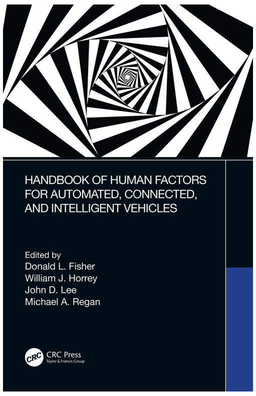

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Driver Capabilities in the Resumption of Control

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10 Driver Capabilities in the Resumption of Control

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CONTENTS

KEY POINTS

- Medical conditions, and their associated characteristics, affect the functional abilities (visual, cognitive, motor, and other sensory) and therefore the performance of drivers.
- These functional abilities are critical to perform the strategic, tactical, and operational tasks associated with driving.
- Driver support features such as in-vehicle information systems (any of the SAE levels, although sometimes identified synonymously with SAE Level 0), lane-centering assist, and braking/acceleration assist (SAE Level 1 and 2) may provide benefits but also challenges for drivers who are medically-at-risk.
- Automated vehicle technologies hold great potential to facilitate fitness-to-drive abilities in drivers wanting to resume control of the vehicle
- Empirical testing of the potential benefits of automated vehicle technologies is mission critical

10.1 INTRODUCTION

Because it is outside the scope of this chapter to focus on all medical conditions that may impact fitness to drive, the authors describe selected medical conditions grouped in four distinct categories, i.e., deskilling, visual disorders, neurological disorders, and neurodegenerative disorders. From these categories, the authors indicate the core clinical characteristics and explicate how those characteristics relate to functional performance deficits. Driving behaviors, an indicator of fitness to drive, are discussed within the structure of Michon's model (Michon, 1985)—which classifies driving behaviors on the strategic, tactical, and operational level.

Rehabilitation scientists and professionals are concerned with empowering clients to overcome deficient driving behaviors. Therefore, this chapter expounds how automation is providing exciting possibilities to address this challenge of deficient driving behaviors. The authors demonstrate the benefits of automated vehicle technologies (SAE Levels 0–2) to enable the driver to resume control of his/her fitness-to-drive abilities (Society of Automotive Engineers International, 2016). SAE Level 3 of automation may yield more risks than benefits for the medically-at-risk driver and will as such not be further discussed in this chapter. Levels 4 and 5 of automation may yield multiple benefits related to transportation equity, especially for the disadvantaged, medically-at-risk, and disabled populations. However, because the driver will not "resume control" when engaged with these levels of automation, but rather be an "operator" (SAE Level 4) or a "passenger" (SAE Level 5), the authors do not further discuss those levels of automation.

The authors present two case studies, to address the issues related to an aging adult with a visual disorder and an adult with a neurodegenerative condition, to tie the previously discussed concepts together.

10.2 MICHON'S MODEL

Michon's model of driving behaviors (Michon, 1985) is widely used and accepted in the driving literature, and it acts as a conduit to communicate driving behaviors in a way that is understandable to transportation engineers, psychologists, road traffic safety officials, and driver rehabilitation specialists. Michon's model categorizes aspects of the driver and the environment into three hierarchical levels. First, the *strategic* level requires the highest cognitive processing for the driver, and involves high-level cognitive skills such as decision-making, planning, and problem-solving to discern where, with whom, how, and how much to drive. The strategic level also incorporates discerning the level of risk, i.e., anticipating risks, such as skidding, sliding, or being unable to come to a stop when encountering icy roads. Usually these decisions are made prior to the driving task over a period of minutes, hours, or days—depending on the complexity of the trip and the environment. The *tactical* level requires intermittent behaviors when maneuvering the vehicle to travel from one destination to another. These behaviors include, but are not limited to, handling the vehicle, avoiding obstacles, accepting gaps, making a turn, backing up, or overtaking another vehicle. Such behaviors occur during the driving task and may last for minutes to hours, depending on the length of the route. The *operational* level demands the driver's skills related to motor coordination, reaction time, visual scanning, and spatial perception and orientation. These behaviors are critical when carrying out distinct tasks, such as braking in time when a child runs across the road or swerving around a distracted pedestrian. Usually such behaviors occur in seconds. Therefore, Michon's model (1985) emphasizes how the driver interacts with the environment when taking the driver's behaviors–influenced by attention, judgment, working memory, cognitive processing, and sensory-motor abilities—into consideration.

10.3 MEDICALLY-AT-RISK CONDITIONS

10.3.1 Deskilling: Implications of the Aging Process

Driving deskilling is a potential consequence of SAE Level 3 of automation, which requires the driver to cede control of all safety-critical functions of the vehicle, under certain conditions, but expects the driver to resume control if such conditions change (Trosterer et al., 2016). As noted earlier in this chapter, SAE Level 3 of automation is not further discussed, as its use may yield more risks than benefits for at-risk drivers. However, changes in the functional skills of drivers can also result in deskilling. For the remainder of this section, we will discuss the normal aging process as an example of natural deskilling and its implications for vehicle automation technologies.

10.3.1.1 Age-Related Deskilling

In the United States alone, in 2016, there were approximately 46 million adults 65 years of age or older—15% of the entire population, and this number is expected to almost double by 2060 when older adults will make up a quarter of the American population (Mather, Jacobsen, & Pollard, 2015). In addition to this expected demographic shift, older adults are also working longer, and prefer to age in place (Mather et al., 2015). The number of licensed older drivers across the United States reflects these demographic trends. In 2015, the Federal Highway Administration estimated that 18% of licensed drivers were 65 years of age and older, and that drivers over the age of 85 were the fastest growing demographic of road users (Federal Highway Administration, 2015). Driving enables the independence and community mobility of older adults, and supports aging in place. However, the functional performance deficits that characterize the normal aging process can result in driver deskilling.

