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National Surface Transportation Safety Center for Excellence

Assessing the Impact of Disability on Drivers' Equitable Use of Advanced Driver Assistance Systems (ADAS)

A Literature Review

Kelly Stulce & Jon Antin, Ph.D., CHFP

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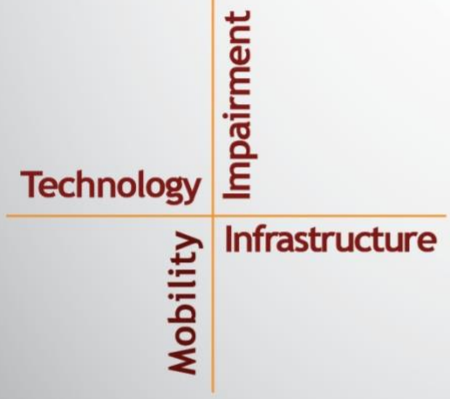

Housed at the Virginia Tech Transportation Institute
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EXECUTIVE SUMMARY

The growing prevalence of advanced driver assistance systems (ADAS) in the U.S. passenger fleet promises increased mobility and enhanced safety outcomes for all drivers, but particularly for disabled drivers, a group that comprises 11.9% of the driving population (U.S. Bureau of Labor Statistics, 2021). For ADAS to realize their full potential, stakeholders need to consider the difficulties associated with ADAS use by disabled drivers as well as the potential benefits. To support this reckoning, the authors reviewed the extant literature to discover emerging themes and to identify gaps in the literature. We then synthesized these results into a proposed road map for future work that addresses the challenges of using ADAS to enhance mobility and improve safety for all drivers, including those who are disabled.

The literature search comprises four primary topical areas and includes a variety of methodological approaches. Our review focuses on (1) models of disability, (2) disability and driving, (3) ADAS and disability, and (4) disability and the human-machine interface (HMI). Our exploration of issues around HMI use led to a consideration of the role of inclusive design and adaptive technologies in addressing interface-related obstacles to effective and equitable ADAS use.

Merriam Webster defines *disability* as "a physical, mental, cognitive, or developmental condition that impairs, interferes with, or limits a person's ability to engage in certain tasks or actions or participate in typical daily activities and interactions." Variability of the disability experience, both among the disabled population and within individual experiences, adds complexity to this initial conception (Verbrugge, 2016). Further, the prevailing models used by researchers to understand the phenomenon of disability are positioned along a continuum (Retief & Letšosa, 2018). This helps us to frame our understanding of the preconceptions different individuals bring to disabled driving research and the negative or positive orientation of those mindsets.

Disability-induced impairments affect a driver's ability to maintain lane position, control speed, and adjust time headway. These performance deficits result in elevated crash risk (Doherty et al., 2022; Dotzauer et al., 2015; Wood, 2022). ADAS such as adaptive cruise control and lane centering are well-positioned to compensate for these performance deficits (Classen et al., 2019; Deffler et al., 2022; Stevens et al., 2022). Further, the benefits of these technologies are not limited to safety outcomes. ADAS may also help to counter the psychosocial impacts of reduced mobility, such as social isolation, diminished life satisfaction, and depression (de Freitas et al., 2019; Sanders et al., 2023).

However, widespread adoption and effective use of ADAS by disabled drivers is hampered by the reluctance of some to embrace technologies that require them to cede control of the vehicle, even temporarily (Deffler et al., 2022) and by challenges around HMI use. Current HMI design guidelines may not adequately consider impairment as a barrier to use (Young et al., 2017). Further, both the level of assistance ADAS offer and the interface used to access that support must be tailored to the functional abilities of the driver (Hancock et al., 2020).

Our review of the literature reveals gaps that point the way forward for further work that will support the optimal implementation of ADAS to compensate for disability-induced driving performance deficits. Specifically, our gap analysis and research road map suggest that this work

should begin with using subjective methodologies (e.g., focus groups, interviews, and surveys) to learn from the disabled driver community in a manner that centers these individuals. Such research should yield results that more authentically capture the experience (or lack thereof) of disabled individuals driving with and making use of ADAS. Additionally, longitudinal research is necessary to support extended observation of real-world ADAS use by disabled drivers across driving environments and their disability-related functional states, which are often transient.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

AD	Alzheimer's disease
ADAS	advanced driver assistance systems
ADHD	attention deficit hyperactivity disorder
AMD	age-related macular degeneration
GUI	graphical user interface
HIID	Health Induced Impairment and Disability
HMI	human-machine interface
IVIS	in-vehicle information systems
JCTF	Joint Conceptual Theoretical Framework
NHTSA	National Highway Traffic Safety Administration
OSA	obstructive sleep apnea
OTR	on the road
PD	Parkinson's disease
SHRP 2 NDS	Second Strategic Highway Research Program Naturalistic Driving Study
SIID	Situationally Induced Impairment and Disability
TBI	traumatic brain injury
UX	user experience
VRU	vulnerable road user

CHAPTER 1. INTRODUCTION

Data show that 11.9% of the U.S. civilian noninstitutional population aged 16–64 report living with a disability, defined as having physical, mental, or emotional conditions that cause serious difficulty with daily activities (U.S. Bureau of Labor Statistics, 2021). These deficits complicate the execution of routine driving tasks such as maintaining lane position, controlling speed, and timing headway (Doherty et al., 2022; Dotzauer et al., 2015; Wood, 2022). Analysis of data from the National Motor Vehicle Crash Causation Survey reveals that 20,000 crashes each year are precipitated by drivers' medical emergencies. In crash interviews, 74% of these drivers reported having a preexisting condition (Hanna, 2010). These statistics demonstrate the potential for disability to exert a negative impact on driving that is not confined to the disabled driver.

As of May 2018, 92.7% of new U.S. vehicles had at least one advanced driver assistance system (ADAS), and by 2043, 95% of the U.S. fleet is projected to be equipped with key ADAS features, such as rear parking sensors, rearview camera, and lane departure warning (CarADAS.com, 2022; Eby et al., 2021). The growing prevalence of ADAS in the U.S. passenger fleet promises increased mobility and enhanced safety outcomes for all drivers, and such systems may hold particular hope for disabled drivers. However, the extended mobility and enhanced safety outcomes ADAS promise can only be realized fully if stakeholders properly consider the degree to which the benefits of these technologies may be offset by difficulties disabled drivers experience in their adoption, acceptance, and use.

Our review of the extant literature explores prevailing themes and seeks to identify gaps in current knowledge regarding benefits and difficulties faced by disabled drivers in the use of ADAS.

Note: For expanded information about the literature reviewed, please see the annotated bibliography in Appendix A.

CHAPTER 2. METHODS

APPROACH

The authors conducted a preliminary appraisal of the extant literature. This resulted in a literature search comprising four primary areas: (1) models of disability, (2) disability and driving, (3) ADAS and disability, and (4) disability and the human-machine interface (HMI). To generate relevant, comprehensive search strings, the research team began by brainstorming lists of synonyms for the keywords presented in Table 1.

Table 1. Keywords and synonyms.

Keyword	Synonyms
Models of disability	1. biomedical model of disability 2. functional model of disability 3. sociopolitical model of disability 4. medical model of disability 5. economic model of disability 6. social model of disability 7. identity model of disability 8. functional solutions 9. sociology of impairment 10. disability barriers 11. intersectionality
Disability	1. chronic disease 2. chronic medical condition 3. impairment 4. functional limitations 5. functional disabilities 6. functional status 7. health status 8. performance limitations 9. age-related declines 10. legibility impairment
HMI	1. graphical user interface (GUI) 2. touchscreen 3. infotainment center 4. human machine cooperation 5. human machine interaction 6. human-systems integration 7. task interface 8. interaction interface 9. embedded computer 10. man-machine systems 11. cryptographic bio-human–machine interface (CB-HMI) 12. bioperception 13. vehicle-activation system 14. finger forces 15. pressure sensing

Keyword	Synonyms
	16. force control 17. brain-computer interface 18. driver information systems 19. natural language interfaces 20. cognitive driver synchronization 21. experiential view 22. information interface 23. user-centered design 24. personas

The research team then used these lists to construct comprehensive search strings (Appendix B) designed to optimize results when used in academic databases as well as the relevant grey literature.

The research team used the keywords to search academic databases, as well as to query Elicit.org, an artificial intelligence engine. Table 2 summarizes databases accessed, topics explored in each, and limits or filters applied.

Table 2. Search engines used.

Resource	Topic(s)	Limits/Filters
Elicit.org	• ADAS and Disability • Disability and HMI	Published in or after 2015
Engineering Village	• ADAS and Disability • Disability and HMI	Published in or after 2015
Google Scholar	• Models of Disability • Disability and Driving • ADAS and Disability • Disability and HMI	Published in or after 2015
Taylor and Francis Online	• ADAS and Disability	
Transportation Research Record	• Disability and Driving • ADAS and Disability	Transportation and infrastructure

The research team strove to include literature developed using a variety of methodological approaches: literature review, experimental, theoretical, case study, thought piece, laboratory, naturalistic, simulation, self-report methods, and mixed methods.

Review Methodology

Covidence software was used to support the review. This is a collaborative platform that affords an efficient and rigorous review process based on specified criteria during the title and abstract screening as well as the full text review stages of the process. We also used Zotero citation manager, which integrates seamlessly with word processing tools.

Title and abstract screening were conducted on 82 articles. Inclusion criteria considered:

- study sample driving age (i.e., for disability research that was not focused on drivers/driving),
- recency, and
- whether the technologies studied were standard OEM ADAS.

If these criteria were not met, the question of whether the source advanced researchers' understanding of disability in general or inclusive design was considered.

Based on this process, we conducted a full text review on 53 studies, evaluating whether the inclusion of each would illuminate gaps or develop emerging themes in the literature concerning the impact of disability on equitable experience of the benefits of ADAS. Thus, we selected 43 studies for inclusion in this review.

Figure 1 summarizes the review process, including counts of articles included and excluded at each stage of the process based on the criteria identified above.

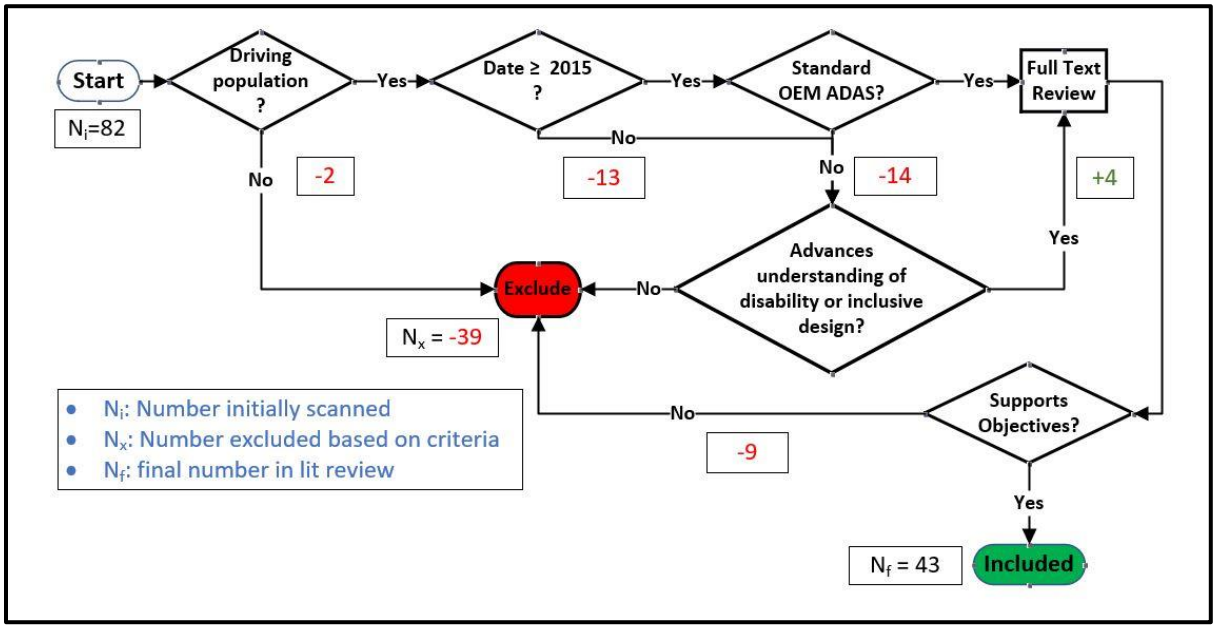

Figure 1. Schematic. Literature review process.

