pick-up and drop-off locations or in transit stations can make the services difficult or impossible to access or use [42]. On-demand, paratransit services can mitigate the route, scheduling, and physical access limitations of public transit, but is inconvenient due to the common requirement for booking trips 24 to 48 h in advance, wide windows for pickup and drop-off times, and increased travel times owing to the trip being shared amongst multiple passengers [43]. In a survey, of two-thirds of PwD aware of a paratransit option in their area, only 10% of them had used that option in the previous 12 month period [40]. Even with this relatively low usage, paratransit services cost $5.2 billion in 2013 [44] and accounted for 14–18% of public transportation budgets where they were offered [45]. Paratransit may not connect to other transportation infrastructure. For instance, 81.3% of airports surveyed said that they did not have any specialized ground transportation options for PwD or service animals [46].

Taxi operators and Transportation Network Companies (TNC) offer travel opportunities for many PwD. Smartphone applications for rideshare services such as Uber and Lyft have been designed to be accessible for smartphone users who rely on screen readers, and many individuals with visual impairments appreciate the ability to use these applications both for paying the fare and knowing when their ride is approaching [47]. A subset of vehicles that are wheelchair accessible is available directly from the operators or through contracts with other providers in some cities [35,48,49]. However, as the contracts are generally with existing providers of accessible taxi services, the new ridesharing platforms may not expand the number of accessible vehicles in a given area [35].

Fraade-Blanar, et al. examined difficulties that older adults have with current TNC services, to project what analogous issues they might have with AVs [50]. They found that lower smartphone ownership relative to the general population and frequent smartphone application changes could be barriers to booking rides. Some older people do not want to pay for rides through an application due to limited familiarity, security concerns, or lack of mobile banking instruments. Older adults express concerns about potential aggression from drivers or other passengers in shared rides.

The majority of sources discuss the needed features of AVs. These data were derived from focus groups with individuals or representatives of stakeholder groups [48,50–54], opinions from experts [38,39,49], secondary source summaries, or organizational positions [26,35,40,55–57], and development guidelines from governmental agencies [58,59]. The publications highlighted the diversity of needs amongst those with a variety of disabilities and impairments, and several findings were encountered repeatedly across findings. For those who use mobility aids (e.g., wheelchairs), ramps, drop floors, raised ceilings, and wheelchair-securement were frequently cited as needed features. The Alliance of Automobile Manufacturers (AAM) notes that there is currently no securement standard compatible with all wheelchairs that can be engaged entirely by the wheelchair user [51]. The AAM raises the concern that in the U.S., due to the focus of The Centers for Medicare and Medicaid on wheelchair use in the home environment, most wheelchairs are not crash-tested [51]. For those who may wish to transfer out of their wheelchairs, a convenient and easy-to-use stowage place should be provided [35,57].

These needs-focused manuscripts observed that user interface requirements varied by disability. For those with visual impairments, audio input and output, as well as tactile interfaces were desired. For example, a project for autonomous shuttles in Birmingham, United Kingdom, included a tactile map that updates in real-time, so those passengers who are blind can know where they are on the route [60], whilst another prototype system developed at the University of Florida gives audio descriptions of the surrounding environment [61]. Some visually impaired users prefer large print data displays over audio interfaces [54]. Those with hearing impairments, on the other hand, require a visual display of information. Individuals with impaired mobility or dexterity need to be able to reach and manipulate controls. Accommodating those with cognitive impairments requires easy-to-understand interfaces, and such interfaces may also be beneficial for older adults who may not always be comfortable with technology [50]. All of these modalities could be incorporated into one, flexible interface structure, which could communicate with the individual's smartphone, which may already have accessibility features tailored to that person's needs [48]. Halsey notes that Waymo has incorporated many of these interface requirements into its current AV design, including a smartphone app built with attention to accessibility, physical buttons with braille labels, a touch screen with a visual display of the route, and dedicated buttons to request the vehicle to pull over or contact emergency support [62].

A journey in an AV includes communicating with the vehicle, locating and getting to the vehicle, boarding the vehicle, disembarking, making one's way to the final destination, and other steps [48]. People who are blind or who have visual impairments may currently rely on the driver calling out to them. They will need a means of locating the specific vehicle that they have hailed. They also often rely on the driver for orientation to the drop-off area (e.g., being told in which direction lies the building entrance that is their ultimate destination). Similarly, some older adults require assistance in orientation or physical assistance or escort, from door-to-door, not just curb to curb [50]. AVs need to pick up and drop off at points that have no physical barriers that would prevent opening a door, deploying a wheelchair ramp, or otherwise impeding access to the vehicle [38,48,50]. Communication and data sharing between AVs and agencies responsible for infrastructure could help to automatically direct the vehicles to drop-off points with few or no barriers [53].

Some publications suggested that AVs be equipped with cameras and audio communication for assisting persons with disabilities in emergency situations [35,52,57], or for monitoring those with developmental disabilities [48]. On the other hand, focus groups and disability organizations have expressed concerns with maintaining the privacy of those who use AVs [26,35,48,50,52,57].

The National Center for Mobility Management notes that, though the ADA does not currently require that personal vehicles be sold as accessible AVs, this may be a requirement on shared AVs as a public accommodation [63]. The National Council on Disability takes the position that shared-ride AVs must be accessible to all under the ADA and Sections 504 and 508 of the Rehabilitation Act [26]. Whether or not it is legally mandated, all focus group publications and expert interviews promote the idea that developers should strive for universal design — designing products that can be used by all. For example, the Renault EZ-GO is an AV prototype that has passengers board through a large door with a ramp that would accommodate wheelchairs [64]. But, while universal design should be the goal, it may not always be possible [35,38]. In those cases, the vehicle that best fits the user's needs can be dispatched from a fleet.

The literature reveals concern for government licensing requirements for AVs [26,35,39,48,56,57]. While it may make sense to mandate that AVs require a human driver in some circumstances and be operated only by those with a valid driver's license, many PwD could needlessly be denied the benefits of AVs if licensing requirements are maintained even as vehicle automation capabilities increase. Easton notes that international law defines a driver as a person who at all times should be able to control the vehicle and suggests that assigning a level of "personhood" to the systems controlling the vehicle may fulfill this requirement [65]. Many PwD are further concerned that other governmental guidelines could either neglect an opportunity to ensure equal access or have the effect of creating barriers to the use of AVs by PwD. For example, commenting on California's recent proposed rules for AVs, the Disability Rights Education, and Defense Fund notes that by electing not to define accessibility, the rules miss an opportunity for mandating equal access to this emerging technology [66]. The same comment criticizes that other provisions of the proposed rules (e.g., those requiring emergency plans for passengers) may have the unintended consequence of barring riders with certain disabilities.

Multiple sources expressed concern that, when confronted with an unavoidable collision, the algorithm governing the AV's actions should not value the lives of PwD less than those of others [26,56,57]. In discussing collision avoidance, Sundararajan suggests that driving algorithms can be specifically programmed to identify PwD (e.g., those in wheelchairs) by communicating with the individual's smartphone or other connected devices. The algorithm could then adapt its driving by giving the person more time to cross the street [53].

Although AVs are widely considered to benefit older adults who may otherwise need to give up driving [35], one broad survey of perceptions of AVs found that older adults were less willing to ride in them [67]. The same survey, which did not focus on PwD, found that those who did not drive were less concerned with the vehicle being in control than were drivers. In contrast, when a team at Virginia Tech partnered with the National Federation of the Blind to develop an autonomous driving system, they found their potential user base was more interested in the autonomous features enabling a driver with visual impairment to exercise executive control than in riding in an AV as a passenger [68].

While generally taking a positive view of the potential benefits of AVs, two reports were concerned that reliance on AVs to fulfill future mobility needs will reduce funding for public transit systems and infrastructure, which could then negatively impact mobility and safety [26,50].

3.3. Scientific literature

Table 1 is a scientific evidence profile of the 35 manuscripts identified. Manuscripts focused on the needs of older adults (n = 17), individuals who are blind or who have low vision (n = 10), individuals with physical disabilities (n = 3), individuals with disabilities in general (n = 3), individuals with intellectual disabilities (n = 1), individuals who are deaf or hard of hearing (n = 1), individuals with epilepsy (n = 1) and a variety of other stakeholders such as caregivers, transportation professionals and people without disabilities. Only 4 articles contained interventions evaluated prospectively in an observational way, all of which were ranked very low according to GRADE criteria. No randomized controlled trials were included.