10.3.1.2 Functional Performance Deficits

Increased age is associated with sensory, cognitive, and motor functional performance deficits. Age-related sensory performance deficits include decreases in visual acuity (which are commonly compensated for with glasses), contrast sensitivity, and peripheral vision, as well as increased glare sensitivity (Haegerstrom-Portnoy, Schneck, & Brabyn, 1999; Karthaus & Falkenstein, 2016). In addition, older adults commonly experience hearing impairments (Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011). The normal aging process also impacts cognitive functions including visual processing speed, divided and selective attention, set shifting, inhibition of irrelevant information, and performance self-monitoring (Karthaus & Falkenstein, 2016). Finally, impaired motor functions include decreased muscle strength, speed of movement, flexibility, motor coordination, and limited range of motion (Chen, Xu, Lin, & Radwin, 2015; Vieluf, Godde, Reuter, Temprado, & Voelcker-Rehage, 2015). Together, these functional performance deficits rather than age alone are factors that decisively contribute to crash involvement in older adults (Papa et al., 2014).

10.3.1.3 Effect on Driving Behaviors

The aging trajectory of older adults will vary according to factors such as access to health and social services, type and severity of comorbidities, socioeconomic status, housing, and other social determinants of health (Sadana, Blas, Budhwani, Koller, & Paraje, 2016). These determinants contribute to the severity of functional impairments and thus play a role in the degree of driving deskilling an individual older adult might experience. Overall, aging results in driving deskilling at the strategic, tactical, and operational levels (Karthaus & Falkenstein, 2016). Examples of each are listed below.

Strategic. Difficulty in navigating busy intersections; negotiating high traffic environments; and planning, executing, and adapting route plans, especially in unfamiliar environments.

Tactical. Difficulty in identifying appropriate gaps in traffic, with lane maintenance, initiating emergency maneuvers in response to roadway hazards, and when merging into traffic.

Operational. Prolongation of braking time, difficulty detecting relevant traffic stimuli in the periphery, insufficient blind spot checking, difficulties with alternative and appropriate use of gas and brake pedals, difficulty maintaining steering wheel control.

Together, impairments at all three of these levels increase older adults' involvement in motor vehicle collisions, particularly due to difficulties with giving the right of way, negotiating turns, driving backwards during parking maneuvers, and navigating complex and unfamiliar roadways (Karthaus & Falkenstein, 2016). In fact, older adults over the age of 65 experience an increase in motor vehicle collisions per mile driven (Davis, Casteel, Hamann, & Peek-Asa, 2018). In addition, older adults can overestimate their driving skills. In a study conducted by Ross and colleagues (2012), 85% of older adults ($N = 350$) rated themselves as either good or excellent drivers, in spite of previous crash or citation rates. However, driving is the primary means of community mobility for older adults, particularly in Western countries. Restrictions in community mobility lead to social isolation, as well as cognitive and mental health decline (Fonda, Wallace, & Herzog, 2001). Furthermore, driving cessation can increase the need for long-term care in older adults compared with active drivers of the same age, independent of health status (Freeman, Gange, Munoz, & West, 2006). Therefore, autonomous vehicle (AV) technologies may provide opportunities for older adults to remain on the road when possible, while compensating for specific functional impairments.

10.3.1.4 AV Technology to Compensate for Functional Driving Impairments by SAE Level

The following are the common functional impairments in the older adult population and the potential AV technologies that can mitigate their impact on the fitness to drive. The mitigating factors are based upon the overview of in-vehicle information systems (IVIS) and advanced driver assistance systems (ADAS) by Alvarez and Classen (2017).

1. Vision: Older drivers experience declines in visual acuity, which impacts their ability to see objects in their path clearly or accurately estimate distances.
   a. *Parking distance control (SAE Level 0):* Provides the driver with information regarding the distance from the vehicle to any outstanding object or obstacle.
2. Vision: Older drivers experience decreased contrast sensitivity and increased sensitivity to glare, which can impair their driving especially at nighttime.
   a. *Automotive night vision (SAE Level 0):* This technology utilizes a thermographic camera to allow the driver to see in darkness or poor weather conditions, beyond the scope of the vehicle's headlights.

3. Vision: Older drivers can experience restrictions in their peripheral field of view which can increase risk for lane changes.
   a. *Lane departure warning (SAE Level 0):* Provides the driver with a visual or auditory warning when the vehicle is drifting from the lane.
4. Cognition: Decreased processing speed can result in difficulties adjusting to the position of the lead vehicle.
   a. *Front collision warning (SAE Level 0):* Monitors the distance to the lead vehicle and warns the driver when such distance becomes critical.
5. Cognition: Older drivers can experience decreased divided and selective attention, as well as set shifting.
   a. *Adaptive cruise control (SAE Level 1):* Maintains a certain speed and distance to the lead vehicle, as set by the driver.
6. Cognition: Older drivers can have difficulty inhibiting irrelevant information and self-monitoring their driving behaviors.
   a. *Lane-keeping assist (SAE Level 1):* Monitors and implements corrective action if the vehicle drifts towards adjacent lane.
   b. *Lane-centering control (SAE Level 1):* Keeps the vehicle continuously centered in the lane.
7. Motor: The normal aging process results in decreased muscle strength, speed of movement, and coordination.
   a. *Adaptive cruise control with steering assist (SAE Level 2):* Maintains the vehicle speed and position in the lane when activated.
8. Motor: Older drivers also experience decreased flexibility and range of motion which can impact complex maneuvers such as parking.
   a. *Parking assist (SAE Level 1):* Assists the driver with the steering of the wheel into a parking space, while the driver remains in control of the accelerator and brake.

10.3.2 Low Vision

Approximately 1.3 billion people around the world experience some form of visual impairment (World Health Organization, 2018). According to the World Health Organization (2018), the five leading causes of visual impairment around the world are uncorrected refractive errors, cataract, age-related macular degeneration (AMD), glaucoma, and diabetic retinopathy (DR). Furthermore, adults over the age of 50 represent 65% and 82% of those who are visually impaired and blind, respectively (Pascolini & Mariotti, 2012). As such, many of these conditions are considered age related.