CHAPTER 3. DISCUSSION OF REVIEWED LITERATURE

DISABILITY

Merriam Webster defines *disability* as "a physical, mental, cognitive, or developmental condition that impairs, interferes with, or limits a person's ability to engage in certain tasks or actions or participate in typical daily activities and interactions." Further, disability is not a static category; the boundary separating the able-bodied community from the disabled one is highly permeable. No healthy or non-disabled person is immune to being rendered temporarily or even permanently disabled by an unforeseen event or illness. Such a disability could drastically impact activities of daily living, such as walking, performing self-care, communicating, or driving.

Also, the construct of disability exists on a vast spectrum in terms of type, severity, and degree of resulting functional limitations, or impairments, both between individuals and within a particular person's experience of disability. The disability experience is characterized by a lack of predictability; level of function may vary from week to week, day to day, or even hour to hour, depending on condition and symptom severity. Additionally, with progressive conditions, functional capability tends to degrade over time, and not in a reliably linear fashion. A grasp of these functional trajectories within individual cases is an essential tool for researchers seeking to propose practicable solutions grounded in a deep understanding of disability (Verbrugge, 2016).

Models of Disability

Any preconceived notions regarding the disabled population might color an investigator's interpretation of their findings. This perspective that an individual brings to bear is often formed, albeit subconsciously, by one or more of the models that have evolved over time as we try to make sense of this area. Retief & Letšosa (2018) identified the roles that such conceptual frames play in guiding whether and how researchers across the spectrum of academic disciplines study and consider disability in their work, and how such inform the formation and implementation of public policy stemming from their conclusions. These models are the medical model, the social model, the identity model, the charity model, the limits model, the economic model, the moral and/or religious model, the human rights model, and the cultural model. All nine models exist along a continuum, with a fundamentally negative conception of disability at one end and an essentially positive one at the other. The authors of this literature review have analyzed these models and assigned each a relative degree of positivity/negativity; Figure 2Our review of the extant literature presents their relative positions along this continuum.

Model	Conceptualization of Disability
Moral and/or religious model	An act of God
Medical model	Disease
Charity model	Victimhood
Economic model	A challenge to productivity
Social model	A socially constructed phenomenon
Cultural model	Contextually bound by culture
Identity model	A positive identity
Limits model	An aspect of being human
Human rights model	An issue of civil, political, social, economic, and cultural rights

Figure 2. Diagram. Disability models along positivity/negativity continuum.

While Retief and Letšosa posited that all models engage one another, Tran (2023) identified the dialogue between the medical model and the social model as speaking most urgently to the transportation safety community. The medical model presents a fundamentally negative conception of disability as a problem located in the body, best solved by medical professionals. The social model defines disability as a socially constructed phenomenon that illuminates the limitations imposed upon categories of people by the incompatibilities between their bodies and the physical and social environments in which they live and navigate (Olkin, 2022). Researchers must design investigations that equip stakeholders to craft solutions that both promote safety and ensure equitable outcomes for disabled drivers.

DISABILITY AND DRIVING

A systematic review of the literature examining the impact of vision impairments on crash risk and driving performance found increased crash risk associated with binocular visual field impairment (Wood, 2022). Individuals with impaired contrast sensitivity due to ocular conditions, including macular degeneration, cataracts, and diabetic retinopathy, were found to be at increased risk of involvement in a crash or near-crash (Swain et al., 2021). On-the-road (OTR) and simulator studies have shown a greater association between driving test failure or crash involvement in drivers with Parkinson's disease (PD; Thompson et al., 2018). Adults suffering with cognitive impairment due to Alzheimer's disease (AD) were found to have a crash risk between two and five times higher than that of healthy older adults (Doherty et al., 2022).

Additionally, developmental disabilities and mood disorders may have a negative impact on driving performance. An analysis of data collected during the Second Strategic Highway Research Program Naturalistic Driving Study (SHRP 2 NDS) examined the relationship between high incidence psychopathologies (e.g., attention deficit hyperactivity disorder [ADHD] and depression) with adverse driving outcomes (Aduen et al., 2015). Their findings revealed a significant increase (222%) in risk for multiple violations among drivers with ADHD relative to healthy controls. Additionally, they found that ADHD was predictive of increased risk for at-fault collision.

Further, the literature is replete with evidence of the correlation between disability-induced impairments and driving performance deficits (e.g., Ahmad et al., 2016; Doherty et al., 2022; Wood et al., 2022). This relationship is most pronounced in the areas of lane control, headway maintenance, and ability to maintain appropriate speed in adherence to legal limits and in response to prevailing conditions (Dotzauer et al., 2015). A tendency has been found for sleep deprivation or poor sleep quality due to obstructive sleep apnea (OSA) and cognitive impairment due to AD to lead to adverse driving behaviors, specifically hard braking, hard acceleration, and speeding (Doherty et al., 2022).

Thompson et al. (2018) conducted a systematic review examining 50 studies comprising 5,410 participants that compared drivers with PD to healthy controls in both naturalistic and simulated settings. The studies reviewed produced evidence of substantive driving performance impairment in subjects with PD. Specifically, negative performance outcomes observed included failure to regulate speed, lane deviations, and signalized intersection errors. The PD symptoms that led to these negative driving outcomes included motor-related symptoms such as tremor, rigidity, postural abnormalities, and slow movements; visual impairments; prolonged response times; and drowsiness, either as a side effect of medication or associated with PD-related fatigue. Failure rates on standardized OTR driving performance tests (comprising lane deviations, speed control and driving maneuvers) were six times higher for subjects with PD compared to healthy controls. Driving assessments were administered in daylight hours in optimal conditions. Poor scores on these evaluations have important implications regarding deterioration of performance in more challenging driving conditions, which may exacerbate symptoms and further tax functional capacity (Thompson et al., 2018). Adequate observation of fluctuating performance level requires longitudinal data collection. Such research would provide context around both “good” and “bad” days to support a more robust understanding of disabled driver performance and behavioral adaptations (Dotzauer et al., 2015).

The same authors also found that individuals suffering with PD may not only experience motor instability but may also have to contend with deficits in executive functioning that complicate driving tasks requiring selective or divided attention and decision-making under pressure, and these lead to increased instances of road errors, poor performance on OTR assessments, and greater risk for collisions. Further, they found that the cognitive complexity and physical demands of the driving task impose mental and physical burdens on the disabled driver, for which even the most elegant compensatory strategies all too often prove woefully inadequate.

Clearly, disabled drivers constitute some of our most vulnerable road users (VRUs); however, encouraging premature driving cessation for these individuals is an overly simplistic solution to a complex problem, ultimately leading to troubling consequences in other domains. Sanders et al.

(2023) found that adults with traumatic brain injury (TBI) who did not resume driving post-injury exhibited worse psychosocial outcomes, including depression, anxiety, and diminished life satisfaction, than those who did resume driving, even with access to alternative forms of transportation. The adverse outcomes associated with reduced mobility for disabled drivers mirror those documented in older populations. Further, extending the mobility of disabled drivers has many of the same benefits that have been documented for older drivers, including reduced social isolation and decreased incidence of depression (de Freitas et al., 2019).

ADAS AND THE DISABLED DRIVING EXPERIENCE

The emergence of ADAS holds promise for more equitable mobility and improved safety for both disabled drivers and for the overall driving population. It has been observed that ADAS such as adaptive cruise control and lane centering possess the potential to improve mobility and increase safety for disabled drivers, specifically by reducing driver avoidance of difficult driving situations, enhancing lane control, and supporting more effective headway maintenance (Classen et al., 2019; Deffler et al., 2022; Stevens et al., 2022). Beyond the improved driving safety benefits of ADAS, the resulting enhancement in mobility and increased independence afforded by these systems can help to mitigate the host of health-related and psychosocial outcomes associated with decreased mobility in the disability community, including social isolation, diminished life satisfaction, and depression (de Freitas et al., 2019; Sanders et al., 2023). ADAS may prove beneficial when compensatory strategies such as slowing or establishing greater headway reach their limits (Dotzauer et al., 2015). However, the promise of these systems may be tempered by the challenge of designing them in such a way that they can affordably be deployed on a broad scale and made accessible to a large population of users with a widely variable range of impairments and functional capacities.

In addition to addressing obstacles to effective design and large-scale deployment, disabled users must be persuaded that they can trust and use these systems. To that end, researchers have examined disabled drivers' experiences with and attitudes toward a variety of advanced in-vehicle technologies. Sultania (2022) conducted an online survey of 153 Canadian adults with a confirmed diagnosis of PD; researchers found perceived ease of use and previous experience the only significant predictors of intention to use ADAS in the near future. Deffler et al. (2022) found older adults diagnosed with age-related macular degeneration (AMD) to be receptive to ADAS use as a potential enhancer of driving safety. Further, the authors pointed out that disabled users show more willingness to use systems that heighten situational awareness through warnings or alerts than technologies that require the driver to cede control of the vehicle, even temporarily.

This reluctance to cede control is not surprising for a population whose abilities to navigate or manipulate their physical environments may be hampered by sensory deficits. Indeed, speaking as a disabled person, the lead author of this literature review can attest that the relationship between a disabled body and the built environment is often tenuous. Diminished capacities of perception due to vision and hearing disabilities, compromised ability to manipulate objects or interact with touchscreen surfaces due to fine motor impairments, or inability to effectively navigate physical spaces due to mobility-related disabilities all contribute to a feeling of destabilization. Any relinquishing of agency, even in cases where that agency is limited at best, that one has over the surrounding environment tends to amplify that sensation. Thus, more

widespread adoption of ADAS requires training protocols designed to address the fears disabled drivers may harbor about systems, such as adaptive cruise control, that offer substantive assistance but may also be perceived as wresting control from the disabled driver.

Sultania (2022) found that training drivers on proper use of ADAS increases their confidence in the system and their willingness to use it. In the case of a disabled driver, achieving this confidence boost requires tailoring training protocols to address a disabled driver's unique needs and specific functional deficits. Training protocols require flexibility to account for the wide spectrum of motor, visual, speech, cognitive, and hearing impairments that exist within the disabled driving population.

As these systems grow increasingly ubiquitous in the U.S. fleet, it is essential that training protocols also equip drivers with an accurate understanding of both the benefits and limitations of ADAS. Sullivan et al. (2016) found that a driver's' mental model of the system, whether accurate or not, determines the nature of their behavioral adaptations in response to the presence of the technology in the vehicle. Provided that the ADAS is used without incident, this model will be reinforced regardless of its inconsistencies or inaccuracies. A driver operating with a mental model that overestimates the capabilities of the system results may over-rely on the technology or improperly use the system outside its intended operational design domain. Drivers' perceptions of the safety benefits of ADAS exert influence not only upon their willingness to use these systems, but also upon the degree to which using these technologies delivers the intended positive performance outcomes.