In 2016, Harper, et al. estimated that AVs could increase travel in the U.S by 295 billion miles, or 14% in annual light-duty vehicle miles traveled, for those age 19 and up [69]. This includes new travel opportunities for older adults and people with medical conditions that prevent travel or restrict driving. They postulate that more AVs using highways could increase costs related to highway repair and maintenance, energy, and emissions. The percent of individual household expenses related to travel may also increase. A review article by Kovacs et al discussed how AVs may positively or negatively affect various economic and social factors for older adults [70].

Several studies investigated the attitudes of PwD about AVs. Studies included individuals with intellectual disabilities [71], visual impairment and blindness [72–74], older adults [75–80], people with epilepsy [81], and people with physical disabilities that result in mobility impairments [82]. Several factors seemed to influence attitudes, including prior knowledge about AVs, hope for the future, perceived safety, skepticism about AVs, affordability, comorbidity, anxiety, and valuing freedom, control, social interaction, privacy, and independence that may result from their use. Most older adults and people with visual impairments were optimistic about the potential of AV technology in affording them travel options. Compared to younger individuals, older adults had higher levels of acceptable safety with respect to fatality risk. They also had neutral opinions from the standpoint of being a pedestrian in the vicinity of an AV, preferences for retaining the ability to control the AV manually, and interest in automation especially when cognitive or physical impairments begin to affect their driving. Over two-thirds of people with physical disabilities had a negative or ambivalent attitude about AVs, particularly surrounding the safety of the vehicles themselves, and individuals with visual impairments raised significant concerns about the safety of AVs themselves and safety in particular environments. Yet, a majority of those with visual impairment expressed an interest in owning an AV and may be willing to pay for the technology. Many expressed reservations about legal liability that were based on rumors or opinions. There was a need for more understanding about laws requiring the driver to have the ability to manually control an AV in an emergency and laws requiring licensing of drivers in operation of AVs. People with epilepsy reported hope that their medications could be down titrated since this is sometimes delayed out of fear that a breakthrough seizure would make them ineligible to drive [81]. It is important to note that attitudes in most of these studies were based on knowledge of or perceptions about AVs, not on real-world experience with AVs or simulators. However, Kemppidis et al conducted facial expression analysis of passengers with various disabilities riding in an AV; the predominant expression was happiness, and self-reported anxiety decreased during the trip [83].

Many barriers specifically in the use of public transportation (paratransit and fixed-route) have been reported [84,85] and are relevant to the design of AVs. Many vehicles that are supposed to be accessible to wheelchairs or scooters have limited space once the device is inside or are not truly accessible to common mobility devices [84]. Inaccessible interior configurations of low-speed automated shuttles include inadequate floor or aisle space for mobility devices, inadequate legroom, nonstandardized seating configurations or locations that may be confusing to individuals who are blind or who have visual impairments, insufficient space for assistive devices like canes or walkers, or inaccessibility caused by crowding from other passengers [85]. Inaccessibility occurs even when the vehicle interiors are compliant with federal accessibility standards [85].

Paratransit trips were noted to be inconvenient (i.e., take too long to reach a destination, unreliable, have limited service areas or hours of operation, inflexible to changes in travel plans, require an advance appointment) [84]. Some PwD reported that paratransit drivers are not friendly towards PwD. Eligibility criteria for paratransit can exclude some PwD. Ridesharing was a popular choice for urgent travel needs, but drivers were noted to be unfamiliar with the needs of PwD, and the cost and limited service areas were considered restrictive [84]. It was thought that AVs may solve some of these issues by affording freedom and flexibility of travel, as well as safety to passengers and pedestrians. Some thought costs of AV travel may be lower due to lower labor costs, mass production, and energy efficiency [84]. Others expressed fear of traveling in an AV without a trained driver or of being stranded if there is a malfunction, or concerns that built environments may not be accessible to AVs.

It was suggested that different AV service models will likely be needed to match the needs of people with varying disabilities, and AV may complement rather than replace current public transportation options for PwD devices [84]. Other authors argued that a model that mixes privately-owned, rideshare, and public AV options may be needed to support individuals of all income levels [86,87]. Kovacs et al stratified 4 possible service models according to the impact they may have on the design of roads and streets, other transportation services, policy surrounding driving, and land use [70]. The concept of AVs being used for street vending, in addition to travel, has also been proposed to meet needs for earning income in India. However, there was no mention of the participation of PwD in the design or development and no measurement of outcomes from its use [88]. Two manuscripts mentioned that it will be important to understand how AVs will affect physical and mental health, physical activity, access to services, or social isolation [86,87], in part because data will be needed to guide policy makers' decisions.

Table 1
Scientific evidence profile.

Last Name of First Author	General Theme	Pub-lication Year	Design	Population of Interest	Country	Inter-vention	Duration of Inter-vention	Limitations	Potential Pub-lication Bias	Inter-vention or Main Sample N	Control N	GRADE Quality Rating	Findings Relevant to PwD
Abdi	Review of emerging technologies for older adults	2020	Review	Older adults	UK	N/A	N/A	Search and analysis conducted primarily by the first author focused on English language and technologies in the USA and UK	None detected	N/A	N/A	N/A	Benefits of AVs will depend on the level of automation achievable.
Bellet	Attitude toward AVs	2017	Focus groups	Older adults	France	N/A	N/A	Small sample size, possible recruitment bias	None detected	30	N/A	N/A	63% of older adults were supportive of automation, especially if physical or cognitive impairments begin to limit driving.
Bennett	Attitudes toward AVs	2019	Interview, survey	Individuals with intellectual disabilities	UK	N/A	N/A	Qualitative data, limited to specific disability, possible sample recruitment bias, no control group	None detected	177	0	N/A	Freedom and fear influenced willingness to use an AV.
Bennett	Attitudes toward AVs	2019	Interview, survey	Individuals with physical disabilities	UK	N/A	N/A	Qualitative data, limited to specific disability, possible sample recruitment bias	None detected	444	353	N/A	2/3 of PwD held negative or ambivalent views of AVs, challenges exist in creating a compelling customer value proposition.
Bennett	Attitude toward AVs	2020	Interview	Individuals who are blind	UK	N/A	N/A	Qualitative data, limited to specific disability, possible sample recruitment bias, no control group	None detected	211	0	N/A	Desire for independence, comorbidity, locus of control, and anxiety mediated 4 topics (hope, skepticism, safety, affordability); 3 topics influenced willingness to travel in an AV.
Brinkley	Attitudes toward AVs	2018	Survey	Individuals who are blind or have visual impairments	USA	N/A	N/A	Possible sample bias toward educated and tech-savvy end-users, no control group	None detected	516	0	N/A	Generally optimistic but concerns with safety.
Brinkley	Design of a voice userinterface prototype	2019	Design	Individuals who are blind or have visual impairments	USA	Voice user interface	N/A	Prototype description but not a formal study	None detected	N/A	N/A	N/A	Authors reported use resulted in belief in usability, more desire to purchase an AV, less fear of safety, and increased trust in AVs.