Refractive errors (e.g., nearsightedness, farsightedness, astigmatism, presbyopia) occur when the shape of the eye prevents it from focusing light directly on the retina, and uncorrected translates to the better eye presenting a visual acuity of 20/50 or poorer which improves with refraction (National Eye Institute, 2010; Willis, Jefferys, Vitale, & Ramulu, 2012). Driving licensing agencies and jurisdictions have established minimum visual acuity requirements that must be met in order for an individual to be eligible for a driver's license. For example, the Canadian Medical Association (2017) requires drivers to have a corrected visual acuity of at least 20/50 with both eyes opened and examined together. In the United States, all but three states have a minimum best corrected visual acuity requirement of 20/40 (Steinkuller, 2010). Refractive errors are commonly corrected through the use of prescription glasses, contact lenses, and refractive surgeries, and as such, global efforts are improving access to such services and interventions (World Health Organization, 2013). These corrections allow individuals to achieve the visual acuity requirements of their jurisdictions. Because correction is the goal of interventions for refractive errors, and drivers who do not meet the required standard are otherwise restricted or prevented from driving, the remainder of this section will focus on the subsequent four leading causes of visual impairment.

10.3.2.1 Cataracts

A cataract is a visual impairment that results from a clouding or opacity of the lens in the eye (National Eye Institute, 2013). The lens, located behind the iris and the pupil, focuses the light onto the retina. When the proteins that make up the lens accumulate, the lens becomes clouded, a phenomenon that can occur in one or both eyes (National Eye Institute, 2013).

10.3.2.1.1 Core Clinical Characteristics

A cataract reduces the sharpness of the image that reaches the retina. As the proteins continue to cluster together, the opacity of the lens can increase and cause blurred vision (National Eye Institute, 2013). Figure 10.1 illustrates a scene as viewed by a person with cataract.

10.3.2.1.2 Functional Performance Deficits

When first formed, a cataract can be small and the individual might not notice any significant changes in vision. As the cataract grows, however, the individual experiences gradual difficulty with glare, contrast sensitivity, poor night vision, increased blurry vision, and fading of color (National Eye Institute, 2013).

FIGURE 10.1 (See color insert.) Scene as viewed by a person with cataract. (Image from the National Eye Institute, National Institutes of Health.)

10.3.2.1.3 Effect on Driving Behaviors

Cataracts have a negative impact on driving performance. Drivers with cataracts are involved in 2.5 times more motor vehicle collisions than age-matched controls (Owsley, Stalvey, Wells, & Sloane, 1999). Specifically, cataracts significantly impair a driver as follows (Wood & Carberry, 2004):

Strategic. Difficulty avoiding low-contrast hazards on the road, including highway debris, speed bumps, or vulnerable road users; and driving in poor weather or under restricted visibility conditions including nighttime driving.
Tactical. Negotiating traffic infrastructure; difficulty recognizing road signs, hazards, or roadway markings in low contrast situations and performing maneuvers to avoid them; and difficulty maintaining their position in the lane.
Operational. Swerving, braking in response to hazards, and steering wheel control in response to lane markings.

10.3.2.1.4 AV Technology to Compensate for Functional Driving Impairments

The following are the common functional impairments in individuals with cataract and the potential AV technologies that can mitigate their impact on fitness to drive. It is important to note that AV technologies could only support drivers that meet the legal visual requirements in their jurisdiction. The mitigating factors are based upon the overview of IVIS and ADAS by Alvarez and Classen (2017).

1. Decreased visual acuity
   a. *Parking distance control (SAE Level 0)*: See Section 10.3.1.4.
2. Low contrast and increased glare sensitivity:
   b. *Automotive night vision (SAE 0)*: See Section 10.3.1.4.
3. Difficulty identifying lane markings:
   c. *Lane departure warning (SAE Level 0)*: Can provide the driver with an auditory warning when the vehicle is drifting from the lane (also see Section 10.3.1.4).

10.3.2.2 Age-Related Macular Degeneration

AMD is a condition that causes progressive loss of central vision (Mitchell, Liew, Gopinath, & Wong, 2018). Approximately 170 million people globally have AMD, with 11 million individuals residing in the United States alone (Pennington & DeAngelis, 2016). Also, in the United States, the prevalence of AMD is similar to that of invasive cancer and almost twice that of Alzheimer's disease (Pennington & DeAngelis, 2016). Age is the primary risk factor for AMD. As the aging population increases, the prevalence of AMD is thus expected to increase proportionally.

10.3.2.2.1 Core Clinical Characteristics

AMD is a degenerative disease that primarily affects the macular—or central—region of the retina, causing blurriness in the center of vision while peripheral vision remains unaltered. As AMD progresses, the blurred area in the center of vision increases in size. Individuals with AMD may also see lines as wavy or distorted

FIGURE 10.2 (See color insert.) Scene as viewed by a person with AMD. (Image from the National Eye Institute, National Institutes of Health.)

and may see dark spots blanking out their central vision (Canadian Association of Optometrists, n.d.). AMD is broadly classified into two types. The dry form is the most common and presents as a gradual degeneration of the tissue in the macula with symptoms developing more slowly. In contrast, the wet form is more severe and results from the bleeding of weakened vessels under the macula which causes the symptoms to progress more rapidly (Mitchell, Liew, Gopinath, & Wong, 2018). Figure 10.2 illustrates a scene as viewed by an individual with AMD.

10.3.2.2.2 Functional Performance Deficits

Persons with AMD primarily experience blurred or blocked central vision. In addition, spatiotemporal contrast sensitivity is also a reliable indicator of functional impairment in individuals with AMD (Midena, Degli Angeli, Blarzino, Valenti, & Segato, 1997). Although in early stages of the disease visual acuity can remain adequate (20/40), individuals with AMD can experience other early symptoms including visual difficulties under reduced illumination and delays adapting to the dark (Owsley & McGwin, 2008).

10.3.2.2.3 Effect on Driving Behaviors

Driving is a primary concern for individuals with AMD. Owsley and colleagues (2006) conducted focus groups with individuals diagnosed with AMD, to discuss their vision. The most commonly cited difficulty by participants was driving. Although the literature exploring the driving performance of drivers with AMD is limited—many studies group visual impairments together, making it difficult to separate out drivers with AMD (Owsley, McGwin, Scilley, & Kallies, 2006)—the extant literature revealed poorer driving performance among individuals with AMD when compared with controls. In fact, drivers with AMD have slower braking response times, slower speed, more lane crossing, and collisions on a driving simulator than controls (Szlyk et al., 1995).