ADAS Use and Driving Performance Outcomes

As discussed previously, the psychosocial benefits afforded older adult drivers when their mobility is extended as they begin to experience age-related cognitive and physical declines may mirror the experiences of disabled drivers. Likewise, Orphanides & Nam (2017) identified that older drivers are a suitable proxy for evaluating the efficacy of ADAS in producing beneficial driving performance outcomes for disabled drivers. In fact, the paucity of driving research with disabled subjects using ADAS compels stakeholders to turn to such substitutes. Classen et al. (2019) examined findings from 28 on-road and simulator studies conducted across nine countries, including the United States. These studies focused on the effect of in-vehicle information systems (IVIS) or ADAS on older drivers' convenience, comfort, or safety. The body of research reviewed found the expected positive performance outcomes in the areas of speed control, lane maintenance, and braking response.

However, in some instances, such benefits may be offset by the interaction demands these systems place on disabled drivers. A full return on investment in these technologies can only be realized if the design of the in-vehicle HMI is informed by a thorough understanding of the ways in which disability affects drivers' ability to make use of these systems. Verbrugge (2016) noted that this understanding must take into consideration heterogeneity in symptomatic severity, both across groups and for individual cases, and their impact on functional state. This knowledge should organically result in designs that offer more tailored support based on specific driver characteristics. Dotzauer et al. (2015) discussed the need for such targeted support in an examination of the effects of ADAS use on speed and headway control in subjects with PD.

HMIs AND THE DISABLED DRIVER

Successful ADAS use that increases safety and enhances mobility for disabled drivers is largely determined by issues around the HMI. Accessibility is the defining factor in determining whether a system is being deployed equitably. The interaction demands these systems currently place on disabled drivers will offset their purported benefits if left unmitigated by thoughtful investigation of the needs of these drivers and inclusive design in response to these requirements. Thus, the design of the in-vehicle HMI must be informed by a thorough understanding of the role of impairment in the driving experience of disabled people.

Much of the literature reviewed here focuses on issues surrounding disabled drivers' use of the HMI. The difficulties confronting disabled drivers when they attempt to interact using HMIs may range from touchscreen entry errors stemming from fine or gross motor control issues to delivering commands using speech-activated interfaces (Ahmad et al., 2016). Sensory and motor deficits complicate disabled drivers' use of HMI, increasing both eyes-off-road time and cognitive burden. These researchers also found that perturbations prevent users from accurately striking intended targets on a touchscreen. Erroneous selections require correction that further divides drivers' attention between the roadway and the HMI, which elevates crash risk (Klauer et al., 2006).

The literature establishes that usability issues stemming from insufficiently inclusive HMI design creates barriers between the driver and safety, comfort, and convenience (Ahmad et al., 2016; Classen et al., 2019; Morgan et al., 2018; Orphanides & Nam, 2017). Historically, HMI design has been insufficiently informed by a disability perspective. Li et al. (2022) found that most development of in-vehicle HMIs has focused on adding more functionality, to the exclusion of the system's user experience (UX). Further, some have argued most current HMI design guidelines do not adequately address age-related impairments (Young et al., 2017). Sesto et al. (2012) found that button size, gap size, and force and/or precision required to successfully engage the system exert a significant impact on interface accessibility and user fatigue for individuals experiencing motor-impairments, regardless of their etiology.

Orphanides and Nam (2017) examined human factors aspects of touchscreen interfaces using a three-dimensional schema comprising system setting, user population, and implementation environment. All three dimensions were found to have a significant impact on usability. Five of the studies included in the authors' review compared usability impacts of resistive, capacitive, optical, and surface-acoustic wave touch input technologies, finding better performance of secondary tasks on capacitive touchscreens, which improved task completion times by 27% and significantly reduced eyes-off-road time. Additionally, the authors looked at a group of studies comparing peak dwell times, peak force, and impulse in subjects with fine and gross motor disabilities with health controls. Disabled users consistently demonstrated longer dwell times and higher impulse than typically abled users. Immediate haptic feedback was found to reduce both glance count and total glance time to these non-driving task elements.

Ahmad et al. (2016) investigated interactions between drivers affected by what they term Health Induced Impairment and Disability (HIID) and in-vehicle HMI design. They pointed out that any driver can experience driving performance deficits due to Situationally Induced Impairment and

Disability (SIID). Non-inclusive design methodologies that fail to adequately consider the full range of capabilities for both disabled and able-bodied users are often a root cause of SIID.

INCLUSIVE DESIGN

Therefore, the challenge of effective ADAS design is twofold. First, both the level of assistance these systems offer and the interface used to access that support must be tailored to the functional abilities of the driver (Hancock et al., 2020). Secondly, moving towards inclusive design, which centers the needs and preferences of disabled drivers, is key to producing HMIs that will promote safer, more equitable use of ADAS by drivers with disparate functional abilities.

Inclusive design is user-centered, positioning the end user's needs at the fulcrum of the design process. One promising approach for rooting design choices in the needs of the user is personas, which involves using fictional people with assigned names, ages, genders, and other characteristics, in the design process. This methodology has found wide application across the design space for disabled end users but has been historically underutilized in ADAS design. Brinkley (2021) explored the effectiveness of personas in helping stakeholders understand the needs and preferences of disabled consumers to better inform design principles for automotive HMI. Their discussion emphasizes the importance of centering disabled voices in designing accessible interfaces. Participatory design approaches include end users in all aspects of the design process. Huff et al. (2020) stressed the value of working collaboratively with a disabled co-designer in examining a four-stage process of participatory design specific to an HMI prototype for an autonomous vehicle. At every stage, the input of a visually impaired participant was integrated into the product design. This integration supported identification of user needs, clarification of design selection, and end user feedback on multiple iterations of the resulting prototype.

The Role of Embodiment in Inclusive Design

The design methodologies using personas and involving disabled co-designers show promise for the future of inclusive design. Merleau-Ponty et al (1996) viewed tools not as separate entities but as extensions of the body itself. One key to successful implementation of inclusive approaches is an acknowledgment of the integral nature of this concept of embodiment in designing accessible, beneficial technologies. In the parlance of transportation safety, ADAS extend the ability of a disabled person to both perceive and react to salient information embedded within the roadway environment. The quality of this extension is determined by the synergy created between driver and technology. The more effectively designed the interface the driver uses to access the technology, the greater the synergy between them. More inclusive HMI designs afford a greater sense of control and transitively, a greater sense of embodiment to the driver, bringing the ideal state of constructive collaboration between driver and vehicle closer to reality.

Gluck et al (2022) found that a driver's sense of control over the vehicle and their ability to gather information about the driving environment are the primary determinants in the level of embodiment experienced while executing the driving task. A disabled individual's sense of control over their physical environment, which may be tenuous at best, could be rendered inconsistent by any number of symptoms or fluctuations in symptom severity. The importance of

stable, reliable systems that compensate for this variability cannot be overstated. In a survey of 46 drivers using a bioptic telescope to magnify distant objects, 83% reported compensatory benefits to using GPS navigation systems, with 50% citing the system as replacing their need to read road signs (Stevens et al., 2022).

Centering the Needs of the Disabled User in Behavioral Models

Inclusively designed systems that adequately center the needs of the disabled user require a shift in the paradigm stakeholders use to anticipate and respond to drivers' behavioral adaptation to ADAS. Sullivan et al. (2016) documented the evolution over the last two decades of models developed by researchers to understand driver behavioral adaptation to ADAS. Disability is absent from early models, such as the qualitative model proposed by Rudin-Brown & Noy (2002). Cotter & Mogilka (2007) introduced driver cognitive abilities into a conceptualization of the driver in their driver appropriation model. Wege et al. (2013) proposed a more expansive list of driver characteristics, including medical state, in their Joint Conceptual Theoretical Framework (JCTF).

The inclusion of cognitive concerns in the driver appropriation model and the presence of the more holistic concept of medical state, encompassing both the physical and the cognitive, in the JCTF suggests a movement toward the kind of thinking that promotes inclusion; however, the use of the term "medical" in the JCTF suggests that the required paradigm change remains incomplete. The JCTF locates inaccessibility in disabled bodies. Models that support the level of inclusive design necessary to produce accessible technologies define inaccessibility according to the barriers between disabled bodies and the systems intended to serve them.

Developing a reliable model that reflects an inclusive paradigm will require user-centered research with disabled drivers. Brinkley (2021) observed that this population is not always easy to recruit, pointing out the value of partnering with disability advocacy organizations to counter this obstacle. User-centered research sampling disabled populations would be invaluable in expanding the Eight Golden Rules framework for interface design to incorporate the needs of disabled drivers (Shneiderman, 1987). Such an expansion is required to achieve the truly inclusive approach to interface design needed to ensure equitable use of ADAS by disabled drivers. Development of sound principles of inclusive interface design requires a keen understanding of the effects of disability on a driver's ability to access ADAS and the fundamental incompatibilities between the HMIs of these systems and disabled bodies.

Adaptive HMI

The rise of adaptive HMIs reflects increasing emphasis on embodiment in inclusive design. Adaptive technologies support accessible user interfaces that promote more equitable use of ADAS. Choromanski and Grabarek (2015) observed that intelligent interfaces support greater compatibility between design features and specific functional states. Symptom severity for an individual driver can be highly variable. A driver experiencing more acute symptom presentation during any given trip will require an enhanced level of support.

Gesture-based interfaces show promise for drivers with speech and motor impairments who are unable to make effective use of more traditional interfaces that require voice and/or touch-based

inputs. Intent-aware displays have the potential to both reduce cognitive load and decrease distraction by inferring the driver's intended target early in the pointing gesture, even in the presence of tremor. Ahmad et al. (2016) found that predictive displays utilizing a gesture tracker reduce workload associated with interactions between drivers and in-vehicle HMIs up to 50%. Małecki et al. (2020) surveyed 23 able-bodied participants and 17 disabled participants with mobility limitations about their physical characteristics and level of awareness of natural user interfaces. They explored the use of gesture-based interfaces in a stationary vehicle. These researchers selected a set of seven gestures, two of which were static and five of which were dynamic. Selected gestures were natural, easy to perform, and engaged a small number of muscles. Participants were asked to use these gestures to complete six scenarios comprising a series of tasks, such as selecting an audio source and turning on and off a multimedia system. Sixty-nine percent of participants completing the gesture-based scenarios did so without errors. Further, 69% of the combined participant pool reported confidence that adaptive technology can have a significant impact on decreasing the disability barrier in their vehicles.

The benefits of intelligent interfaces that respond to fluctuations in a driver's cognitive or emotional state extend beyond the disabled driving population. Joshi et al. (2019) found that non-disabled drivers who are subject to elevations in mood or emotional state that affect speech and motor function would also derive benefits from intelligent interfaces capable of detecting and responding appropriately to frustration, as gauged by gestural indicators, facial features, eye tracking, and electrodermal response.

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The population of individuals for whom disability-induced impairments may result in elevated crash risk crosses boundaries of age, gender, race, and ethnicity. Functional deficits in disabled drivers have been shown to result in negative performance outcomes in the areas of lane control, speed control, and headway maintenance. ADAS have the potential to both extend mobility and improve driving performance outcomes for disabled drivers. Improvements in lane and speed control and headway maintenance promise safer roadways, not only for disabled drivers, but for all drivers.

The intersectional nature of those whom the literature identifies as most vulnerable requires that stakeholders deploy technological solutions such as ADAS judiciously to meet the needs of as wide a swath of this population as possible. This requirement translates to thoughtful, disability-informed product design and tailored training protocols that deliver robust content in an accessible manner. As Sultania (2022) points out, training content that increases perceived usefulness of and comfort with ADAS encourages adoption and use. Beyond the training phase, longitudinal observation is needed to ensure that any necessary course corrections are applied in a timely and meaningful manner (Dotzauer et al., 2015).