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Last Name of First Author	General Theme	Pub-lication Year	Design	Population of Interest	Country	Inter-vention	Duration of Inter-vention	Limitations	Potential Pub-lication Bias	Inter-vention or Main Sample N	Control N	GRADE Quality Rating	Findings Relevant to PwD
Brinkley	Policy proposal on AV accessibility	2019	Policy proposal	Individuals who are blind or have visual impairments	USA	N/A	N/A	Limited to U.S.	None detected	N/A	N/A	N/A	Need for guidance on accessibility related to AVs but legislation must be balanced with the need for rapid technology development.
Brinkley	User evaluation of an HMI in a driving simulator	2019	Quasi-naturalistic observational	Individuals who are blind or have visual impairments	USA	HMI	One 60 min session	Only 4 tasks were studied, no control group, risk of acquiescence bias, use of a simulator instead of on-road AV.	None detected	20	0	Very low	Use resulted in higher belief in usability, more desire to purchase an AV, less fear of safety, and increased trust in AVs.
Brinkley	Attitudes toward AVs	2020	Survey, focus group	Individuals who are blind or have visual impairments	USA	N/A	N/A	Did not distinguish blind and low-vision in one study, used functional and not medical definitions, no control groups, limited generalizability due to many having college degrees, one study had a small sample of mostly blind individuals	None detected	516, 39	0	N/A	Most were generally optimistic with some concerns about safety, costs, driver licensing, and policies/laws. HMIs will need to have many features to support needs.
Classen	Review of in-vehicle technologies	2019	Review	Older adults	USA	N/A	N/A	Studies used inconsistent terminology, reviewers made some assumptions for classifying the technology, samples may have been heterogeneous, possible selection bias, authors did not rate studies, methods for delineating improvements or decreases in outcomes were incomplete, possible drawer effect	None detected	N/A	N/A	N/A	IVIS and ADAS enhanced safety and mitigated age-related declines; enhanced safety and comfort by increasing speed control, lane maintenance, and braking responses; IVIS may reduce cognitive workload, but may jeopardize safety if the systems are overly complicated.
Harper		2016			USA	N/A	N/A			N/A	N/A	N/A	

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Last Name of First Author	General Theme	Pub-lication Year	Design	Population of Interest	Country	Inter-vention	Duration of Inter-vention	Limitations	Potential Pub-lication Bias	Inter-vention or Main Sample N	Control N	GRADE Quality Rating	Findings Relevant to PwD
	Estimation of travel increases due to AVs		Bounding analysis	Older adults, individuals with medical conditions that restrict driving, non-drivers				Limited to older adults, non-drivers, and those with medical conditions; changes to population size over time, cost, market penetration rates, improvements in public transportation, and increases in urban density and ridesharing were not considered in the analysis.	None detected				Total annual light-duty travel would increase by about 14% (295 billion miles), females would make up most of this increase and the oldest senior cohort would have the largest percent increase.
Hartwich	Effects of automation and driving style familiarity on driving comfort, enjoyment, and acceptance	2018	Quasi-experimental observational	Older adults, younger adults	Germany	Driving simulator with different driving styles	Approximately 200 min	Limited standardization of styles in a fixed-base driving simulator environment, could be confounded by the quality of driving performance, no sensory or motion feedback, dropout due to simulator sickness, convenience sample, some had prior simulator experience, the intervention of interest is automated driving while the experimental intervention was emulated by using manual driving	None detected	20	20	Very low	Automated driving was more comfortable and enjoyable than traditional driving for older adults, older adults preferred unfamiliar driving styles compared to their driving style. The results may differ significantly if the emulation by human driving is replaced with true automated driving.
Hong	Development of a semi-autonomous vehicle for people with visual impairment	2008	Design	Students without visual impairments	USA	Vibrating chair and headphones that provide sensory feedback	N/A	Sample size is small, system tested by students without visual impairment, testing methods were not rigorous, results mostly descriptively	Unclear if any participants were also developers	10	0	Very low	Participants felt that steering wheel and pedals should have been used instead of a joystick; lag in reaction time; mental demand high

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Last Name of First Author	General Theme	Pub-lication Year	Design	Population of Interest	Country	Inter-vention	Duration of Inter-vention	Limitations	Potential Pub-lication Bias	Inter-vention or Main Sample N	Control N	GRADE Quality Rating	Findings Relevant to PwD
								reported; testing was not completed in a real-world setting.					
Hwang	Attitudes toward AVs	2020	Focus groups	Individuals with physical disabilities, individuals who are blind or who have low vision, public transit service experts	USA	N/A	N/A	Sample size is small and focused on 2 disability types, all participants were >35 years old, possible sampling bias due to limited geography, no control group, limited description of disabilities of participants in results	None detected	23 people with disab-ilities and 10 transit experts	N/A	N/A	Enthusiasm for AV potential, concern for safety and accessibility including in built environments, need for cooperative relationships among stakeholders and education programs
Indu Rani	Solar-powered vehicle designed as a mobile shop	2018	Design	Individuals with physical disabilities	India	Solar-powered mobile shop	N/A	Design of a vehicle with no mention of participatory design, no outcome measures	None detected	N/A	N/A	N/A	Limited relevance due to lack of stakeholder participation in design
Kempapidis	Experience riding in AV	2020	Ride in AV, survey, and facial expression analysis	Passengers with and without disabilities	UK	Arthur (AV)	7 min	Possible sample recruitment bias, descriptive analysis of results, image analysis only on a subset of data, possible response bias	Partial funding from Aurrigo, Ltd.	419	N/A	Very low	Happiness was the predominant expression; anxiety decreased over journey
Knoefel	Semi-autonomous vehicles as cognitive assistive devices	2019	Model	Older adults	Canada	N/A	N/A	Applicability of model can change with rapidly changing technology, changes in vehicle ownership patterns, impacts of public policy regarding AV operations, and data security; no data presented	None detected	N/A	N/A	N/A	Semi-autonomous vehicles can serve as countermeasures for cognitive decline, interdisciplinary collaboration is needed.
Kovacs	Impact of AVs on older adults	2020	Review	Older adults	Australia	N/A	N/A	Search terms not provided, authors did not rate studies or discuss limitations of the review itself	None detected	N/A	N/A	N/A	Potential impact of AVs on social and economic factors discussed. Policy scenarios presented for different service models.
Lee	Transporting children in AVs	2020	Survey		USA	N/A	N/A	Specific contexts and use cases not	None detected	1310	0	N/A	Although the survey was based on a prior

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Last Name of First Author	General Theme	Pub-lication Year	Design	Population of Interest	Country	Inter-vention	Duration of Inter-vention	Limitations	Potential Pub-lication Bias	Inter-vention or Main Sample N	Control N	GRADE Quality Rating	Findings Relevant to PwD
				Parents without disabilities				included, AVs were broadly defined, no formal definitions of automation levels provided, participants were required to imagine scenarios, up sampling used, no control group					study with PwD the results have limited relevance, except that features may be needed to monitor and protect the user and ensure safe handoff to an adult at the end of a journey, or provide the means to monitor the user or to communicate with a caregiver during the journey.
Li	Attitudes toward AVs	2019	Driving simulator and interview	Older adults	UK	N/A	N/A	Sample size is small, possible sample recruitment bias, no control group, participant experience with AVs limited to a simulator	None detected	24	0	N/A	Older adults want to retain ability to manually control vehicle and would prefer AVs to have a driving style similar to them, but which corrects errors. Other design preferences are explored.
Mele	Liability and regulatory barriers for drivers of AVs who are blind	2013	Review	Individuals who are blind	USA	N/A	N/A	Focused only on drivers who are blind; author did not discuss limitations of the review itself; based on technology developed until 2013	None detected	N/A	N/A	N/A	Explores issues of liability and lack of regulation of AVs being used by drivers who are blind.
Millonig	Connected and AVs relevant to older adults	2019	Review	Older adults	Austria	N/A	N/A	Focused on older adults; the author did not discuss limitations of the review itself	None detected	N/A	N/A	N/A	Connected and AV may increase barriers if not designed inclusively; private ownership of AVs will not be realistic for many users; human attendants may be needed; AVs may impact social isolation and physical activity.
Peng	Effect of age on safety of AVs	2019	Survey and expressed	Older adults	China	N/A	N/A	Small sample size, possible recruitment bias,	None detected	300 older adults	304 younger individuals	N/A	Compared to younger individuals, older adults had

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Last Name of First Author	General Theme	Pub-lication Year	Design	Population of Interest	Country	Inter-vention	Duration of Inter-vention	Limitations	Potential Pub-lication Bias	Inter-vention or Main Sample N	Control N	GRADE Quality Rating	Findings Relevant to PwD
			preference approach					possible bias in the interpretation of small numbers, many participants were not drivers; some data removed due to aberrant responses					higher levels of acceptable safety with respect to fatality risk, less positive attitude toward and acceptance of AVs.
Pettigrew	AVs for older adults	2019	Interview	Variety of professional stakeholders	Mostly Australia	N/A	N/A	Not all stakeholders represented, details about interviewees not reported, international study but respondents mostly from one country, older adults were not interviewed, no control group	None detected	43	0	N/A	Privately-owned, rideshare, and public AV options may be needed to support individuals of all income levels; the dominance of commercial interests in the market; the need for participatory design and research that drives design.
Rahman	Attitudes toward AVs	2019	Survey	Older adults	USA	N/A	N/A	Possible sampling bias, responses based on perceptions but not experiences, no control group	None detected	173	0	N/A	A generally positive attitude from the perspective of the driver, but neutral or negative from the perspective of pedestrian, familiarity plays a role.
Rhui	Smart vehicles and older adults	2015	Review	Older adults	South Korea	N/A	N/A	Older adult topic was not part of original search strategy so articles may have been excluded. Results relevant to older adults were a secondary aim.	None detected	N/A	N/A	N/A	Studies on older adults focused mainly on the recognition of the driver's physical or mental state of being, but not capability of driving. Fewer studies focused on driver action suggestions (e.g., warnings, notifications), but was not as thorough as research for younger drivers without disabilities.
Robertson	AVs and older adults	2019	Survey, focus group	Older adults	Canada	N/A	N/A	Responses based on perceptions but not experiences, possible response	Funded by the Toyota Canada Found-ation	2662, 38	0	N/A	Knowledge and safety are related to intention to use, older adults