10.3.2.2.4 AV Technology to Compensate for Functional Driving Impairments

The following are common functional impairments in drivers with AMD and the potential AV technologies that can mitigate their impact on fitness to drive (Alvarez & Classen, 2017). It is important to note that these technologies can be helpful to drivers in the early stages of the condition when visual requirements are met. As such, these technologies cannot compensate for severe visual deficits; they can only provide support to fit drivers.

1. Decreased visual acuity and central processing speed:
   a. *Front collision warning (SAE Level 0)*: Monitors distance to the lead vehicle straight ahead of them (central vision) and warns the driver when such distance becomes critical (also see Section 10.3.1.4).
2. Decreased contrast and limited vision in low illumination settings:
   b. *Automotive night vision (SAE 0)*: See Section 10.3.1.4.

10.3.2.3 Glaucoma

The term glaucoma refers to a group of diseases characterized by progressive damage to the optic nerve. In the absence of early detection and treatment, glaucoma can eventually lead to blindness (National Eye Institute, 2015b). In 2013, it was estimated that approximately 64 million people around the world lived with glaucoma, a number that is expected to almost double by 2040 (Tham et al., 2014).

10.3.2.3.1 Core Clinical Characteristics

Glaucoma refers to a group of degenerative eye diseases that compromise the integrity of the optic nerve, often associated with elevated intraocular pressure (Cohen & Pasquale, 2014). The most common type of glaucoma is open-angle glaucoma, which accounts for nearly 90% of all glaucoma cases (Glaucoma Research Foundation, n.d.). Open-angle glaucoma is a result of a progressive clogging of the eye's drainage canals, which in turn increases pressure on the optic nerve. This clogging develops in spite of an adequately wide and open angle where the cornea and the iris meet, and the symptoms emerge only after the disease advances (Cohen & Pasquale, 2014). Angle-closure glaucoma, on the other hand, develops when the drainage canals are blocked due to the angle closure between the iris and the cornea. Angle-closure glaucoma develops rapidly and leads to severe noticeable symptoms (See: Aquino et al., 2011). Other types of glaucoma include normal-tension glaucoma, where the optic nerve is damaged in spite of relatively normal intra ocular pressure—the cause of which remains poorly understood (Anderson, 2011), and secondary glaucoma, which results from an injury around the eye that increases pressure on the optic nerve (Papadopoulos, Loh, & Fenerty, 2015). Figure 10.3 illustrates a scene as viewed by a person diagnosed with glaucoma.

10.3.2.3.2 Functional Performance Deficits

The onset of symptoms varies according to the type of glaucoma. For open-angle glaucoma, functional performance deficits can develop painlessly and gradually and

FIGURE 10.3 (See color insert.) Scene as viewed by a person with glaucoma. (Image from the National Eye Institute, National Institutes of Health.)

can go undetected until the disease has advanced considerably (Cohen & Pasquale, 2014). Once present, performance impairments are most often characterized by a loss of peripheral vision. As the disease progresses, it might compromise an individual's central vision and even cause blindness (National Eye Institute, 2015b).

10.3.2.3.3 Effect on Driving Behaviors

Glaucoma can impact the operational and tactical driving levels. These impairments result in increased crash risk for drivers with glaucoma when compared with controls (Szlyk, Mahler, Seiple, Edward, & Wilensky, 2005). In addition, glaucoma is a significant determinant of self-reported crashes (Tanabe et al., 2011). Specifically, drivers with glaucoma make more critical driving errors than controls including lane maintenance and gap acceptance, particularly at traffic lights and yield/give-way intersections (Wood, Black, Mallon, Thomas, & Owsley, 2016).

10.3.2.3.4 AV Technology to Compensate for Functional Driving Impairments

In addition to visual acuity requirements, driving licensing jurisdictions have established visual field requirements. For example, Canadian drivers must have a 120° continuous visual field in the horizontal meridian, and 15° above and below fixation with both eyes open and examined together (Canadian Medical Association, 2017). In the United States, similar requirements have been established by individual states, ranging from 110° to 140° minimum continuous visual field (Bron et al., 2010). Thus, the following are the potential AV technologies for drivers with glaucoma that meet their jurisdiction visual field requirements, in relation to visual field restrictions—the main characteristic of glaucoma.

1. Restricted visual field leading to lane maintenance errors:
   a. *Blind spot detector (SAE Level 0)*: Monitors and warns the driver if there are vehicles in the driver's blind spot.
2. Restricted visual field leading to gap acceptance errors:
   a. *Intersection assistant (SAE Level 0; requires V2V communications)*: Monitors traffic at an intersection or junction and prompts the driver to initiate braking if the gap becomes unsafe.

10.3.2.4 Diabetic Retinopathy (DR)

Approximately 285 million people around the world currently live with diabetes mellitus, a third of whom experience symptoms of DR (Lee, Wong, & Sabanayagam, 2015). DR is the most common form of vision loss among people with diabetes, and as the aging population increases, a rise in DR is also expected (Lee, Wong, & Sabanayagam, 2015).

10.3.2.4.1 Clinical Characteristics

DR is caused by damage to the small blood vessels in the retina, due to a high in-blood sugar concentration. As a result, the small vessels in the retina can hemorrhage and distort vision. As the disease progresses, new abnormal blood vessels can increase in number on the retina's surface, leading to scarring and damage to the retina (National Eye Institute, 2015a).

10.3.2.4.2 Functional Performance Deficits

In the early stages, DR can cause no noticeable symptoms. As the disease progresses, however, the hemorrhaging in the retina creates the appearance of "floating spots" in the person's field of view. Figure 10.4 illustrates a scene as viewed by an individual with DR.

FIGURE 10.4 (See color insert.) Scene as viewed by a person with DR. (Image from the National Eye Institute, National Institutes of Health.)