Equipping stakeholders to design and deploy systems that realize this potential requires research that fully explores the disability driving experience and interrogates the challenges associated with effective use of ADAS by disabled drivers.

The gaps in the research reviewed here point the way toward such investigations. In Table 3, we cross-reference the main areas of relevance with the key research methods. The matrix is then color-coded to illustrate the research gaps requiring attention, with the most researched cells having no color, cells with modest research shaded peach, and the least-researched cells both shaded and outlined in red.

Table 3. Gaps in reviewed literature.

Method	HMIs and the Disabled Driver (%)	Disability and Driving (%)	ADAS and Disability (%)	Inclusive Design (%)	Models of Disability (%)	Total (%)
Literature Review	9	7	7	2	2	**28**
Experimental	9	5	2	2	0	**19**
Theoretical	12	0	0	0	0	**12**
Case Study	2	0	0	7	0	**9**
Thought Piece	0	0	0	2	7	**9**
Laboratory	2	0	0	0	0	**2**
Naturalistic	0	7	0	0	0	**7**
Simulation	2	2	2	0	0	**7**
Subjective (e.g., surveys, questionnaires,	0	2	5	0	0	**7**

Method	HMIs and the Disabled Driver (%)	Disability and Driving (%)	ADAS and Disability (%)	Inclusive Design (%)	Models of Disability (%)	Total (%)
interviews, focus groups)						
Mixed Methods	0	0	0	0	0	**0**
Total	**37**	**23**	**16**	**14**	**9**	**100**

In addition, the current effort considered the broad range of functional disabilities together. Future research efforts will need to focus more narrowly to properly investigate the capabilities and needs of individuals with different types or categories of disability.

The circuitous nature of the road picture in Figure 3 conveys the way the results of each stage of the research will determine the direction of subsequent stages.

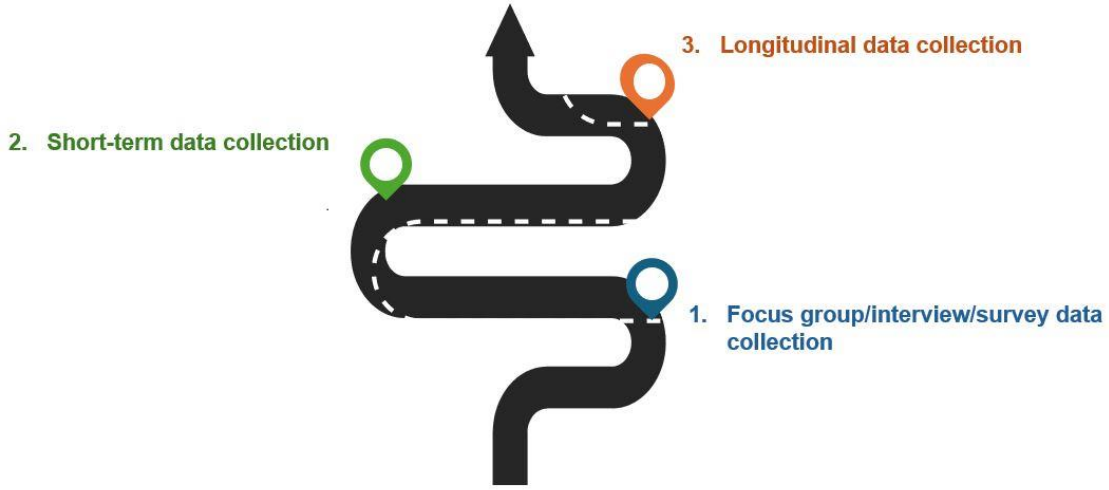

Figure 3. Illustration. Refined research road map.

Specifically, we propose a three-stage approach to further investigate both the benefits and challenges associated with ADAS use by disabled drivers:

1. **Focus group/interview/survey data collection exploring the disabled driving experience**
   The first stage of our proposed approach embraces the model suggested by Huff et al. (2020), eliciting the needs and perspectives of disabled participants in focus group and interview settings. Recognizing the challenges of recruiting disabled subjects, we propose following the recommendation to engage with disability advocacy organizations and, as necessary, turn to older driver as proxies (Brinkley, 2021; Orphanides & Nam, 2017). The results of these focus group sessions and interviews

would inform survey instruments following the iterative process proposed by Huff et al. (2020) for use in Stage Two.

2. **Short-term mixed methods data collection investigating ADAS use with a focus on driver interactions with HMIs.**

   A short-term mixed methods approach would serve two functions. First, subjective data collected via survey instruments developed during Stage 1 can be used to inform the research design for the test track and/or naturalistic data collection. Second, short-term test track and/or naturalistic data collection would refine research questions that will shape the longitudinal data collection in Stage 3. Classen et al. (2019) identified naturalistic driving data collection as essential to both measure safety and performance outcomes and address questions surrounding driver comfort and convenience using these systems. Deffler et al. (2022) call for future observational research that seeks to identify which ADAS are most helpful to drivers in specific driving environments.

3. **Longitudinal mixed-methods data collection studying ADAS use by disabled drivers**

   The paucity of naturalistic driving and simulator research represented here points to a need for longitudinal data collection that supports extended observation of ADAS use. Ideally, this data collection should occur in a variety of driving environments over a sufficiently long period to capture both the driver's adjustment to the technology and fluctuations in the presentation of symptoms (Verbrugge, 2016). The lack of context for a subject's "good" and "bad" days reinforces the need for naturalistic data collected over sufficiently long periods of time to support meaningful observation of ADAS use across environments and possibly transient functional states (Dotzauer et al., 2015).

It is also interesting to note that most of the literature reviewed here comes from the work of North American and European researchers. However, forecasts of rapid growth in the ADAS global market over the next decade compel us also to continue to consider the important work of others around the globe (Fortune Business Insights, 2022). Table 4 presents the literature included herein by continent of publication.

Table 4. Included literature by continent of publication.

Continent	%
Africa	2.33
Asia	6.98
Australia	9.30
Europe	23.26
North America	55.81
South America	2.33
Total	**100**

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APPENDIX A. ANNOTATED BIBLIOGRAPHY

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Metadata	Description
Year: 2015 **Country:** USA **Method:** Naturalistic **Category:** Disability & Driving **Keywords:** ADHD, depression, driving, collisions, violations, driving outcomes	**Approach:** Researchers analyzed data collected during the SHRP 2 NDS to examine the relationship between high incidence psychopathologies (e.g., ADHD, depression) and adverse driving outcomes. **Key Findings:** There is significantly increased risk for multiple violations and collisions among drivers with ADHD relative to healthy control drivers. No significant risk was found in drivers with self-reported depression relative to their counterparts in the healthy control cohort. **Future Work:** The authors point out the need for further investigation that seeks to identify the mechanisms by which ADHD, depression, and other high incidence psychiatric disabilities lead to adverse driving outcomes.

Ahmad, B. I., Murphy, J. K., Langdon, P. M., & Godsill, S. J. (2016). Predictive Pointing from Automotive to Inclusive Design. In *Universal Access in Human-Computer Interaction. Users and Context Diversity: 10th International Conference, UAHCI 2016, Held as Part of HCI International 2016, Toronto, ON, Canada, July 17-22, 2016, Proceedings, Part III 10* (pp. 527-537). Springer International Publishing. https://doi.org/10.1007/978-3-319-40238-3_50.

Metadata	Description
Year: 2016 **Country:** UK **Method:** Theoretical **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** interactive displays, Bayesian inference, target assistance, motor impairment, endpoint prediction, inclusive design	**Approach:** The authors investigated interactions between drivers with HIID and in-vehicle HMIs. Stipulating that any driver can be subject to SIID by non-inclusive design methodologies that fail to adequately consider the full range of capabilities for both disabled and able-bodied users, the authors explored the efficacy of a predictive display utilizing a gesture tracker. **Key Findings:** Researchers point out the potential for a touchscreen HMI to affect drivers with motion-visual impairments, as additional effort is required to correct erroneous selections. This effort is further compounded by the resulting tendency to divide attention between the roadway and the HMI. Their findings show predictive displays utilizing a gesture tracker can reduce workload associated with interactions between drivers and in-vehicle HMIs up to 50%. **Future Work:** These findings make a compelling argument for the adoption of the user-centered design approach to HMI development. Further work exploring integration of disabled users into the development process would support this adoption.

Brinkley, Julian. (2021, September). Using Personas with Visual Impairments to Explore the Design of an Accessible Self-Driving Vehicle Human-Machine Interface. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *65*(1), 337–41. https://doi.org/10.1177/1071181321651223.

Metadata	Description
Year: 2021 **Country:** USA **Method:** Case Study **Category:** Inclusive Design **Keywords:**	**Approach:** This case study collected survey and focus group data from visually impaired drivers to explore the effectiveness of using personas to help stakeholders understand the needs and preferences of disabled consumers to better inform design principles for automotive interfaces. **Key Findings:** The authors emphasize the importance of centering disabled voices in designing accessible interfaces that heighten the potential for the anticipated benefits of ADAS for disabled drivers to be fully realized. Aggregated survey and focus group data reveal a need for speech, touch, and smartphone interface capabilities and comprehensive vehicle status warnings. **Future Work:** The authors stress the need for user-focused research methodologies and identify recruitment of members of the disability community as one of the most prominent obstacles to truly inclusive disability-informed research, suggesting cooperation with established disability-related organizations to address this challenge.

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Metadata	Description
Year: 2015 **Country:** Poland **Method:** Theoretical **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** Urban transport; Driver-vehicle system; HMI; Standardization	**Approach:** The authors propose the Hybrid Vehicle and Transit System for Urban Application (HVTSUA), a transport system that integrates the PodCar system and components of the Eco-Car system, to adapt to drivers of varying ability and mobility by standardizing solutions for new systems. **Key Findings:** The authors point out the potential for using intelligent interfaces to inform human machine interface (HMI) design in vehicles equipped with ADAS. **Future Work:** The importance of creating compatibility between HMI design features, such as multifunctional steering wheels that rely on electromyographic (EMG) signals rather than mechanical inputs, and specific illness profiles, as well as the need for benchmarked tests to assess accessibility solutions are highlighted as areas for future exploration.

Classen, Sherrilene, Mary Jeghers, Jane Morgan-Daniel, Sandra Winter, Luther King, and Linda Struckmeyer. (2019, April 1). Smart In-Vehicle Technologies and Older Drivers: A Scoping Review." *OTJR: Occupational Therapy Journal of Research, 39*(2), 97–107. https://doi.org/10.1177/1539449219830376.

Metadata	Description
Year: 2019 **Country:** USA **Method:** Literature Review **Category:** ADAS and Disability **Keywords:**	**Approach:** The authors expand on a project conducted by the University of Florida and AAA (Smart Features for Older Drivers) to identify the impacts of IVIS and/or ADAS features in vehicles driven by older adults as reported by studies that met researcher criteria. Selected studies were from the United States, Canada, Australia, Japan, and several countries in Europe. Most studies reviewed had a minimum participant age of 65, but some contained younger drivers of unspecified ages. Studies that involved IVIS and ADAS features were examined for convenience, comfort, and/or safety. **Key Findings:** Based on aggregate results, ADAS features such as adaptive cruise control, assisted parallel parking, active steering assist, brake assist, and lane keep assist had the greatest potential to improve driver safety as well as comfort. **Future Work:** Naturalistic studies were recommended for further ADAS research. None of the on-road studies included in this review addressed comfort or convenience.

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Metadata	Description
Year: 2023 **Country:** USA **Method:** Thought Piece **Category:** Models of Disability **Keywords:** disabilities, children	**Approach:** The author provides an overview of the moral, medical, and social models of disability. **Key Findings:** The strengths and weaknesses of each model are discussed, as is the way each model is reflected in prevailing attitudes towards disability. **Future Work:** An exploration of the perspectives of disabled individuals regarding the usefulness of each model is identified as an area for future research.