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Last Name of First Author	General Theme	Pub-lication Year	Design	Population of Interest	Country	Inter-vention	Duration of Inter-vention	Limitations	Potential Pub-lication Bias	Inter-vention or Main Sample N	Control N	GRADE Quality Rating	Findings Relevant to PwD
								bias, no control group, one dataset had small sample					receptive to various training strategies.
Rovira	Trust in AVs	2019	Survey	Older adults, younger adults	USA	N/A	N/A	Responses based on perceptions and possibly media but not experiences, younger adults were more sedentary potential confounding of trust in automation with a need for automation, convenience sample, disability focus is minimal	None detected	86	52	N/A	Trust varies according to several factors.
Son	Audification and visualization system for AVs	2019	Design and performance analysis	Individuals who are blind, individuals who are deaf	South Korea	Audification and visualization system for AVs	N/A	Users may be more interested in situation awareness information, no detail about participatory design	None detected	N/A	N/A	N/A	Performance analysis showed that it can provide useful information to users quickly.
Steinfield	Ethics and policy implications for inclusive intelligent transportation systems	2010	Policy proposal	Individuals with disabilities and older adults in general	USA	N/A	N/A	Limitations of the review itself not stated scope limited to author's perceptions about what is relevant	None detected	N/A	N/A	N/A	Important to incorporate inclusive and universal design approaches when designing intelligent transportation systems, policymakers must consider many factors, including liability, cost, potential societal benefits, and privacy.
Sultan	AVs for people with epilepsy	2020	Focus groups	Individuals with epilepsy, caregivers	UK	N/A	N/A	Descriptive analysis of participants not available, convenience sample, small sample, no control group	None detected	8	0	N/A	Concerns of this population may mirror those of other PwD but also present unique challenges such as the need to "safety-proof the car's cabin in case of a seizure".
Tabattanon	Accessible design of low-speed	2019	Review	Individuals with disabilities and older	USA	N/A	N/A	Exclusion from a review of some travel chain components such as	None detected	N/A	N/A	N/A	Accessibility research on shared-use low-speed automated shuttles is

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Last Name of First Author	General Theme	Pub-lication Year	Design	Population of Interest	Country	Inter-vention	Duration of Inter-vention	Limitations	Potential Pub-lication Bias	Inter-vention or Main Sample N	Control N	GRADE Quality Rating	Findings Relevant to PwD
	automated shuttles			adults in general				moving to and from transportation stations and stops, focus on publications on manned transit systems to infer accessible design issues for low-speed automated shuttles					non-existent, and accessibility research on other public transit modes is limited. The latter was mostly focused on physical mobility impairments. Interior configuration of vehicles is critical to accessibility and maybe an issue even when compliant with federal accessibility standards. Mock-up prototypes could help promote accessible design.
Tremoulet	Transporting children in AVs	2020	Simulator, interviews, and focus group	Parents without disabilities; children without disabilities	USA	Driving simulator	Simulator visit 60 or 25 min, focus group 60 min.	Included parents only of 8- to 16-year-old children, small sample, driving simulator included traditional manual controls, no exposure to scenarios where the car failed or risk was high, no control group	None detected	19, 14	0	Very low	The results have limited relevance to PwD, except that features may be needed to monitor and protect the user and ensure safe handoff to an adult at the end of a journey, or provide the means to monitor the user or communicate with a caregiver during the journey.
Voinescu	Usability of HMIs of AVs	2020	Pre/post simulator study	Older adults	UK	4 journeys in a simulator	25 min workshops, in-lab testing up to 4 hrs	The sample was underpowered for initial intended analysis, cross-sectional design, basic HMI design, journeys restricted to urban/city surroundings, subjective measures, no control group	None detected	25	0	Very low	HMIs that are perceived as simple to use and require less interaction are likely to be preferred by older adults.

Several articles focused on AVs potentially being used by older adults. One manuscript reviewed grey literature to identify emerging technologies relevant to older adults [89]. Self-driving vehicles were highlighted, but authors felt that their relevance depends on the level of automation that can be achieved. Rhiu, et al published a review article on features of intelligent vehicles and included manuscripts that evaluated features relevant to older adults [90]. Most studies focused mainly on the recognition of the driver's physical or mental state of being, but not the capability of driving. Fewer studies focused on driver action suggestions (e.g., warnings, notifications), but were not as thorough as research on younger drivers without disabilities. A manuscript by Knoefel et al maps cognitive changes associated with aging to their impact on driving, showing how various sensors could be used to automate steering, speed, braking, and navigation to compensate [91].

Human-machine interfaces (HMIs) that are perceived as easy to use and require less interaction may be more usable by older adults [92]. In a study using a driving simulator, automated driving was more comfortable and enjoyable than non-automated driving for older adults; interestingly, older adults preferred the unfamiliar driving style of the AV compared to their driving style, presumably because they had become familiar with using compensatory strategies to mitigate the effects of aging [93]. In a different study, however, older adults stated a preference for AVs that would mimic their driving style while correcting their errors; these participants also expressed ideas for vehicle design that would promote comfort, provide information updates, and prevent delays in responding to warnings requiring manual override [78].

A scoping review examined in-vehicle information systems (IVIS) and advanced driving assistance systems (ADAS) in older adults [94]. Reviewed studies showed evidence that using IVIS may require a lower cognitive workload, but safety can be compromised when the system is too complex. Also, ADAS affords speed control, lane maintenance, and braking responses which all may improve safety. Authors propose that designers of IVIS and ADAS should consult occupational therapists skilled in adaptive driving.

Millonig notes that SAE automation levels 0–3 require some interaction of a human driver and that this may have serious implications for safety and trust when the driver is an older adult experiencing a decline in reaction time or other skills [86]. Features that allow the user to plan, book, and pay for trips or that connect the vehicle to pedestrians, infrastructure, networks, and other vehicles and devices could lead to exclusion of users who do not have smartphones, or who have difficulty learning new skills as technology continues to advance. On the other hand, connectedness could provide the user with helpful information about the vehicle, such as its accessibility to wheelchairs.

One publication reported on two studies that detail specific needs for the design of HMIs for AVs for individuals who are blind or who have visual impairments [95]. Respondents expressed that the HMI would need to provide navigation assistance, situational awareness, and location verification. A need for accurate speech recognition is apparent, but many individuals expressed concern over accuracy and stated they would prefer to control an AV with an accessible smartphone application, although a backup system would be needed. Individuals who are blind expressed a preference for accessible applications over touchscreens, including touchscreens with voiceover capabilities, while those with low vision acknowledged some potential utility for touchscreen if they were made more accessible. The desire to manually control the vehicle in an emergency was a desire expressed by fewer respondents. Older respondents were more open to solutions that did not involve smartphone technology and expressed a need for navigation assistance to and from the AVs. Opinions varied as to whether the needs of the disability community are understood or being considered in AV accessible design, or whether designers and manufacturers understand the importance of this. Some expressed the need for systems that are secure against hacking.