10.3.2.4.3 Effect on Driving Behaviors

Given the extent and trajectory of the condition, DR can result in severe visual loss below the legal jurisdictional visual requirements. However, drivers in earlier stages of the condition, or those treated for DR (Vernon, Bhagey, Boraik, & El-Defrawy, 2009), may experience visual impairments that, though not fully restricting their participation in driving, can impact their driving performance at the tactical and operational level including difficulty watching for hazards which results in slower brake response times and increased brake pressure; longer reaction and response times; and lane excursions and increased off-road times (Szlyk et al., 2004).

10.3.2.5 AV Technology to Compensate for Functional Driving Impairments by SAE Level

The following are the potential AV technologies that can support drivers with DR.

1. Decreased visual acuity and "spotting" in the field of view:
   a. *Parking assist (SAE Level 1)*: See Section 10.3.1.4.
2. Decreased contrast sensitivity:
   b. *Automotive night vision (SAE 0)*: See Section 10.3.1.4.

Finally, drivers diagnosed with all of the above-mentioned visual disorders experience difficulty watching for hazards. Pedestrian detection systems (SAE Level 0) can alert these drivers if there is a vulnerable road user (e.g., pedestrian) in the vehicle's path.

10.3.2.6 Case Study: Zane, an Older Adult with a Diagnosis of Glaucoma

Zane is a 72-year old male who immigrated to Canada in his 20s. Zane lives alone in a retirement condominium, where he moved five years ago after his wife passed away. He has two daughters, one who lives close to him and another who lives across the country. Zane is an accountant who worked in an accounting firm until his retirement, i.e., when he turned 65 years old. He enjoys reading and taking walks with his dog. Zane has a history of high blood pressure and a diagnosis of open-angle glaucoma. He underwent a laser trabeculoplasty—a laser surgery used to lower intraocular pressure—two years ago. He takes Acetazolamide to manage his glaucoma. He is experiencing worsening of his peripheral field of view even after surgery, and the optometrists have noticed some loss of visual acuity. He has been a licensed driver for over 50 years, and currently drives approximately three times a week in familiar environments and routes. He avoids driving at nights and in inclement weather. Table 10.1 summarizes Zane's strengths and challenges, which help guide the assessment process.

As part of his comprehensive driving evaluation, Zane underwent a visual assessment (details of these assessments are beyond the scope of this chapter). The findings included: 20/50 binocular visual acuity (20/50 is the jurisdictional visual requirement for driving); 125° continuous peripheral field of view (70° in the right eye; 55° in the left eye); intact contrast sensitivity, depth perception, color discrimination, and lateral and vertical phorias. No cognitive or motor impairments are noted.

TABLE 10.1
Strengths and Challenges

Strengths	Challenges
1. Has insight and has implemented self-restrictions on his driving. 2. Drives in familiar environments and routes while avoiding hazardous climates and nighttime driving. 3. Has medical care and adequate follow-up from his circle of care. 4. Has no known comorbidities beside high blood pressure. 5. Has a family network of support.	1. Visual impairments are increasing even after surgical intervention. 2. Has high blood pressure which affects severity of his symptoms.

On-road assessment. The certified driving rehabilitation specialist (CDRS) conducted the on-road assessment noting the following:

- Zane makes narrow turns, potentially overcompensating for peripheral vision loss;
- he occasionally drifts from his lane, potentially as a result of difficulty seeing lane markings, but corrects lane positioning;
- he has difficulty navigating four-way stops, where he takes a long time to proceed even when having the right of way, potentially given the restricted peripheral field of view;
- he performs full head turns continuously throughout the drive, as a way of compensating for reduced peripheral field;
- he stops too close to the lead vehicle at intersections.

Recommendations. The CDRS recommended that Zane uses the two-second rule, leaving at least 2 seconds between him and the lead vehicle, as well as stopping where he can see the tires of the lead vehicle. She also suggests an alternative route to the supermarket that avoids four-way stops completely. She suggests that Zane works with her during upcoming sessions to practice this new route and build confidence. She recommends the use of a lane change assist and a blind spot detector. These technologies will warn Zane when he is drifting from the lane, as well as provide a warning if there are objects in his blind spot or in a position where a lane change would be unsafe. Other technologies that could support Zane include lane-centering control, adaptive cruise control, and a pedestrian/bicycle collision warning system so that when Zane is turning his head away from the forward view the forward roadway is being monitored by the AV technology to the extent possible to provide Level 2 assistance. However, given Zane's age and the resulting deskilling that is expected to emerge, integrating all these technologies could result in increased cognitive load. As such, the CDRS prioritizes these two.

Before recommending the technologies, however, she explores Zane's AV technology acceptance. Zane wants to be able to drive for as long as possible and is willing to purchase technologies that might be helpful. He heard one of his daughters talking about a new device in her car and he is actually excited to try one himself. The CRDS conducts education sessions with a vendor before any purchase, so that Zane can try the technology and use it appropriately.

10.3.3 Neurological and Neurodegenerative Disorders

10.3.3.1 Introduction

This section will present autism spectrum disorder (ASD) and attention deficit hyperactivity disorder (ADHD) as neurological disorders of concern, and Parkinson's disease (PD) as a neurodegenerative disorder of concern. The effect of each condition on the strategic, tactical, and operational components is discussed as a group in Section 10.4.4. The AV technologies that would benefit drivers with ASD, ADHD, and PD are discussed as a group later in Section 10.4.4.4.

10.3.3.2 ASD and ADHD

In the United States, ASD affects 1 in 59 children (Centers for Disease Control and Prevention, 2018). ADHD affects 1 in 11 of 4- to 17-year olds (Centers for Disease Control and Prevention, 2017; Visser, Bitsko, Danielson, Perou, & Blumberg, 2010) and approximately 13.2% of males and 5.6% of females under the age of 18. Should they meet the diagnostic criteria for both conditions, teens receive a dual diagnosis of ADHD/ASD (American Psychiatric Association, 2000, 2012; Clark, Feehan, Tinline, & Vostanis, 1999). The prevalence of those with a dual diagnosis is unknown.