Deffler, R. A., Xu, J., Bittner, A. K., Bowers, A. R., Hassan, S. E., Ross, N., ... & RADARS Study Group. (2022). Use and perceptions of advanced driver assistance systems by older drivers with and without age-related macular degeneration. *Translational Vision Science & Technology, 11*(3), 22-22. https://doi.org/10.1167/tvst.11.3.22.

Metadata	Description
Year: 2022 **Country:** USA **Method:** Experimental **Category:** ADAS and Disability	**Approach:** The survey study discussed here recruited 166 participants aged 60 and older from the clinical practices or research databases of four sites across the United States to collect data regarding participants' perceptions and frequency of use of eight ADAS. Within the sample, 80 survey respondents had a diagnosis of

Keywords: driver assistance, age-related macular degeneration, older drivers	AMD. **Key Findings:** The researchers found no significant difference in level of trust in ADAS systems between participants with AMD and those without. Drivers with AMD were found to be more likely to avoid difficult driving situations. Increased ADAS use was associated with reduced avoidance of difficult driving situations. **Future Work:** The authors call for future longitudinal and/or observational research that seeks to identify which ADAS are most helpful to drivers with AMD in specific driving environments.

de Freitas, R. C., Alves, R., da Silva Filho, A. G., de Souza, R. E., Bezerra, B. L., & dos Santos, W. P. (2019). Electromyography-controlled car: A proof of concept based on surface electromyography, Extreme Learning Machines and low-cost open hardware. *Computers & Electrical Engineering, 73*, 167-179.

Metadata	Description
Year: 2019 **Country:** Brazil **Method:** Theoretical **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** Electromyographic control, human machine interface, extreme learning machines, car functionalities	**Approach:** Their proposed prototype relies on EMG signals for intention recognition to eliminate the noise-related limitations of visual gesture-based HMI adaptations and the accuracy, throughput, and latency difficulties associated with speech recognition and natural language processing solutions. In the prototype proposed here, a neural network would use a device comprising an Arduino UNO, a Raspberry Pi, and a sensor for detecting EMG waves to recognize and classify muscular signals to steer the vehicle **Key Findings:** The authors propose a gesture-based alternative to adaptive solutions that require paraplegics to control all vehicle functionalities with the upper limbs, hypothesizing that their approach will significantly reduce visual and biomechanical distraction, resulting in decreased crash risk. Researchers found that it is possible to activate functions through recognition of gestures based on EMG signal activity but were unable to capture EMG signals of sufficiently high quality to mitigate noise and successfully control the vehicle. **Future Work:** Researchers suggest exploration of alternative methods, such as a more robust radio powered by Bluetooth Low Energy (BLE) for activation of functions based on gesture recognition. Additionally, they point out the need for devices sufficiently robust to noise to better attenuate high quality EMG signals.

Disabled World. (September 10, 2010). Models of Disability: Types and Definitions. *Disabled World*. https://www.disabled-world.com/definitions/disability-models.php.

Metadata	Description
Year: 2010 **Country:** N/A **Method:** Thought Piece **Category:** Models of Disability **Keywords:**	**Approach:** This webpage briefly details 19 models of disability, including the medical model, the social model, and the religious model. **Key Findings:** Although this source covers more models, the article by Retief and Letšosa provides more comprehensive explanations. Notably, Disabled World separates the minority model from the social model; Retief and Letšosa combine them. **Future Work:** As researchers undertake further work in this field, they must be cognizant of the lens through which they perceive disability and its impact on their scholarship.

Doherty, J. M., Roe, C. M., Murphy, S. A., Johnson, A. M., Fleischer, E., Toedebusch, C. D., ... & Babulal, G. M. (2022). Adverse driving behaviors are associated with sleep apnea severity and age in cognitively normal older adults at risk for Alzheimer's disease. *Sleep, 45*(6), zsac070. https://doi.org/10.1093/sleep/zsac070.

Metadata	Description
Year: 2022 **Country:** USA **Method:** Naturalistic **Category:** Disability and Driving **Keywords:** obstructive sleep apnea, driving, Alzheimer's disease, older adults	**Approach:** This naturalistic driving study collected driving data via commercial GPS logger, sleep apnea-related data via a one-night home sleep test, and cognitive data using a suite of cognitive assessments. **Key Findings:** The authors, focusing on adverse driving behaviors in participants with OSA and AD, found OSA and AD pathology exert independent effects on adverse driving behaviors associated with elevated crash risk. **Future Work:** A limitation of this work, and one that points the way forward for future study seeking to understand the impact of comorbidities on driving performance, is that only a subset of the sample had moderate-to-severe OSA and none of their participants presented with cognitive impairment.

Dotzauer, M., Caljouw, S. R., Waard, D. D., & Brouwer, W. H. (2015). Longer-term effects of ADAS use on speed and headway control in drivers diagnosed with Parkinson's disease. *Traffic injury prevention, 16*(1), 10-16. https://doi.org/10.1080/15389588.2014.909037.

Metadata	Description
Year: 2015 **Country:** The Netherlands **Method:** Simulation **Category:** ADAS and Disability **Keywords:** ADAS, older drivers, Parkinson's Disease, speeding, headway control	**Approach:** Using a driving simulator, the researchers investigated the effects of ADAS on the driving performance of older drivers diagnosed with PD. The study was conducted over 12 sessions; the first and seventh sessions were done without ADAS. **Key Findings:** When compared to healthy controls, drivers with PD had a greater degree of difficulty maintaining lane position, controlling speed, and timing headway. **Future Work:** This study was limited by the small sample size and the heterogeneity of its participants.

Dubs, A., Correa Andrade, V., Ellis, M., Karaman, B., Demirel, D., Alnaser, A. J., & Toker, O. (2022, June). Drive a vehicle by head movements: An advanced driver assistance system using facial landmarks and pose. In *International Conference on Human-Computer Interaction* (pp. 502-505). Springer International Publishing. https://doi.org/10.1007/978-3-031-06417-3_67.

Metadata	Description
Year: 2022 **Country:** USA **Method:** Laboratory **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** Advanced Driver Assistance Systems (ADAS, drive-by-wire systems, facial landmarks	**Approach:** The authors describe their initial prototype for an ADAS comprised of a facial landmark and pose estimation system and a drive-by-wire hardware that permits drivers to operate the vehicle using only head movements. Later iterations of their design utilized Google's FaceMesh artificial intelligence model to develop a facial landmark detection feature. **Key Findings:** Dubs and her coauthors hypothesize that the system will increase safety and comfort for disabled drivers. **Future Work:** The authors identify the addition of automation and other assistance features for other use cases as areas for future work.

Duff, S. N., Irwin, C. B., Skye, J. L., Sesto, M. E., & Wiegmann, D. A. (2010, September). The effect of disability and approach on touch screen performance during a number entry task. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 54, No. 6, pp. 566-570). SAGE Publications. https://doi.org/10.1177/154193121005400605.

Metadata	Description
Year: 2010 **Country:** USA **Method:** Experimental **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:**	**Approach:** Acknowledging the growing ubiquity of touchscreen interfaces in all facets of 21st century life, including banking, shopping, air travel, and driving, the authors examine the effect of disability on performance of a touch screen number entry task. Comparing the performance of participants with motor impairments affecting the upper limbs (n=12) and those without (n=7), the research team considered variables of button size, gap size, and approach type (directly in front of versus parallel to the touchscreen interface). This study was conducted using the ADA standards for ATMs, though with touchscreens becoming more commonplace in vehicles, recommendations for button size and gap size could prove beneficial to drivers with motor control impairments. **Key Findings:** The potential for technologies constructed without adequate attention to the principles of universal design to have detrimental effects is discussed. **Future Work:** Future research should include an examination of the performance and interaction characteristics of persons with a wide range of abilities to support the design of optimally accessible interfaces.

Gibson, Amelia, Kristen Bowen, and Dana Hanson. (2023, April 13). We Need to Talk About How We Talk About Disability: A Critical Quasi-Systematic Review. *In the Library with the Lead Pipe*. https://www.inthelibrarywiththeleadpipe.org/2021/disability/.

Metadata	Description
Year: 2021 **Country:** USA **Method:** Literature Review **Category:** Models of Disability **Keywords:**	**Approach:** The authors discuss how disability is defined and how disability research is approached in the field of librarianship and information science (LIS). **Key Findings:** They observe that disability research frameworks often reflect the medical model of disability, with LIS researchers valuing the perspectives of those with more institutional power over the experiences of marginalized groups. The literature review examined the inclusion and input of people with disabilities in LIS research; among the most frequently mentioned in their pool of articles were generalized disability, vision-related disability, and learning disabilities. The least frequently mentioned marginalized groups were palliative care patients, people with MS, and people with HIV. **Future Work:** The underrepresentation of people with MS in the research space has implications for research sampling in future studies.

Gluck, A., Huff, E. W., Boateng, K., & Brinkley, J. (2022, November). Toward a Framework for Embodiment in Emerging Transportation Technologies for Facilitating In-Vehicle Experiences for Vulnerable and Disabled Road Users. In *2022 IEEE 3rd International Conference on Human-Machine Systems* (ICHMS) (pp. 1-5). IEEE. https://doi.org/10.1109/ICHMS56717.2022.9980810.

Metadata	Description
Year: 2022 **Country:** USA **Method:** Literature Review **Category:** Disability and Driving **Keywords:** embodiment, transportation technology, older adults, people with disabilities	**Approach:** Gluck and his coauthors discuss similarities in mobility-related challenges (e.g., social isolation) experienced by older drivers and disabled drivers. French phenomenologist Merleau-Ponty's theory of embodiment, which defines tools as extensions of the body rather than separate entities, is applied by the authors to the transportation space, with the driver's level of control and ability to gather information identified as the determining factors in defining the driver's level of embodiment. **Key Findings:** A framework for evaluating ADAS and AVs based on the level of embodiment they confer upon the driver is presented. Within this schema, passive embodiment, wherein a driver has little control or ability to gather information, is associated with ridesharing or getting a ride from a friend. Driving a vehicle with active safety systems is associated with more active embodiment. **Future Work:** The authors conclude that automotive technologies that are designed with adopt embodiment as a guiding principle will more likely be accepted and used by older adults and people with disabilities.

Hancock, P. A., Kajaks, T., Caird, J. K., Chignell, M. H., Mizobuchi, S., Burns, P. C., ... & Vrkljan, B. H. (2020). Challenges to human drivers in increasingly automated vehicles. *Human Factors*, *62*(2), 310-328.

Metadata	Description
Year: 2020 **Country:** Canada **Method:** Literature Review **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver; ADAS and Disability **Keywords:** Human driver capacity, trust, access, mobility, human-vehicle interaction	**Approach:** This paper summarizes a panel discussion among experts from the fields of human factors, psychology, engineering, occupational therapy, and medical decision sciences at the Driving Symposium hosted by the Toronto Rehabilitation Institute in March 2017. Topics explored by the panel included five major considerations for automated vehicles: driver independence and mobility, driver acceptance and trust, failure management, third-party testing, and political support. Contextualizing their discussion to North America, the panel discussed these issues in furtherance of four stated goals: to identify research gaps related to the use of semi- and fully autonomous vehicles and their HMI; to enumerate specific challenges related to the use of semi- and fully autonomous vehicles by particular populations, including older and disabled drivers; to distinguish methods of investigating the identified research questions; and to suggest collaborative research opportunities in the advanced vehicle technology space. **Key Findings:** A number of impediments to full realization of the benefits of semi- and fully autonomous vehicles by older and disabled populations emerged in the discussion, including vehicle egress and ingress, appropriate licensure standards for vulnerable populations and the design challenges associated with tailoring the level of automation to the functional abilities of the driver. **Future Work:** The authors recommend further research into the circumstances surrounding disengagement of automated technologies and the ability of drivers to regain control of the vehicle following disengagements. Further, they advocate for the development of a roadmap that outlines appropriate steps stakeholders should take as they develop increasingly automated vehicles.