Four studies reported designs or evaluations of specific HMIs. An "Audification and Visualization System" for AVs was created for individuals who are blind or deaf [96]. This system has a customizable touchscreen, provides support for text-to-speech and speech-to-text, and manages data collected from vehicle sensors. Performance analysis showed that it can provide useful sensor and diagnostic information to users quickly. The Accessible Technology Leveraged for Autonomous vehicles System (ATLAS) is an HMI with speech recognition that provides PwD with navigation assistance and spatial orientation [97]. It was designed using participatory design with input from people with visual impairments. When individuals with visual impairments interacted with ATLAS in a vehicle, they had a higher belief in usability, more desire to purchase an AV, less fear of safety, and increased trust in AVs [95]. Finally, Hong et al described the design of a vibrating chair and audio feedback system for drivers with visual impairments; reaction time and mental demand were high when tested by students without visual impairments [98].

A dearth of research addressed children with disabilities being transported in AVs or PwD using AVs to transport their children. Sultan provided results of a focus group of people with epilepsy and their caregivers. Participants felt a need for sensor technology that could detect a seizure in a passenger [81]. Simulator and survey studies have assessed the views of parents transporting children within AVs [99,100]. Although the participants in these studies were not PwD or parents of children with disabilities, one study was informed by the above study by Brinkley, et al. [95] and showed some overlap in the needs of children and those who need a caregiver. One concern was that there may be a need for features to monitor and protect the user and ensure safe handoff to a caregiver at the end of a journey or provide the means for the user to communicate with a caregiver during the journey. The need or preference for a human caregiver or attendant being involved at points in the journey may be relevant to PwD, which may enhance trust and safety, but decrease the spontaneity of travel [86]. Robots and drones may also someday provide useful assistance with cargo and mobility devices [86].

Older adults have expressed a view that because the private sector has been driving AV technology development, there has been a lack of government legislation or guidance in many countries to plan for regulatory and infrastructure issues or voucher systems [87]. The need for legislation on accessibility related to AVs must be balanced with the need for rapid technology development, given that overregulation can impede such development [101,102]. Concern for liability can also be a barrier for the production and marketing of AVs [102]. Nevertheless, developers and manufacturers can be encouraged to begin addressing accessibility in design, especially by including PwD in the process. Policymakers should develop more guidance and best practices while considering many factors including liability, cost, potential societal benefits, and privacy [103].

4. Discussion

4.1. Synthesis of findings

The findings of this review echo the words of the National Council on Disability, "…the disability community knows better than any other how being involved in planning from day one is critical to a successfully accessible product, regardless of how many years in the future it lies." [26]. This review reveals a need for guidance on accessible and usable design and planning and policy surrounding AV technology and infrastructure. The grey and scientific literature highlight opportunities and barriers to accessible and usable AVs and services. Older adults are represented more than other groups including PwD, in the scientific literature. The literature paints a colorful picture of how PwD are a diverse group, and that accessible and usable design solution will therefore need to be tailored to each group's needs and preferences. However, research is still in its infancy and must advance to include more participatory action design and engineering studies and higher quality, prospective experimental studies to evaluate outcomes of accessible and usable AV technology. Studies will need to address not only the vehicles but also all aspects of the vehicle's features and travel journey.

4.2. Policy and knowledge translation implications

The grey and scientific literature demonstrate a clear need for federal and international guidance on accessible and usable design. Universal design and participatory action design and engineering principles should be part of the development of AVs, AV services, and the built environment. Participatory action design and engineering should include PwD and all other important stakeholders, including transportation service experts, adaptive driving instructors, travel companions, caregivers, and others. While over-regulation can stifle technology advancement, the rights and needs of PwD must be considered in the process, so reservations about legislation on accessible and usable design and engineering should be balanced with the need for equity and safety. Because some vehicles that meet accessibility standards are not truly accessible to all PwD or their mobility devices, especially in situations where crowding occurs, guidance on accessible design will need to evolve to accommodate this issue. A traveler's entire journey, from arranging a ride to arriving at the destination, parking, and entering a building, should be considered in guidance on accessible and usable design. Accessible and usable design is needed for the built environment and connecting infrastructure, the vehicle, wheelchair, and scooter securement, the HMI, sensors and monitors, infotainment systems, vehicle connectedness and networks, stowage, mobile devices applications, assistive robots, and drones. The HMI of AVs will need to be customizable with accessibility features suitable for a variety of disabilities and should enhance rather than compromise their safety. Safety standards for AVs must evolve to include criteria relevant to PwD, and companies should report on such criteria. Safety algorithms must be able to detect pedestrians with disabilities. Accessible design standards should be based on full-scale prototypes that have been tested in a laboratory setting [85].

Legislation on and planning for automated travel will need to be informed by a multitude of factors. Along with the expansion of the travel system to include more vehicles, travel options, and changes to the built environment, concepts such as liability, privacy, and impact on energy, and emissions will all factor into the decisions. Policymakers will need to address how to match the availability of different types of AVs (i.e., private vehicles, paratransit, public transportation) to the needs of each community, including the number and type of accessible vehicles in each fleet. Because it is unlikely that private ownership of AVs will be common in the disability community, policy surrounding payment for services, including benefits, state and federal coverage, and voucher systems, is needed, especially given the potential impact AVs could have on medical, employment, and education outcomes. Development of successful service delivery models will need to consider human resources, such as the decreased need for drivers in parallel to the potential need for humans to serve as monitors, emergency contacts, attendants, or escorts, depending on the level of AV automation, and how to train these people. Policy will need to be developed on driver licensing requirements for AVs that do not unnecessarily exclude specific groups of PwD. Planning can be guided by geospatial analyses that outline trends in AV use, travel patterns, and associated changes in infrastructure, as well as associated projected costs. Policy will likely be informed by research on how AV use affects physical or mental health, social determinants of health, and society at large [70].

This review demonstrates a need for market research to determine the best methods for educating PwD and other stakeholders as end-users of AV technology. Important education topics are the current state of AV technology development, the extent of involvement of PwD and other stakeholders in accessible design, safety, privacy, the various transportation options (paratransit, ridesharing, private vehicles, and public transportation), and laws surrounding the operation of AVs. The method of delivering this information and the content of the message will need to be tailored to specific disability populations. Older adults, for example, have shown interest in the classroom and hands-on learning opportunities (e.g., closed course and simulator driving) [76]. Those who are blind will likely need additional information about safety, how AVs provide freedom to travel, and the inevitability that AVs will be on the road [74]. Crowdsourcing may be a way for users to get up-to-date information about their travel options and help them report issues [103].

4.3. Research gaps

Research gaps identified in this review are listed in Table 2.

4.4. Limitations and future research directions

Some limitations of our review deserve discussion. One limitation of this article is that we did not search every available scientific database. However, we did use core databases for technical papers and disability literature [104] and databases that include literature on psychosocial outcomes and social determinants of health such as transportation outcomes. We used citation-chaining to identify other potentially relevant articles. Second, we limited our review to publications since the advent and implementation of the ADA but may have excluded older articles of relevance. Third, we reviewed studies only in English. As a result, some international studies may have been excluded. Fourth, the grey literature identified may have over-represented some populations because of the expertise of the Advisory Board. Fifth, while our definition of AV was broad, most literature identified focuses on ground transportation. Finally, we also used a broad definition of disability. Although driving limitations due to aging are not necessarily the same limitations faced by younger individuals with visual, physical, or cognitive impairments [87], we have taken an inclusive approach because the literature does show some overlap in needs and opinions of these groups and because young PwD experiences the effects of aging too. However, the external validity of the studies in this review is limited to populations similar to those in each study. Our synthesis points out salient similarities and differences in these populations. It will be important for designers, planners, manufacturers, and policymakers to include the voices of both groups in their future work.

Further research is needed in many areas. The literature has only just begun to outline the needs of people with various disabilities in terms of accessible and usable design for AVs and the travel journey. High-quality prospective observational and randomized controlled trials will be needed to evaluate designs according to many outcomes such as safety, usability, and accessibility. This research needs to incorporate principles of participatory action design and engineering, where all stakeholders work collaboratively in a transdisciplinary fashion. A robust simulation infrastructure for software and hardware will be necessary for measurement of outcomes, to provide users with realistic experiences on which to base their opinions and preferences and to inform policy such as for drivers licensing. More research on AVs is also needed within specific disability groups and with respect to the intersectionality of disability and other factors. For example, most older adults will experience an eye condition at some point if they live long enough [105] and many people with blindness have comorbid conditions that also influence attitudes about AVs [74].