10.3.3.2.1 Core Clinical Characteristics

ASD is characterized by deficits in executive functions (e.g., mental flexibility, planning, sequencing, and self-monitoring), visual-motor coordination, and motor coordination. Core ASD symptoms include repetitive behaviors, fixated interests, social interaction and communication deficits, and unusual response to sensory input—all of which may impact independent and safe driving. A survey of parents of teens (ages 15–18) with high-functioning ASD found that 12% of teens were involved in one or more motor vehicle crashes as the driver at fault—and another 12% received a citation for a moving violation in the prior year (Huang, Kao, Curry, & Durbin, 2012). ADHD symptoms are characterized by inattention, hyperactivity, and impulsivity (Centers for Disease Control and Prevention, 2017)—all of which may predict impaired fitness to drive.

10.3.3.2.2 Functional Performance Deficits

Functional performance, of those teens with ASD and/or ADHD, is impaired by deficits in *visual, cognitive, and motor* functions as described below.

Specifically, for *visual functions,* teens with ASD do not scan the driving environment as effectively as neurotypical peers, but instead maintain their visual focus on the driving horizon (Reimer et al., 2013). Teens with ASD have difficulty making eye contact (National Institute of Mental Health, 2017). Thus, they may fail to make eye contact with pedestrians at a crosswalk (Sheppard, Ropar, Underwood, & Van Loon, 2010), orient slower to driving hazards (Sheppard, Van Loon, Underwood, & Ropar, 2017), or perform worse in visual attention skills than neurotypical peers (Reimer et al., 2013). Thus, they may not notice potential hazards in their immediate path. Compared with neurotypical peers, teens with ADHD have impaired right visual acuity and impaired right peripheral field (Classen, Monahan, & Brown, 2013;

Classen et al., 2013); and teens with ADHD/ASD did worse on measures of visual performance (Classen, Monahan, & Brown, 2013; Classen et al., 2013).

For *cognitive functions,* teens with ASD have difficulty in *problem-solving* driving events such as approaching an emergency vehicle. During these driving maneuvers, when they experience increased demands on *working memory,* they make more steering and braking errors (Cox et al., 2016). Noticeably, as can be seen from Video 1, teens with ASD have difficulty carrying out the correct sequence when performing a turn.

Video 10.1: Teen with ASD Performing a Turn [UPLOAD VIDEO]

As such, they may not effectively sequence the adjustment of speed and rotation of the steering wheel to control a vehicle through a turn (Classen et al., 2013). Moreover, these teens divert their attention away from complex roadway situations that require increased cognitive demands (Reimer et al., 2013). Teens with ASD and/or ADHD performed worse than neurotypical peers on measures of cognition (Classen, Monahan, & Brown, 2013). Specifically, in the Classen et al. study, they responded late or not at all to traffic lights, regulatory signs, or pedestrians.

Reduced ability to estimate risk and impulsive tendencies of teens with ADHD impairs their judgment when driving (Barkley, 2004). Such impairments are evident in *misjudging* gaps in traffic and not *adjusting speed* for hazardous conditions. Compared with neurotypical peers, teens with ADHD also demonstrate impaired selective attention (Classen, Monahan, & Brown, 2013).

For *motor functions*, teens with ASD have difficulty with bilateral upper extremity motor coordination for turning the wheel when negotiating a turn in a high-fidelity driving simulator (Classen, Monahan, & Brown, 2013). Compared with neurotypical peers, teens with ADHD also showed impaired motor coordination during a simulator driving task (Classen, Monahan, Brown et al., 2013).

10.3.3.2.3 Effect on Driving Behaviors

Teens with ASD take longer to learn to drive and are older than their peers when obtaining a driver's license (Almberg et al., 2015). In one study, 33% of teens with ASD reported that they were driving, 12% were involved in crashes, and 12% had citations for moving violations (Huang et al., 2012). Compared with neurotypical drivers, drivers with ADHD had more self-reported motor vehicle crashes, more traffic citations, drove more without a driver's license, and drove more under the influence of alcohol (Fabiano et al., 2010; Jerome, Habinski, & Segal, 2006; Jerome, Segal, & Habinski, 2006). Teens with ASD and/or ADHD have more crashes in a driving simulator as compared with neurotypical peers (Classen et al., 2013).

10.3.3.3 Parkinson's Disease

In the United States, PD affects about 1 million Americans (Parkinson's Foundation, 2018). PD is most commonly diagnosed in people over the age of 60, with only 5% of all cases diagnosed before the age of 60. Men are 1.5 times more likely diagnosed with PD than women, and the incidence of PD increases with age (Parkinson's Foundation, 2018).

10.3.3.3.1 Core Clinical Characteristics

PD is an age-related, progressive, neurodegenerative disorder characterized by the development of four cardinal symptoms, i.e., resting tremor, rigidity, bradykinesia, and postural instability. In addition to motor difficulties, non-motor symptoms account for a significant source of disability, particularly as many non-motor symptoms often do not respond to dopaminergic medications. Non-motor symptoms may include visual deficits, cognitive impairment, depression, or other emotional impairments (e.g., apathy and disinhibition), sleep disorders, and autonomic dysfunction (Riggeal et al., 2007; Uc et al., 2005). These clinical features of PD may affect not only body functions but also functional performance or activities of such individuals (World Health Organization, 2001).

10.3.3.3.2 Functional Performance Deficits

Functional performance of those with PD is impaired by demographic factors, such as *age* (Crizzle et al., 2013), *disease duration,* and *disease severity* (Classen et al., 2011; Singh, Pentland, Hunter, & Provan, 2007; Worringham, Wood, Kerr, & Silburn, 2006). Other complicating factors include *daytime sleepiness* (Lachenmayer, 2000; Meindorfner et al., 2005), *medication use* (Meindorfner et al., 2005), as well as the accompanying *comorbidities* (Crizzle, Classen, & Uc, 2012).