Huff Jr, E. W., Lucaites, K. M., Roberts, A., & Brinkley, J. (2020, December). Participatory design in the classroom: exploring the design of an autonomous vehicle human-machine interface with a visually impaired co-designer. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 64, No. 1, pp. 1921-1925). SAGE Publications. https://doi.org/10.1177/1071181320641463.

Metadata	Description
Year: 2020 **Country:** USA **Method:** Case Study **Category:** Inclusive Design **Keywords:**	**Approach:** This case study reflects upon the value of working collaboratively with a disabled co-designer when designing an HMI for a self-driving vehicle. Three sessions with the visually impaired co-designer are described, progressing from an interview to elicit information about needs and preferences to the presentation of a high-level concept for an Autonomous Vehicle Accessibility System (AVAS) to the co-designer. **Key Findings:** The authors acknowledge the potential for

	autonomous vehicles to overcome transportation barriers for low-vision and visually impaired drivers, discussing the importance of adopting a participatory approach to interface design in order to adequately consider the unique needs of disabled users. **Future Work:** Identified areas for future research include involvement of multiple co-designers and co-designers with multiple disabilities.

Jordan, J. B., & Vanderheiden, G. C. (2010, September). Accessibility experience lab: Discovering the impact of design on disabilities. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 54, No. 19, pp. 1396-1400). SAGE Publications. https://doi.org/10.1177/154193121005401909.

Metadata	Description
Year: 2010 **Country:** USA **Method:** Case Study **Category:** Inclusive Design **Keywords:**	**Approach:** The authors highlight the efforts of the University of Wisconsin to produce engineers trained to view design through a more disability-informed lens. The UW-Trace Experience lab, in which first-year engineering students are afforded a simulated experience that exposes them to the challenges faced by disabled users of everyday objects, locates disability in the incompatibility between the individual and his or her built environment. Inclusion of programs like the one described here in human factors education programs apply the principles of universal design to ensure accessibility. **Key Findings:** Ninety-two percent of students surveyed cited the lab as increasing their awareness of disability issues they had not previously encountered. Ninety-six percent identified the lab experience as a worthwhile one. **Future Work:** The authors point out the potential usefulness of comparing attitudes of subjects before and after the lab experience. They also acknowledge the weaknesses of disability simulations as isolated experiences but point out their potential value in altering attitudes toward people with disability when integrated into a comprehensive approach.

Joshi, A., Attia, Y., & Mishra, T. (2019, September). Protocol for eliciting driver frustration in an in-vehicle environment. In *2019 8th International Conference on Affective Computing and Intelligent Interaction* (ACII) (pp. 620-626). IEEE. https://doi.org/10.1109/ACII.2019.8925489.

Metadata	Description
Year: 2019 **Country:** USA **Method:** Simulation **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** frustration, in-car sensing, emotion elicitation protocol, multimodal	**Approach:** This simulator study implements a protocol for eliciting driver frustration while interacting with an in-vehicle HMI. This research was undertaken to address the potential for driver frustration when an HMI fails to respond as they desire or expect to contribute to driver distraction and increased driver aggression. **Key Findings:** The review of relevant literature includes modeling, measurement, and prediction of frustration based on gestural indicators, facial features, eye tracking, and electrodermal response and a discussion of methodologies for obtaining frustration labels

	based on participant self-report and predefinition of "frustrating" tasks. **Future Work:** The authors advocate for the development of in-cabin sensors that can accurately detect driver frustration and the design of HMI capable of de-escalating the driver from a state of frustration. Due to the wide variance in manifestations of frustration across modalities, collection of natural frustration datasets with which to build machine learning models must be conducted using a wide population.

Kunimatsu-Sanuki, S., Iwase, A., Araie, M., Aoki, Y., Hara, T., Nakazawa, T., ... & Itoh, M. (2015). An assessment of driving fitness in patients with visual impairment to understand the elevated risk of motor vehicle accidents. *BMJ open*, *5*(2), e006379. https://doi.org/10.1136/bmjopen-2014-006379.

Metadata	Description
Year: 2015 **Country:** Japan **Method:** Experimental **Category:** Disability and Driving **Keywords:**	**Approach:** This simulator study investigated assessment of driving fitness in 36 patients with advanced glaucoma, who were found to be involved in a significantly higher number of collisions with simulated hazards than 36 age-matched and driving exposure-matched subjects with normal visual fields (119 vs. 40, $p < 0.0001$). The study was designed to establish the efficacy of driving simulators in assessing driving fitness in subjects with visual field impairments and to educate drivers with visual field impairments about the limitations imposed by their disorder. **Key Findings:** Of 14 scenarios, the four identified as most representative of the heightened crash risk resulting from visual field impairment involved oncoming right-turning vehicles and vehicles approaching from the sides. **Future Work:** The authors point out that current guidelines focus on visual acuity rather than minimum acceptable visual field required for licensure or license renewal.

Li, W., Wu, Y., Zeng, G., Ren, F., Tang, M., Xiao, H., ... & Guo, G. (2022). Multi-modal user experience evaluation on in-vehicle HMI systems using eye-tracking, facial expression, and finger-tracking for the smart cockpit. *International journal of vehicle performance*, *8*(4), 429-449. https://www.inderscienceonline.com/doi/10.1504/IJVP.2022.125931.

Metadata	Description
Year: 2022 **Country:** China **Method:** Theoretical **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** HMI, human-machine interaction, user experience, driver emotion, behaviour analysis, smart cockpit	**Approach:** Their approach blended objective and subjective data across three dimensions; it took into account sense experience, interaction experience and emotional experience, relying on eye-tracking, facial expression, and finger movement to evaluate sense experience, interaction experience, and emotional experience. **Key Findings:** The authors describe an evaluation method for assessing UX with in-vehicle HMIs based on data collected via multiple modalities. They point out that most development of in-vehicle HMIs has focused on adding more functionality, to the exclusion of the UX of the system. A subjective evaluation scale

	administered after completion of the scenario was used to collect additional emotional experience data. In their review of relevant literature, they identify shortcomings of applying the formula method based on mathematical models or the experiment method, which collects data about physiological changes in the user, in isolation. **Future Work:** The authors acknowledge that conducting HMI assessment on a stationary vehicle outfitted with the two systems to be evaluated omitted the primary driving task and identify application of their methodology to subjects engaged in the driving task as a way to fill this gap.

Małecki, K., Nowosielski, A., & Kowalicki, M. (2020). Gesture-based user interface for vehicle on-board system: a questionnaire and research approach. *Applied Sciences, 10*(18), 6620. https://doi.org/10.3390/app10186620.

Metadata	**Description**
Year: 2020 **Country:** Poland **Method:** Experimental **Category:** Inclusive Design **Keywords:** natural user interface (NUI); human computer interaction (HCI); gesture-based user interface; gesture recognition; people with physical disabilities; image processing	**Approach:** The authors explored the application of natural user interfaces that rely on a driver's gestures, body movements, or speech as inputs to the design of in-vehicle HMIs for use by both able-bodied and disabled drivers. The study discussed here surveyed 40 participants about their physical characteristics and level of awareness of natural user interfaces and explored the use of gesture-based interfaces in a stationary vehicle. A sensor relying on depth map technique to detect gestures was mounted either in the center dashboard or near the arm rest and gear shift, depending on participants' degree of disability and preference. Researchers selected a set of seven gestures, two of which were static and five of which were dynamic. Selected gestures were natural, easy to perform, and engaged a small number of muscles. Thirteen subjects naïve to natural user interfaces used the seven selected gestures to complete six scenarios involving a series of tasks, such as selecting an audio source and turning on and off a multimedia system. **Key Findings:** Sixty-nine percent of participants surveyed reported confidence that technology can have a significant impact on decreasing the disability barrier in their vehicles. Sixty-nine percent of participants completing the gesture-based scenarios did so without errors. **Future Work:** The authors identify further research to more clearly identify the needs of drivers and standardization of gestures across OEMs as area for future work.

Morgan, P. L., Voinescu, A., Williams, C., Caleb-Solly, P., Alford, C., Shergold, I., ... & Pipe, A. (2018). An emerging framework to inform effective design of human-machine interfaces for older adults using connected autonomous vehicles. In *Advances in Human Aspects of Transportation: Proceedings of the AHFE 2017 International Conference on Human Factors in Transportation*, July 17− 21, 2017, The Westin Bonaventure Hotel, Los Angeles, California, USA 8 (pp. 325-334). Springer International Publishing. https://doi.org/10.1007/978-3-319-60441-1_33.

Metadata	Description
Year: 2018 **Country:** UK **Method:** Literature Review **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** connected autonomous vehicle, human machine interface, older adults, design	**Approach:** The authors propose a framework for design of HMIs for connected autonomous vehicles (CAVs), focusing on older adults, who tend to have the highest levels of cognitive, sensory, and physical impairments, which present impediments to effective use of HMIs. This work was undertaken as part of an Innovate UK funded project – Flourish – Empowerment through Trusted Secure Mobility (2016–2019). **Key Findings:** Starting from the premise that CAV HMI's should be designed with an emphasis on the usability and accessibility requirements of this population, the authors further emphasize the need for interfaces that are sufficiently adaptable for users with a wide range of impairments and for individuals with varying levels of impairment over time. **Future Work:** Factors beyond level of impairment that must be considered include driving habits, culture, and preferences. The authors point out the critical need for research on the design and testing of in-vehicle HMIs for CAVs focused on older adults.

Orphanides, Andreas, and Nam, Chang. (2017). Touchscreen Interfaces in Context: A Systematic Review of Research into Touchscreens across Settings, Populations, and Implementations. *Applied Ergonomics, 61*, 116–43.

Metadata	Description
Year: 2017 **Country:** USA **Method:** Literature Review **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** touchscreen interface, human factors and ergonomics, user-centered design	**Approach:** The authors conducted a systematic review of the extant literature pertaining to touchscreen interfaces, using a three-dimensional schema comprising system setting, user population, and environment of implementation, A specific concern animating the review was the effects of touchscreens on safety, task performance, and user satisfaction relative to the context of use. The dual purposes of this review were to provide design and implementation recommendations for practitioners, including enumerating dimensions of interface design with implications on inclusive design, and to identify opportunities for future research for human factors researchers. **Key Findings:** Researchers found that all three parameters considered exert a significant impact on the human factors and ergonomics of touchscreens. **Future Work:** Among the suggested areas for future research were the combination of audio, visual, and tactile feedback, the use of

	voice inputs, and the ergonomics of touchscreen use for specific populations.

Peillon, A., Chêne, D., & Chaumon, M. E. B. (2016, October). HMI and visually-disabled user: the emergence of specific issues. In *Actes de la 28ième conference francophone sur l'Interaction Homme-Machine* (pp. 259-263). https://doi.org/10.1145/3004107.3004136.

Metadata	Description
Year: 2016 **Country:** France **Method:** Case Study **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** User-centered design, visual impairment, human interface	**Approach:** This research explored the adjustment of interface interaction modes to optimize consistency with users' needs. The authors focused on interaction between visually impaired persons and a touch phone and considered how an iterative design approach can be implemented to correct aspects of interface design poorly adapted to users' needs. The work is premised on the notion that rooting interface development in the most severe constrains, in this case restricted manipulation and lack of visual feedback, yields the most universal, and thus most widely accessible, design. **Key Findings:** Researchers grouped their findings thematically into four main areas. First, systems must be designed with sufficient robustness to respond to diverse interactions among individual user. Secondly, mere transposition of visual elements to audio is insufficient; new modalities must be created to present visual objects in other forms. Thirdly, visual elements presented in audio form must be presented sequentially in order for them to be intelligible and useful to a visually impaired user. Finally, audio and haptic signals must clearly differentiate navigation feedback from action feedback. **Future Work:** The authors stress the need to incorporate feedback and observations from disabled users during user testing into any iterative interface design process centered on use case developed with these users in mind.