Our future research plans include using the research gaps generated by this review to carry out surveys, focus groups, and journey mapping studies to answer important research questions. We plan to leverage the data obtained in these future experiments and data from publicly available datasets to understand factors that influence travel and to develop solid models that illustrate key features and parameters for implementing AVs and services. Finally, we plan to create a roadmap for manufacturers and transportation system providers that is responsive to the needs of PwD and demonstrates a path forward for the integration of accessible AVs and services.

Table 2
Research gaps.

Transportation trends and socio-demographic factors
What are the current trends in use by PwD of different types of travel (e.g., AVs, ride-share, taxi, bus, personal vehicle, etc.) and the trends in the travel behavior of PwD? What changes in travel patterns for PwD are expected in the future? How will these trends and patterns affect planning for AV services?
How are the changing demographics, prevalence, and incidence of disability in the U. S. influencing the needs for accessible automated transportation specifically related to geographic region, vehicle type and number, and vehicle features?
What are the sociodemographic differences among PwD depending on whether they drive or have access to a driver or vehicle?
How do travel needs of PwD differ based on the purpose of the trip (e.g., medical appointments, shopping, leisure, employment, etc.)?
What factors influence the proportion of automated public transportation, paratransit, and private AVs needed in certain geographic regions, or the number of accessible vehicles in a fleet?
What impact will increased travel by PwD in AVs have on highway repair and maintenance, energy, emissions, and individual household expenses related to travel? Will the use of air taxis reduce traffic congestion on the ground?
How do characteristics of travelers with disabilities impact the demand for travel (e.g., disability type, financial status, age, presence of a caregiver or service animal, family role, gender, minority or Veteran status, availability of waiver or subsidy programs, etc.).
How do wait times, weather, and geographic location affect the travel demands of PwD?
How does the accessibility (or lack thereof) of streets, sidewalks, public buildings, lodging, and airplanes affect the demand for travel of PwD?
What is the incidence of accidents and injuries that result from travelers with disabilities attempting to use non-accessible transportation?
How do the availability of adaptive driving training, vehicle modifications, and funding for training and modifications influence the need for AVs?
Accessibility and usability of AVs and services
How do the needs and opinions of PwD, caregivers, travel companions, designers, medical providers, mobility service experts (e.g., vehicle manufacturers and modifiers, ride-share companies, adaptive driving training instructors) and people using service animals affect the design and implementation of AV vehicles, vehicle features, and AV services? How do their needs inform the usability and accessibility of each aspect of the travel journey?
How can improvements in accessibility and usability of AVs improve travel outcomes for PwD?
What technologies do PwD use to arrange travel? How accessible and useable are these technologies?
What features of "connectedness" for planning, booking, and paying for trips, or connecting the vehicle to other networks, people, or devices are necessary for people with varying disabilities?
How do vehicle characteristics affect the potential for travel for PwD (e.g., ease of vehicle entry/exit, storage capacity for equipment, number of potential passengers, audio or visual aids, etc.)?
How can further advances in IVIS and ADAS improve safety and accessibility or decrease cognitive load for PwD using AVs?
How can adaptive driving instructors customize IVIS and ADAS for PwD to enhance driving safety with AVs?
What AV driving styles (familiarity of driving maneuvers and ideal maneuver execution) are most comfortable and enjoyable and perceived as most safe?
Are sensors effective in detecting driving capacity, emotional state, or driving impairments related to disabilities, and do they improve vehicle control for certain disability populations?
How should notifications on an HMI or connected app be presented to individuals with different disabilities?
Outcomes of AV use
What effect will the use of AVs have on physical activity such as wheelchair propulsion or walking, physical and mental health, social isolation, and community participation?
Does AV technology improve education and employment outcomes for PwD and what impact will this have on tax revenue for governments?
Does the use of mobile technology (e.g., smartphone applications) enhance the ability of PwD to travel?
How can human attendants, robots, or drones be incorporated into parts of the travel journey, and will this impact trust, safety, and spontaneity of travel?
Research to inform policy or knowledge translation
What industry barriers exist for developing accessible automated vehicles and services? What critical services are provided by people that are not or cannot easily be replicated by AVs? What services may need to be provided by people even if AVs are used by PwDs?
What topics of education about AV are needed for specific disability groups? What format of education about AVs is most effective in improving the acceptance of AVs in PwD?
How can the need for monitoring and communicating with users of an AV be balanced with privacy concerns?
How can testing of PwD in simulators inform plans for driver licensing for AVs for PwD?
How can PwD other stakeholders gain realistic experience with current and likely future AV capabilities and limitations, allowing them to make better-informed decisions about the safety and suitability of AV for their specific sets of disabilities?
What training is needed to prepare PwD and caregivers or travel companions for automated travel?

5. Conclusions

This review highlights opportunities and barriers to accessible AVs and services. People with disabilities are a diverse group. Accessible and usable design solutions for AVs will therefore need to be tailored to each group's needs, circumstances, and preferences. Future research in diverse disability groups should include more participatory action design and engineering studies and higher quality, prospective experimental studies to evaluate outcomes of accessible AV technology. Studies will need to address not only the vehicles and their features but also the entire travel journey. A community of practice built upon stakeholder engagement will accelerate the development and deployment of accessible AVs and services in an inclusive manner, which will be beneficial to the plurality of stakeholders and sensitive and responsive to the needs of PwD.

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Appendix A. Supplementary data

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References

[1] US Census Bureau, American Community Survey (2016).
[2] World Health Organization, World Report on Disability. 2011; Available from: https://www.who.int/disabilities/world_report/2011/report.pdf last accessed 11 May 2021).
[3] Bureau of Transportation Statistics, Transportation Difficulties Keep Over Half a Million Disabled at Home. 2003; Available from: https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/special_reports_and_issue_briefs/issue_briefs/number_03/pdf/entire.pdf (last accessed 23 Mar 2021).
[4] Roessler, R.T., et al., Specialized housing and transportation needs of adults with multiple sclerosis. Work, 45(2) (2013) 223–235.
[5] M. Mitra, et al., Unmet needs for home and community-based services among persons with disabilities in Massachusetts, Disability Health J. 4 (4) (2011) 219–228.
[6] Elizabeth M. Bertera, Assessing perceived health promotion needs and interests of low-income older women, J. Women's Health Gender-based Med. 8 (10) (1999) 1323–1336.