Relationships exist between functional performance deficits resulting from PD and driving behaviors. Specifically in PD, such deficits pertain to: *binocular acuity* and *contrast sensitivity* (Uc et al., 2005; 2009; Worringham et al., 2006); *visual scanning and speed of processing* (Classen et al., 2011; Uc et al., 2006a; Worringham et al., 2006); *cognitive impairments* (Amick, Grace, & Ott, 2007; Dubinsky et al., 1991; Worringham et al., 2006); *set shifting and cognitive flexibility* (Amick et al., 2007; Uc et al., 2006a; 2006b; 2009); and *psychomotor speed,* including *reaction time*, *slowed walking, and fine motor movements* (Classen et al., 2011; Crizzle et al., 2012; Worringham et al., 2006). Such performance deficits can greatly impair functional driving ability and potentially lead to an elevated crash risk (Uc & Rizzo, 2008; Uitti, 2009), even in the early stages of PD (Crizzle et al., 2012; Devos, Ranchet, Akinwuntan, & Uc, 2015).

10.3.3.3.3 Effect on Driving Behaviors

Drivers with PD may have an increased risk of crashes per million miles traveled, specifically in those with greater disease severity (Dubinsky et al., 1991). In a small study ($N = 15$), researchers found that a third of the PD patients thought that their PD symptoms may have contributed to a recent crash (McLay, 1989), while another study suggests that PD drivers have no greater crash risk when compared with the rest of the population (Lings & Dupont, 1992). Yet, Meindorfner et al. (2005) found that 15% of over 6,000 PD respondents reported involvement in a motor vehicle crash, with 11% of the 15% reporting being at fault. However, whether crash rates are truly higher in PD is still unclear due to the lack of well-controlled studies.

10.3.3.4 Strategic, Tactical, and Operational Deficits for Those with ASD, ADHD, and/or PD

Taken together, the evidence indicates that the functional performance deficits experienced by drivers with ASD and/or ADHD, or PD result in impairments in driving behaviors on the strategic, tactical, and operational levels (Michon, 1985). Examples of such impairments on each of the levels of driving behavior are indicated below:

10.3.3.4.1 Strategic Impairment

Strategic impairments may include decisions that are made a priori, before starting to drive and incorporate decision-making, problem-solving, reasoning, judgment, and/or initation of strategies to overcome potential driving difficulties. Examples of impairments include experiencing

- Challenges with decisions related to trip planning, prior to the actual drive, which result in getting lost during travel, or being disoriented in time and space;
- Difficulty with judgment and decision-making, during the actual drive, when the driver with a cognitive impairment needs to negotiate a complex travel route; and
- Increased cognitive load when driving during peak traffic hours (vs. non-peak hours) which result in deterioration of driving performance.

10.3.3.4.2 Tactical Impairment

These impairments are evident during the driving task with routine functions being deficient. Such functions include steering, braking, accelerating, stopping, or controlling the vehicle in the driving environment, while adhering to the rules of the road and the traffic regulations. Examples include:

- Speeds too high or too low when merging on a highway;
- Difficulty with parking, backing up, pulling away, changing lanes, merging into traffic, or maintaining a safe headway distance;
- Challenges with anticipating and adjusting to traffic stimuli, such as not being able to supress road side distractions while making a turn; and
- Inadequately negotiating the traffic infrastructure, such as difficulty judging and accepting an appropriate gap when turning against oncoming traffic.

10.3.3.4.3 Operational

Such impairments occur when a swift reaction of the driver is necessary to avoid a potential obstacle or adverse condition. Examples include:

- Inability to swerve to avoid an obstacle in the road that may cause harmful effects;
- Challenges to control the gas and/or brake pedals in an emergency situation, such as a child running across the road; and
- Limited ability to manipulate swift steering control when a potential adverse event is unfolding, such as a driver in a parked car opening a car door in front of one's moving vehicle.

As such, because driving behaviors seem to be impaired at all levels (strategic, tactical, and operational) in those with ASD, ADHD, and/or PD drivers, AV technology holds out the promise to mitigate at least some of the functional impairments.

10.3.3.4.4 AV Technology Compensate for Functional Driving Impairments by SAE Level

Table 10.2 indicates the main functional deficits of drivers with neurological and neurodegenerative disorders, the AV technology by type and SAE level, as well as the potential to offset the functional deficits. *Note*: Most of the operational definitions of the AV technology were obtained from the MyCarDoesWhat.org site (*https://mycardoeswhat.org/*, 2018).

TABLE 10.2
Functional Deficits of Drivers with Neurological or Neurodegenerative Disorders, the AV Technology by Type and SAE Level, as Well as the Potential to Offset the Functional Deficits Caused by the Disorder

Source	Deficit	AV Technology
	Teens with ASD and/or ADHD	
Vision	Teens with ASD do not scan the environment as effectively as neurotypical peers and may not notice potential hazards in their immediate path.	*Pedestrian detection and avoidance system (SAE Level 0)*: Assist the driver to detect pedestrians in the path by alerting the driver to such stimuli, and braking the car, should the driver not adjust his/her response. *Blind spot detection (SAE Level 0)*: See Section 10.3.4.4.
Visual perception	Teens with ADHD may misjudge gaps in traffic.	*ACC (SAE Level 1)*: ACC automatically adjusts the vehicle speed to maintain a safe distance from vehicles ahead.
Cognition	Teens with ASD make more steering and braking errors when experiencing increased demands on working memory.	*Intelligent speed adaptation (SAE Level 0–1)*: On-board camera scans for signs and reads the speed limit while the GPS satellite passes road speed limits (Level 0) directly to the car, and the on-board computer warns the driver and slows (Level 1) the car to match the speed limit information received.
Cognition	Teens with ASD have difficulty carrying out the correct sequence of actions when performing a turn. As such, they may not effectively sequence the adjustment of speed and rotation of the steering wheel to control a vehicle through a turn.	*Intersection assist (SAE Level 0 or 1)*: Monitors cross traffic in an intersection or road junction. When it detects a hazardous situation, it prompts the driver to start emergency braking by activating visual and/or auditory warnings or automatically engages the brakes (also see Section 10.3.4.4).