Retief, M., & Letšosa, R. (2018). Models of disability: A brief overview. *HTS Teologiese Studies/Theological Studies, 74*(1). https://www.ajol.info/index.php/hts/article/view/177914.

Metadata	Description
Year: 2018 **Country:** South Africa **Method:** Thought Piece **Category:** Models of Disability **Keywords:**	**Approach:** Retief and Letšosa provide an overview of nine models of disability, examining how each provides a unique lens through which to view disability. **Key Findings:** The moral/religious model interprets disability as a challenge given by a higher power, while the medical model views disability as a medical problem which must be cured. The social model views disability as a social construct that hinders people with impairments. Other models discussed include the identity model, human rights model, cultural model, charity model, economic model, and limits model. **Future Work:** All models impact the perception of people with disabilities and the perception of disability itself. As researchers undertake further work in this field, they must be cognizant of the lens

	through which they perceive disability and its impact on their scholarship.

Reyes, G. (2020, March). An adaptive and personalized in-vehicle human-machine-interface for an improved user experience. In *Companion Proceedings of the 25th International Conference on Intelligent User Interfaces* (pp. 35-36). https://doi.org/10.1145/3379336.3381882.

Metadata	Description
Year: 2020 **Country:** Germany **Method:** Theoretical **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** Adaptive interfaces; continuous learning; incremental learning	**Approach:** Acknowledging the impossibility of designing an in-vehicle HMI that meets the needs of all users, the author reviewed literature highlighting work that pertains to prioritizing adaptability to external input sources and to the needs of the driver in HMI design. **Key Findings:** Reyes identifies four primary external HMI input sources: the environment, the vehicle, media, and other passengers. He then goes on to discuss internal factors, such as the driver's emotional state and level of attentiveness, that influence a driver's engagement with the HMI and thus should ideally be constantly monitored by an adaptable interface. **Future Work:** Identified areas of future work include research that integrates external and internal input sources and examines which of three forms of adaptation, static, dynamic, or continuous, is most effective.

Sanders, G., Rapport, L. J., Marwitz, J. H., Novack, T. A., Walker, W., Tefertiller, C., ... & Zhang, Y. (2023). Barriers to driving and psychosocial outcomes after traumatic brain injury. *Brain injury, 37*(5), 412-421. https://doi.org/10.1080/02699052.2023.2172611.

Metadata	Description
Year: 2023 **Country:** USA **Method:** Subjective (e.g., surveys, questionnaires, interviews, focus groups) **Category:** Disability and Driving **Keywords:** Return to driving; barriers to driving; functional status; psychosocial; traumatic brain injury	**Approach:** This cross-sectional study examined perceived barriers to driving and associated psychosocial outcomes among adults with TBI who had not driven since the time of their injury or who had attempted a resumption of driving activity and then stopped.. **Key Findings:** The authors began with a review of prior research indicating that adults with TBI who did not resume driving post-injury exhibited worse psychosocial outcomes, including depression, anxiety, and life satisfaction, than those who did return to driving, even in the presence of access to alternative forms of transportation. Four categories of barriers were identified: physical, emotional, cognitive, and social. Physical abilities, opinions of healthcare providers, and need to drive were found to be the most prominent factors in the decision of whether to resume driving. Social barriers, such as caregiver influence, were perceived to be a stronger impediment to resumption of driving activity than physical barriers. Notably, researchers found that the relationship between barriers to driving and well-being differed by level of disability, with the role of disability emerging as the key to understanding the relationship between experiencing barriers to driving and subjective well-being. When asked about considerations in return to driving, study participants most frequently endorsed physical abilities and the need

	to drive, and least frequently endorsed licensure status and resources needed to drive. **Future Work:** The authors recommend further research that explores the extent to which self-appraisal of fitness to drive aligns with objective predictors of ability to return to driving activity, as well as qualitative studies that explore barriers to driving for disabled populations and adaptive responses to those impediments.

Schölkopf, L., Lorenz, M., Stamer, M., Albrecht, L., Klimant, P., Hammer, N., & Tümler, J. (2021). Haptic feedback is more important than VR experience for the user experience assessment of in-car human machine interfaces. *Procedia CIRP, 100*, 601-606. https://doi.org/10.1016/j.procir.2021.05.130.

Metadata	Description
Year: 2021 **Country:** Germany **Method:** Experimental **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** Virtual reality; user study; automotive; user experience; haptic	**Approach:** This research examined UX assessments of in-vehicle HMIs conducted using virtual reality (VR) as compared to physical prototype studies, focusing on whether the absence of haptic feedback in the VR environment diminished the reliability and value of the UX ratings and the feasibility of transferring the results of VR studies to the real-world context. Researchers recruited a group of Volkswagen employees from a plant in Wolfsburg, Germany, to compare their UX ratings of a virtual in-car HMI lacking haptic feedback with an actual in-car HMI. **Key Findings:** The authors found that in the absence of haptic feedback in the VR environment, no meaningful conclusions regarding the usefulness of the HMI can be drawn. **Future Work:** The authors advocate for the use of VR with a physical in-car HMI to increase the ecological validity of the study environment. Additionally, they suggest that the development of active-passive mockups for knobs, buttons, touch panels, and stalks or haptic displays would facilitate performance of reliable VR UX studies early in product development.

Sesto, M. E., Irwin, C. B., Chen, K. B., Chourasia, A. O., & Wiegmann, D. A. (2012). Effect of touch screen button size and spacing on touch characteristics of users with and without disabilities. *Human Factors, 54*(3), 425-436. https://doi.org/10.1177/0018720811433831.

Metadata	Description
Year: 2012 **Country:** USA **Method:** Experimental **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** touch screen, force, impulse, disability	**Approach:** The authors investigated the effect of button size and spacing on touch characteristics (i.e., dwell times, forces, and impulses) during a digit entry touch screen task. A sample comprising participants with fine motor and gross motor control disabilities and a control group of non-disabled subjects supported further consideration of the effect of disability on touch characteristics. Dwell time was defined as the total amount of time that each button was depressed. **Key Findings:** Forces increased with button size, while dwell times and impulses decreased. Gap size had minimal effect on dwell time, force, and impulse. Participants with gross motor disabilities were found to have significantly greater dwell times than subjects with fine

	motor control disabilities and nondisabled subjects, and participants with fine motor disabilities had longer dwell times than their nondisabled counterparts. A prominent theme in the authors' review of the extant literature is that considering touch characteristics due to their impact on user performance and fatigue leads to better interface design. **Future Work:** The authors suggest examination of the muscle groups contributing to the differences in touch characteristics and research using longer duration tasks more fully exploring the effect of button size and spacing on user fatigue as areas for future work.

Sinha, M., & Dasgupta, T. (2021). A web browsing interface for people with severe speech and motor impairment. *Journal of Enabling Technologies, 15*(3), 189-207. https://doi.org/10.1108/JET-07-2020-0029.

Metadata	Description
Year: 2021 **Country:** India **Method:** Experimental **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** Web browser, severe speech and motor impairment, HTML link parsing, switch scan interface, evaluation, cerebral palsy, iconic keywords search, web accessibility	**Approach:** The authors propose a web-browsing interface with automatic scanning mechanisms for use by persons with severe speech and motor impairments to access web contents with minimum cognitive effort. WebSanyog is intended to address challenges stemming from impairments in speech generation and limb movements faced by this population in accessing the Internet. Browser performance was evaluated through field testing with students at the Indian Institute of Cerebral Palsy (ICP) along three dimensions: task execution time (TET), error rates analysis (ERI), and overall usability score. **Key Findings:** The WebSanyog browser was found to be effective in reducing task execution time and improving error rates when used over multiple sessions. Overall subjective ratings of the usefulness of the browser exceeded 7.5 on a 10-point scale for all participants surveyed. **Future Work:** This application of principles of universal design resulting in dynamic interfaces tailored to the abilities of a wide range of users has implications for the design of in-vehicle HMIs.

Stasiak-Cieślak, B., & Grabarek, I. (2022). The method of selecting adaptive devices for the needs of drivers with disabilities. *Open Engineering, 12*(1), 263-272. https://doi.org/10.1515/eng-2022-0007

Metadata	Description
Year: 2022 **Country:** Poland **Method:** Simulation **Category:** Disability and Driving **Keywords:** Adaptive devices, adaptation, expert system, disabled driver, disability	**Approach:** In this Polish study, authors created the Automatic Adaptation Selection System (ASA System) to address the gap in literature regarding a method to select adaptive devices and tailor their automation to people with disabilities. This system was coded to be easily embedded in a website and used by anyone, not just those with expert knowledge. **Key Findings:** Three experts and 44 drivers with disabilities helped refine the methods for the ASA System; all three experts agreed with

	the System recommendation in at least one set of devices 86% of the time. **Future Work:** Further refinement of this method should involve professionals with interdisciplinary knowledge in fields of ergonomics, psychology, medicine, and technical sciences so that the selections of the ASA System can better fit its recipients.

Stevens, C., Xu, J., & Bowers, A. R. (2022). Use of Advanced Driver Assistance Systems by Bioptic and Normal Vision Drivers. *Investigative Ophthalmology & Visual Science, 63*(7), 2466-F0043.

Metadata	Description
Year: 2022 **Country:** USA **Method:** Subjective **Category:** ADAS and Disability **Keywords:**	**Approach:** This survey study examined use of eight ADAS by drivers with reduced visual acuity permitted to use a bioptic telescope to magnify distant objects as compared to drivers with normal vision. **Key Findings:** The survey results showed that drivers with reduced visual acuity using bioptic devices had newer cars and used more ADAS features compared to normal vision (NV) drivers. GPS, rearview camera, and blind spot warning were the ADAS most commonly used by the experimental cohort. **Future Work:** Data collection was limited to a telephone survey. More comprehensive work that includes objective measures, such as naturalistic data collection supporting researcher observation of ADAS use by subjects, would provide a fuller picture of driver performance and safety benefits and specific challenges associated with system use.

Sullivan, J. M., Flannagan, M. J., Pradhan, A. K., & Bao, S. (2016). *Literature review of behavioral adaptations to advanced driver assistance systems*. https://trid.trb.org/view/1445984.

Metadata	Description
Year: 2016 **Country:** USA **Method:** Literature Review **Category:** ADAS and Disability **Keywords:**	**Approach:** The authors conducted a literature review examining drivers' use of ADAS that automate control of the vehicle or provide advisory support by monitoring the roadway and alerting the driver to developing conflicts through the lens of driver behavioral adaptation. This research defined a positive behavioral adaptation as one in which the net safety benefit of ADAS is greater than anticipated and a negative behavioral adaptation as one in which the ADAS fall short of driver expectations, either due to a misunderstanding of the benefits of the system or an overestimation of its capabilities in a given context. Their review included an evaluation of driver response to longitudinal and lateral control of lane position and driver awareness of ACC limitations in the context of trust and understanding of ADAS features. Researchers examined whether drivers relied on haptic or auditory stimuli to reinforce warning signals from intelligent speed adaptation (ISA), curve speed warning (CSW), and lane departure warning (LDW). **Key Findings:** A driver's mental model of the system, whether accurate or not, exerts a great deal of influence on their response to the assistance the system offers; provided that the ADAS are used

	without incident, this model will be reinforced regardless of its inconsistencies. Driver awareness of the limitations of ADAS were found to drift over time; that is, drivers tend to generalize rules of ADAS functionality until explicitly confronted with exceptions. Owner's manual accounts of such exceptions were found to be inadequate due to driver inattention to owner's manuals. Driver behavioral adaptation was found to be more closely related to the perceived effects of a particular technology rather than to broad changes in risky driving. **Future Work:** The lack of research on driver behavioral adaptation to ADAS warning systems and in the context of forward collision warning (FCW) was noted. Recommendations for more effective shaping of drivers' mental models of ADAS technologies are offered.