[7] Rizzolo, M.C., et al., Home and Community Based Services (HCBS) Waivers: a nationwide study of the states. Intell. Dev. Disabilities 51(1) (2013) 1–21.
[8] C. Friedman, M.C. Rizzolo, The state of transportation for people with intellectual and developmental disabilities in Medicaid Home and Community-Based Services 1915 (c) waivers, J. Disability Policy Stud. 27 (3) (2016) 168–177.
[9] B.E. Dicianno, et al., The voice of the consumer: a survey of veterans and other users of assistive technology, Mil. Med. 183 (11–12) (2018) e518–e525.
[10] Intelligent Transportation Systems Joint Program Office, Automated Vehicle Research, 2015; Available from: https://www.its.dot.gov/automated_vehicle/index.htm (last accessed 29 Mar 2021).
[11] R.A. Cooper, B.E. Dicianno, Where To?, in Paraplegia News (2021).
[12] Ackerman, E., After Mastering Singapore's Streets, NuTommy's Robo-taxis Are Poised to Take on New Cities, 2016. Available from: http://spectrum.ieee.org/transportation/self-driving/after-mastering-singapores-streets-nutonomys-robotaxis-are-poised-to-take-on-new-cities?utm_source=Tech+Alert&utm_medium=Email&utm_campaign=TechAlert_01-12-17&bt_ee=8fKIKC0MfXV7z1d+LOEfSATe9Zr4QiUxzdnJ0zwBr8KfawcMVlTjGfxdGyU215TW&bt_ts=1484235486250. (last accessed 23 Mar 2021).
[13] Leopold, G., DOD-funded pilot to test cyber defenses for driverless vehicles. 2015; Available from: https://defensesystems.com/articles/2015/01/23/cyber-defense-for-autonomous-ground-vehicles.aspx (last accessed 23 Mar 2021).
[14] Tobe, F. Ford Motor to invest $1 billion in Pittsburgh startup Argo AI. 2017; Available from: https://www.therobotreport.com/news/ford-motor-to-invest-1-billion-in-pittsburgh-startup-argo-ai (last accessed 23 Mar 2021).
[15] E. Ackerman, Toyota's gill pratt on self-driving cars and the reality of full autonomy, IEEE Spectr. 23 (2017).
[16] National Conference of State Legislatures, Autonomous Vehicle Self-Driving Vehicles Enacted Legislation. 2020; Available from: https://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx (last accessed 30 Mar 2021).
[17] USDOT Automated Vehicles 2.0 Activities. 2017; Available from: https://www.transportation.gov/av/2.0 (last accessed 23 Mar 2021).
[18] National Highway Traffic Safety Administration, Automated Driving Systems: A Vision for Safety. 2017 23 Mar 2021]; Available from: https://www.nhtsa.gov/document/automated-driving-systems-20-voluntary-guidance (last accessed 23 Mar 2021).
[19] Preparing for the Future of Transportation: Automated Vehicles 3.0. 2018; Available from: https://www.transportation.gov/av/3 (last accessed 23 Mar 2021).
[20] National Science & Technology Council & United States Department of Transportation, Ensuring American Leadership in Automated Vehicle Technologies, U.S.D.o. Transportation, Editor. 2020, United States Department of Transportation: Washington DC.
[21] Transportation, U.S.D.o., Automated Vehicles Comprehensive Plan. 2021.
[22] United States Department of Transportation. Department of Transportation Inclusive Design Challenge. 2021; Available from: https://www.transportation.gov/accessibility/inclusivedesign (last accessed 29 Mar 2021).
[23] National Highway Traffic Safety Administration. Voluntary Safety Self-Assessment Template. 2020; Available from: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/voluntary_safety_self-assessment_for_web_101117_v1.pdf (last accessed 30 Mar 2021).
[24] National Highway Traffic Safety Administration. Voluntary Safety Self-Assessment. 2021; Available from: https://www.nhtsa.gov/automated-driving-systems/voluntary-safety-self-assessment (last accessed 30 Mar 2021).
[25] United Nations Economic Commission for Europe. Automated Driving. Available from: https://unece.org/automated-driving (last accessed 26 Mar 2021).
[26] National Council on Disability, Self-Driving Cars: Mapping Access to a Technology Revolution. Washington DC, 2015.
[27] Society of Automotive Engineers. Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles. 2016 23 Mar 2021]; Available from: http://standards.sae.org/j3016_201609 (last accessed 23 Mar 2021).
[28] Armstrong, E.C., The well-built clinical question: the key to finding the best evidence efficiently. WMJ: official publication of the State Medical Society of Wisconsin, 98(2) (1999) 25–28.
[29] M. Ioerger, et al., Developing a systematic search strategy related to people with disability: A brief report testing the utility of proposed disability search terms in a search about opioid use, Disability Health J. 12 (2) (2019) 318–322.
[30] Guyatt, G., et al., GRADE guidelines: 1. Introduction—GRADE evidence profiles and summary of findings tables. Journal of clinical epidemiology, 64(4) (2011) 383–394.
[31] G.H. Guyatt, et al., What is "quality of evidence" and why is it important to clinicians? BMJ 336 (7651) (2008) 995–998.
[32] G.H. Guyatt, et al., GRADE: an emerging consensus on rating quality of evidence and strength of recommendations, BMJ 336 (7650) (2008) 924–926.
[33] Brumbaugh, S., Travel Patterns of American Adults with Disabilities. 2018, United States Department of Transportation - Office of the Secretary of Transportation: Washington, D.C. p. 1-10.
[34] des Cognets, J.R., Greg, Assessing the Unmet Transportation Needs of Americans with Disabilities. 2019.
[35] Claypool, H., A. Bin-Nun, and J. Gerlach, Self-Driving Cars: The Impact on People with Disabilities. 2017, Securing America's Future Energy & Ruderman Family Foundation.
[36] Burns, C., The Projected Impact that Autonomous Vehicles Could Have on Vocational Rehabilitation Outcomes. 2020, Massachusetts Commission for the Blind: Boston, MA. p. 62.
[37] D. Blais, A.M. El-Geneidy, Better Living Through Mobility: The relationship between access to transportation, well-being and disability, Transportation Research Board, Washington DC, 2014.
[38] S. Ahlqvist, The Innovation for All Podcast, in Disability Advocacy for Self-Driving Cars with Henry, Claypool (2020).
[39] H. Claypool, Automakers Must Deliver on the Promise of Self-Driving Car Technology, in The New York Times, 2018.
[40] S. Rosenbloom, Transportation Pattterns and Problems of People with Disabilities. The future of disability in America, 2007.
[41] Blagg, K., et al., The Unequal Commute: Examining the Inequities in Four Metro Areas' Transportation Systems. The Unequal Commute [Blog] 2020; Available from: https://www.urban.org/features/unequal-commute (last accessed 23 Mar 2021).
[42] United Nations Development Programme, A Review of International Best Practice in Accessible Public Transportation for Persons with Disabilities. 2010: Malaysia. p. 1-100.
[43] Texas Governor's Committee on People with Disabilities, A Study Regarding the Use of Certain Public Transportation Services by Persons with Disabilities. 2014: Austin, Texas. p. 147.
[44] Kaufman, S., et al., Intelligent Paratransit. 2016, NYU Wagner.
[45] Anderson, J.M., et al., Autonomous Vehicle Technology: A Guide for Policymakers. 2016: Sana Monica, California, USA.
[46] National Academies of Sciences Engineering and Medicine, Last Mile in General Aviation Courtesy Vehicles and other Forms of Ground Transportation. 2020, Washington, DC: The National Academies Press.
[47] L.B. Ettelman, et al., Safety Perceptions of Transportation Network Companies by the Blind and Visually Impaired, College Station, Texas, 2018.
[48] Bayless, S.H. and S. Davidson, Driverless cars and accessibility: Designing the future of transportation for people with disabilities. 2019.
[49] Partners for Automated Vehicle Education and United States Department of Transportation. AVs for All: Inspiring Solutions for Accessible Design. [YouTube Video] 2020; Available from: https://www.youtube.com/watch?v=8E77maHcLJs&feature=youtu.be (last accessed 23 Mar 2021).
[50] Fraade-Blanar, L., et al., Older Adults, New Mobility, and Automated Vehicles. 2021, AARP Public Policy Institute. p. 58.
[51] The Alliance of Automobile Manufacturers, AVs and Increased Accessibility: A Workshop Series. 2019: Washington, D.C. p. 52.
[52] Office of Disability Employment Policy, Autonomous Vehicles: Driving Employment for People with Disabilities, in Information Gathering Session. 2018, U.S. Department of Labor: Office of Disability Employment Policy: Washington D. C. p. 10.
[53] S. Sundararajan, et al., Automated Vehicles (AVs). for People with Disabilities, 2017.
[54] Brooks, J.O., et al., A User-Centered Design Exploration of Fully Autonomous Vehicles' Passenger Compartments for At-Risk Populations. 2018, SAE Technical Paper.
[55] Transportation Research Board, Preparing for Automated Vehicles and Shared Mobility. 2020.
[56] Consortium for Citizens with Disabilities CCD Transportation Task Force Autonomous Vehicle Principles. 2018.
[57] Disability Rights Education Defense Fund. Fully Accessible Autonomous Vehicles Checklist. 2018 November 7, 2018 [cited 2020 November 2, 2020]; Working Draft Fully Accessible Autonomous Vehicles Checklist]. Available from: https://dredf.org/wp-content/uploads/2018/12/DREDF-Fully-Accessible-Vehicle-Checklist-110718.pdf (last accessed 23 Mar 2021).
[58] San Francisco County Transportation Authority, Guiding Principles for Emerging Mobility Services and Technologies, San Francisco County Transportation Authority, Editor. 2019: San Francisco, California. p. 1.
[59] United Kingdom: Department for Transport, Future of Transport regulatory review: call for evidence on micromobility vehicles, flexible bus services and Mobility-as-a-Service, in Autonomous Road Vehicles. 2020: United Kingdom. p. 86.
[60] Centre for Connected & Autonomous Vehicles. Project Insight. 2017; Available from: http://insight-cav.com (last accessed 23 Mar 2021).
[61] Dearen, J. Driverless cars give hope to visually impaired, but automakers unsure. 2018; Available from: www.ctvnews.ca (last accessed 5 May 2021).
[62] Halsey, A. Driverless cars promise far greater mobility for the elderly and people with disabilities. 2017; Available from: www.washintonpost.com (last accessed 5 May 2021).
[63] National Center for Mobility Management, Autonomous vehicles: Considerations for people with disabilities and older Adults. 2018.
[64] K. Wiggers, Autonomous vehicles should benefit those with disabilities, but progress remains slow, Making sense of AI, The Machine, 2020.
[65] Easton, C. Driverless cars could change lives for disabled people, if we let them. 2014; Available from: https://theconversation.com (last accessed 5 May 2021).
[66] National Disability Rights Education and Defense Fund, Comments on Proposed Decision of California PUC Commissioner Shiroma Authorizing Deployment of Autonomous Vehicle Passenger Service. 2020.
[67] Schoettle, B.S., Michael, Autonomous and Self-Driving Vehicles in the U.S., the U. K., and Australia. 2014, University of Michigan Transportation Research Institute: Ann Arbor, Michigan, USA.
[68] D. Hong, The interface that touches the mind: Advancing beyond autonomous vehicles, Braille Monitor 53 (10) (2010) 798–803.
[69] C.D. Harper, et al., Estimating potential increases in travel with autonomous vehicles for the non-driving, elderly and people with travel-restrictive medical conditions, Transp. Res. Part C: Emerg. Technol. 72 (2016) 1–9.

[70] F.S. Kovacs, S. McLeod, C. Curtis, Aged mobility in the era of transportation disruption: Will autonomous vehicles address impediments to the mobility of ageing populations? Travel Behav. Soc. 20 (2020) 122–132.
[71] R. Bennett, R. Vijaygopal, R. Kottasz, Willingness of people with mental health disabilities to travel in driverless vehicles, J. Transp. Health 12 (2019) 1–12.
[72] Brinkley, J., J.E. Gilbert, and S.B. Daily, A survey of visually impaired consumers about self-driving vehicles. 2018.
[73] J. Brinkley, et al., Exploring the Needs, Preferences, and Concerns of Persons with Visual Impairments Regarding Autonomous Vehicles, ACM Trans. Accessible Comput. (TACCESS) 13 (1) (2020) 1–34.
[74] R. Bennett, R. Vijaygopal, R. Kottasz, Willingness of people who are blind to accept autonomous vehicles: An empirical investigation, Transp. Res. Part F: Traffic Psychol. Behav. 69 (2020) 13–27.
[75] Rahman, et al., How the older population perceives self-driving vehicles, Transp. Res. Part F: Traffic Psychol. Behav. 65 (2019) 242–257.
[76] R.D. Robertson, et al., Automated vehicles and older drivers in Canada, J. Saf. Res. 70 (2019) 193–199.
[77] E. Rovira, et al., Looking for Age Differences in Self-Driving Vehicles: Examining the Effects of Automation Reliability, Driving Risk, and Physical Impairment on Trust, Front. Psychol. 10 (2019) 800.
[78] S. Li, et al., Investigation of older drivers' requirements of the human-machine interaction in highly automated vehicles, Transp. Res. Part F: Traffic Psychol. Behav. 62 (2019) 546–563.
[79] T. Bellet, J.-C. Paris, C. Marin-Lamellet, Difficulties experienced by older drivers during their regular driving and their expectations towards Advanced Driving Aid Systems and vehicle automation, Transp. Res. Part F: Traffic Psychol. Behav. 52 (2018) 138–163.
[80] P. Liu, Y. Zhang, Z. He, The effect of population age on the acceptable safety of self-driving vehicles, Reliab. Eng. Syst. Saf. 185 (2019) 341–347.
[81] M. Sultan, R.H. Thomas, Self-driving cars: a qualitative study into the opportunities, challenges and perceived acceptability for people with epilepsy, J Neurol. Neurosurg. Psychiatry 91 (7) (2020) 781–782.
[82] R. Bennett, R. Vijaygopal, R. Kottasz, Attitudes towards autonomous vehicles among people with physical disabilities, Transp. Res. Part A: Policy Pract. 127 (2019) 1–17.
[83] T. Kempapidis, et al., A scientific evaluation of autonomous vehicle user experience on sighted and visually impaired passengers based on FACS (Facial Analysis Coding System) and a user experience questionnaire, J. Transp. Health 19 (2020) 100906.
[84] J. Hwang, et al., A focus group study on the potential of autonomous vehicles as a viable transportation option: Perspectives from people with disabilities and public transit agencies, Transp. Res. Part F: Traffic Psychol. Behav. 70 (2020) 260–274.
[85] K. Tabattanon, N. Sandhu, C. D'Souza, Accessible design of low-speed automated shuttles: A brief review of lessons learned from public transit, SAGE Publications Sage CA:, Los Angeles, CA, 2019.
[86] A. Millonig, Connected and Automated Vehicles: Chances for Elderly Travellers, Gerontology 65 (5) (2019) 571–578.
[87] S. Pettigrew, S.L. Cronin, R. Norman, Brief Report: The Unrealized Potential of Autonomous Vehicles for an Aging Population, J. Aging Social Policy 31 (5) (2019) 486–496.
[88] B. Indu Rani, et al., A low cost solar powered vehicle - a boon for physically challenged persons, Disabil. Rehabil. Assist. Technol. 14 (7) (2019) 669–674.
[89] S. Abdi, L. de Witte, M. Hawley, Emerging Technologies With Potential Care and Support Applications for Older People: Review of Gray Literature, JMIR Aging 3 (2) (2020) e17286.
[90] I. Rhiu, et al., Research issues in smart vehicles and elderly drivers: a literature review, Int. J. Human-Comput. Interact. 31 (10) (2015) 635–666.
[91] F. Knoefel, et al., Semi-Autonomous Vehicles as a Cognitive Assistive Device for Older Adults, Geriatrics (Basel) 4 (4) (2019).
[92] Voinescu, et al., The utility of psychological measures in evaluating perceived usability of automated vehicle interfaces-A study with older adults, Transp. Res. Part F: Traffic Psychol. Behav. 72 (2020) 244–263.
[93] F. Hartwich, M. Beggiato, J.F. Krems, Driving comfort, enjoyment and acceptance of automated driving - effects of drivers' age and driving style familiarity, Ergonomics 61 (8) (2018) 1017–1032.
[94] S. Classen, et al., Smart In-Vehicle Technologies and Older Drivers: A Scoping Review, OTJR (Thorofare N J) 39 (2) (2019) 97–107.
[95] J. Brinkley, et al., An open road evaluation of a self-driving Vehicle human–machine interface designed for visually impaired users, Int. J. Hum.-Comput. Interact. 35 (11) (2019) 1018–1032.
[96] S. Son, Y. Jeong, B. Lee, An Audification and Visualization System (AVS) of an Autonomous Vehicle for Blind and Deaf People Based on Deep Learning, Sensors (Basel) 19 (22) (2019).
[97] Brinkley, J., S.B. Daily, J.E. Gilbert, Implementing the ATLAS Self-Driving Vehicle Voice User Interface, 2019.
[98] D. Hong, et al., Development of a semi-autonomous vehicle operable by the visually-impaired, IEEE, 2008.
[99] P.D. Tremoulet, et al., Transporting Children in Autonomous Vehicles: An Exploratory Study, Hum Factors 62 (2) (2020) 278–287.
[100] Y.C. Lee, S.H. Hand, H. Lilly, Are parents ready to use autonomous vehicles to transport children? Concerns and safety features, J. Saf. Res. 72 (2020) 287–297.
[101] J. Brinkley, S.B. Daily, J.E. Gilbert, A Policy Proposal to Support Self-Driving Vehicle Accessibility, J. Technol. Persons Disabilities (2019) 36.
[102] D.M. Mele, The quasi-autonomous car as an assistive device for blind drivers: Overcoming liability and regulatory barriers, Syracuse J. Sci. Tech. L. 28 (2013) 26.
[103] A. Steinfeld, Ethics and policy implications for inclusive intelligent transportation systems. Second international symposium on quality of life technology, 2010.
[104] E.S. Walsh, J.J. Peterson, D.Z. Judkins, Searching for disability in electronic databases of published literature, Disability Health J. 7 (1) (2014) 114–118.
[105] World Health Organization. World Report on Vision. 2019; Available from: https://www.who.int/publications/i/item/9789241516570 (last accessed 11 May 2021).