Sultania, A. (2022). *Perception and Attitudes of Canadians living with Parkinson's disease towards using Advanced Driver Assistance Systems (ADAS)* (Master's thesis, The University of Western Ontario (Canada)). https://ir.lib.uwo.ca/etd/8783.

Metadata	Description
Year: 2022 **Country:** Canada **Method:** Subjective (e.g., surveys, questionnaires, interviews, focus groups) **Category:** ADAS and Disability **Keywords:** Parkinson's disease, Advanced Driver Assistance Systems, ADAS, perception, attitudes	**Approach:** Sultania conducted a survey to investigate the perceptions and attitudes of ADAS as exhibited by Canadians with PD. In the author's review of the body of extant literature, he examined the driving performance of older adults with PD. **Key Findings:** Subjects with PD were found to be prone to making more road errors, performing more poorly during on-road assessments, and at greater risk for collisions. These issues are associated with impairments in executive, motor, and visual function—all areas in which ADAS features can assist. Most survey respondents had prior experience with ADAS; features participants were most likely to have in their vehicles were pedestrian automatic emergency braking, forward collision system, lane-centering control, and blind spot detector. Lane-keeping assist, park assist, and ACC were the least likely to be found useful. Lane-centering control, lane-keeping assist, and pedestrian automatic braking were ranked as the easiest to use. Perceived ease of use was a good predictor of intention to use ADAS in the near future, and training drivers on ADAS increased their confidence in the system. **Future Work:** Self-selection bias limited the participant pool in this study, as did the fact that the survey was conducted online, limiting the sample to those with internet access and technological literacy. Future work should seek to address these constraints.

Swain, T. A., McGwin, G., Wood, J. M., Antin, J. F., & Owsley, C. (2021). Naturalistic driving techniques and association of visual risk factors with at-fault crashes and near crashes by older drivers with vision impairment. *JAMA ophthalmology, 139*(6), 639-645. https://doi.org/10.1001/jamaophthalmol.2021.0862.

Metadata	Description
Year: 2021 **Country:** USA **Method:** Naturalistic **Category:** Driving and Disability **Keywords:**	**Approach:** Using naturalistic driving methods, the authors studied the driving behaviors of participants with an age-related eye condition in at least one eye. Ocular conditions included macular degeneration, cataracts, and diabetic retinopathy. **Key Findings:** Impaired contrast sensitivity was associated with involvement in a crash or near-crash; slowed visual processing speed was associated with a heightened risk of crash or near-crash. Most crashes and near-crashes occurred during the day, and over half of these events involved other vehicles. **Future Work:** Future research might include a larger pool of drivers, especially older drivers with impaired visual acuity, to learn more about how the condition influences crash and near-crash involvement.

Thompson, T., Poulter, D., Miles, C., Solmi, M., Veronese, N., Carvalho, A. F., ... & Uc, E. Y. (2018). Driving impairment and crash risk in Parkinson disease: a systematic review and meta-analysis. *Neurology*, *91*(10), e906-e916. https://doi.org/10.1212/WNL.0000000000006132.

Metadata	Description
Year: 2018 **Country:** USA **Method:** Literature Review **Category:** Driving and Disability **Keywords:**	**Approach:** This research reviewed studies that compared drivers with PD to healthy controls; data sources included naturalistic driving, OTR studies, and simulator studies. Data collected from real-life driving studies typically relied on self-report assessments; OTR data focused on test pass/failure and/or overall performance score, while simulator assessment data focused on crash rate and/or performance score. Studies used participant samples from the United States, Canada, Australia, Thailand, and several countries in Europe. Participants with PD were primarily recruited from movement disorder clinics; cognitive or visual dysfunction associated with PD were not factors in disease severity **Key Findings:** PD severity most often led to meta-regression and was based on motor dysfunction. OTR and simulator studies showed a greater association between driving test failure or crash involvement in drivers with PD. NDS had a high rate of inconsistent results, which could be attributed in part to self-imposed restrictions or compensatory strategies employed by drivers with PD. Additionally, although PD is a progressive disease, no relationship between its progression and driving impairment was found. **Future Work:** Notable limitations of the studies discussed here are fear of license revocation and self-selection bias. Further investigation ought to include non-motor PD symptoms, as cognitive and visual

	symptoms may impact driving performance as much, if not more, than motor symptoms.

Tran, M. (2023). The Intersection of Social Impact, Technology and Design: A Catalyst for Cultural Change. In *Cultural Robotics: Social Robots and Their Emergent Cultural Ecologies* (pp. 109-126). Springer International Publishing. https://doi.org/10.1007/978-3-031-28138-9_8.

Metadata	Description
Year: 2023 **Country:** Australia **Method:** Thought Piece **Category:** Inclusive Design **Keywords:**	**Approach:** This research discusses the medical and social models of disability in the context of assistive technology, placing a greater importance on empathy and collaboration when designing assistive devices. **Key Findings:** The authors identify human connection as fundamental to the development of improved assistive technologies, **Future Work:** The author recommends collaboration *with* those who have disabilities over deciding *for* them what is best. Future research should seek to include disabled voices at every stage of study design and conduct.

Wood, J. M. (2022). Vision impairment and on-road driving. *Annual review of vision science, 8*(1), 195-216. https://doi.org/10.1146/annurev-vision-100820-085030.

Metadata	Description
Year: 2022 **Country:** Australia **Method:** Experimental **Category:** Disability and Driving **Keywords:** Driving performance, closed road, open road, vision impairment, eye disease, visual function	**Approach:** Wood reviews studies conducted on driving safety, vision impairment, and older drivers. Vision impairments ranged from refractive conditions to AMD to homonymous hemianopsia and quadrantanopia. Driving studies were conducted in a variety of settings, including closed test tracks, open roads, and in naturalistic environments using in-vehicle measurement devices. Measurements of visual function included visual acuity, visual field, contrast sensitivity, useful field of view (UFOV), and motion sensitivity. **Key Findings:** Visual acuity tests were found to be poor predictors of closed-road night driving, and contrast sensitivity tests would likely be a better indicator due to their frequent use when surveying road environments, especially at night. **Future Work:** More research is needed into the extent to which vision impairment impacts driving performance, as well as the impact of where a driving study focused on nighttime driving needs is conducted (e.g., closed road, open road, naturalistic).

Wood, Joanne M., Alex A. Black, Kaeleen Dingle, Cameron Rutter, Marilyn DiStefano, Sjaan Koppel, Judith L. Charlton, and Sharon A. Bentley. "Impact of Vision Disorders and Vision Impairment on Motor Vehicle Crash Risk and On-Road Driving Performance: A Systematic Review." *Acta Ophthalmologica* 100, no. 2 (2022): e339–67. https://doi.org/10.1111/aos.14908.

Metadata	Description
Year: 2022 **Country:** Australia **Method:** Literature Review **Category:** Disability and Driving **Keywords:** Driving ability, driving safety, motor vehicle crash risk, on-road driving performance, vision disorders, visual impairment	**Approach:** This literature review examines studies focused on the effect of vision disorders on motor vehicle crash (MVC) risk and on-road driving performance. Visual impairments mentioned were visual acuity (VA) impairment, visual field (VF) impairment, AMD, cataracts, and glaucoma. **Key Findings:** Review of nearly 50 articles found that the method by which visual impairments were measured was not standardized and that half of the studies used self-reported, not state-recorded, MVC risk. While self-reported data is more convenient, it is more susceptible to driver recall bias or deliberate concealment out of fear that the participant's license could be revoked. State-recorded crash data is not without its limitations; it may have inaccurate reporting of crash or driver characteristics. **Future Work:** Future research should have larger sample sizes and employ naturalistic driving methodologies.

Yan, Ming, Lucia Rampino, and Giandomenico Caruso. "User Acceptance of Autonomous Vehicles: Review and Perspectives on the Role of the Human-Machine Interfaces." *Computer-Aided Design and Applications*, January 18, 2023, 987–1004. https://doi.org/10.14733/cadaps.2023.987-1004.

Metadata	Description
Year: 2023 **Country:** Italy **Method:** Literature Review **Category:** Human-Machine Interfaces (HMI) and the Disabled Driver **Keywords:** Autonomous vehicles, user acceptance model, human-machine interface, vulnerable road users	**Approach:** The authors conducted a literature review analyzing user acceptance of HMI in automated vehicles (AVs). **Key Findings:** Researchers divided their findings into (1) internal and external HMI in AVs and (2) how user acceptance models influence AV interface design. Interactions between VRUs and AVs were impacted by the type of external HMI, and trust and perceived risk were the most common factors affecting user acceptance of AVs. **Future Work:** Future research should focus on user acceptance of technologies at specific levels of automation and on issues around transfer of vehicle control between drivers and technologies.

Young, K. L, S. Koppel, and J. L Charlton. "Toward Best Practice in Human Machine Interface Design for Older Drivers: A Review of Current Design Guidelines." *Accident Analysis & Prevention* 106 (September 1, 2017): 460–67. https://doi.org/10.1016/j.aap.2016.06.010.

Metadata	Description
Year: 2017 **Country:** Australia **Method:** Literature Review **Category:** Inclusive Design	**Approach:** Authors reviewed documents detailing HMI design standards in order to find the extent to which age-related impairments of drivers (e.g., visual, physical, and/or cognitive impairments) have been addressed.

Keywords: Older drivers, aging, age-related functional impairments, Human Machine Interface guidelines, Advanced Driver Assistance Systems, In-Vehicle Information Systems	**Key Findings:** ADAS and IVIS technology may be able to assist older drivers, though if these systems are not designed to accommodate age-related needs and limitations, they may present rather than solve challenges. Most current HMI design guidelines do not adequately address age-related impairments. **Future Work:** The authors identify several areas for further research, including development of training materials to acclimate older drivers to in-vehicle technologies and build their awareness of the capabilities and limitations of ADAS. Additionally, more robust design guidelines must be developed that take into account vision impairments, reduced sensitivity to touch and vibration, and decreased processing speed. Research that helps stakeholders address the question of how and where HMI design guidance is implemented is also essential.

APPENDIX B. SEARCH STRINGS BY TOPICAL AREA

Search Term: Models of disability

Search string(s):

1. "biomedical model of disability" OR "functional model of disability" OR "sociopolitical model of disability" OR "medical model of disability" OR "economic model of disability" OR "Social model of disability" OR "identity model of disability" OR "functional solutions" OR "sociology of impairment" OR "disability barriers" OR intersectionality

Search Term: Disability and driving

Search string(s):

1. disability AND driving
2. impairment AND driving
3. functional limitations AND driving

Keyword: ADAS and Disability

Search String(s):

1. disability AND advanced driver assistance systems
2. impairment AND advanced driver assistance systems
3. functional limitations AND advanced driver assistance systems

Keyword: Disability and HMI

Search String(s):

1. disability AND human-machine interface (HMI) OR graphical user interface (GUI)
2. impairment AND human-machine interface (HMI) OR graphical user interface (GUI)
3. functional limitations AND human-machine interface (HMI) OR graphical user interface (GUI)

APPENDIX C. PRELIMINARY RESARCH ROAD MAP