(*Continued*)

TABLE 10.2 (*Continued*)
Functional Deficits of Drivers with Neurological or Neurodegenerative Disorders, the AV Technology by Type and SAE Level, as Well as the Potential to Offset the Functional Deficits Caused by the Disorder

Source	Deficit	AV Technology
Cognition	Teens with ASD may have difficulty diverting from routines. Subsequently when their habitual driving route is interrupted with a detour, they show a decline in driving performance.	*ANS (SAE Level 0)*: The ANS helps to find the route for the vehicle via satellite navigation. When directions are needed, routing can be calculated in real time.
Cognition	Teens with ADHD may have difficulty with planning aspects of driving such as route selection and time management for punctual arrival.	*Automated GPS (SAE Level 0 or 1)*: Navigation (Level 0) is integrated with the steering and wayfinding abilities of the vehicle. It indicates the estimated time of arrival and will steer the vehicle (Level 1) in the shortest or most advantageous route to offset deficits in route planning and time management.
Motor	Teens with ASD have difficulty with bilateral upper extremity motor coordination when turning the steering wheel. Teens with ADHD have impaired motor coordination resulting in difficulty maneuvering the vehicle in a parking bay.	*Parking assist (SAE Level 1 or 2)*: The system uses sensors and cameras to assist in parking. Parking assist is at a Level 1 when the driver controls the speed, but Level 2 where both steering and braking/accelerating/decelerating are controlled by the vehicle (also see Section 10.3.5.4.)
Driving performance	Teens with ADHD have more crashes and citations compared with neurotypical peers. Teens with ASD and/or ADHD have more crashes in a driving simulator compared with neurotypical peers.	*Adaptive cruise control with steering assist (SAE Level 2)*: The front and rear collision avoidance systems are designed to help maintain safe distances between vehicles as well as to prevent and reduce front and rear-end crashes and accompanying injuries (see, Section 10.3.1.4).
	Drivers with PD	
Vision	Contrast sensitivity is impaired in drivers with PD, and drivers may not be able to clearly distinguish dark objects from a dark background.	*Automotive night vision assist (SAE Level 0)*: see Section 10.3.1.4.
Vision	Binocular acuity is impaired in drivers with PD, which may impair functions to detect approaching vehicles.	*Blind spot detection (SAE Level 0)*: See Section 10.3.4.4.
Vision	Contrast sensitivity is impaired in drivers with PD and drivers may not be able to clearly distinguish dark objects from a dark background.	*Automotive night vision assist (SAE Level 0)*: Section 10.3.1.4.

(*Continued*)

TABLE 10.2 (*Continued*)
Functional Deficits of Drivers with Neurological or Neurodegenerative Disorders, the AV Technology by Type and SAE Level, as Well as the Potential to Offset the Functional Deficits Caused by the Disorder

Source	Deficit	AV Technology
Visual scanning	Visual scanning may be impaired in drivers with PD when multiple tasks are required, such as making a turn and scanning the environment for pedestrians.	*Pedestrian detection system (SAE Level 0)*: The system acts as an extra set of eyes for the driver, helping them to avoid potentially catastrophic collisions by delivering either a visual or audible alert, or both (also see above).
Visual construction	This ability may be impaired in drivers with PD to adequately perceive all of the complexities in the driving environment.	*Pedestrian and cyclist detection (SAE Level 0) and avoidance (SAE Level 0)*: The system uses advanced sensors to detect pedestrians and cyclists and to alert the driver to respond. If the driver does not respond, the system will apply the brakes, via AEB, to slow and stop the vehicle (see above).
Visual-motor	Visual-motor tracking may be impaired in drivers with PD, and as such keeping the vehicle in the center of the lane while looking at the other traffic may be problematic.	*Lane-keeping assist (SAE Level 1) and lane-centering (SAE Level 1)*: See Section 10.3.1.4.
Cognition	Speed of processing and attention may be slowed in PD drivers and compromises the driver's ability to make a turn at an unprotected intersection adequately and safely.	*Intersection assistant (SAE Level 0)*: This requires V2V connectivity along with AEB (Level 0). Monitors cross traffic in an intersection or road junction. When it detects a hazardous situation, it prompts the driver to start emergency braking by activating visual and/or auditory warnings or automatically engages the brakes (also see Section 10.3.4.4).
Cognition	Set shifting and cognitive flexibility may be impaired in drivers with PD, which means that the driver may drive under the speed limit to offset the demands of cognitive load.	*ACC (SAE Level 1)*: See above.
Cognition	Verbal memory deficits affect working memory in drivers with PD and may lead to wayfinding problems.	*Automated wayfinding systems (SAE Level 0)*: Wayfinding systems include informational, directional, and identification signs and maps that work together to help drivers find their way.
Motor	Disdiadochokinesis may affect hand over hand coordination in drivers with PD, which is necessary in turning the steering wheel for parking a vehicle.	*Parking assist (SAE Level 2)*: The system uses sensors and cameras to automatically park the vehicle in a parking bay (also see Section 10.3.5.4.)

(*Continued*)

TABLE 10.2 (*Continued*)
Functional Deficits of Drivers with Neurological or Neurodegenerative Disorders, the AV Technology by Type and SAE Level, as Well as the Potential to Offset the Functional Deficits Caused by the Disorder

Source	Deficit	AV Technology
Motor	Reaction time is slowed in drivers with PD, resulting in slow response time to brake for an oncoming vehicle making a turn at an intersection.	*Turning assistant (SAE Level 0)*: The system monitors opposing traffic when turning left at low speeds. In critical situations, it uses AEB, to brake the car.
Motor	Fine motor movement may be impaired in drivers with PD, impeding their ability to activate controls, e.g., ACC and lane-centering, on the steering wheel of the vehicle.	Because activation of the controls is integrated into the steering wheel of the vehicle, and requires fine motor control, drivers with PD may have difficulty in engaging these systems. Consider different designs to accommodate fine motor control issues for drives with PD in activating controls for the in-vehicle technologies. For more information, see Chapter 16.

10.3.3.5 Case Study: Elizabeth, a Client with PD

Elizabeth is a 74-year-old female with a diagnosis PD and glaucoma in the right eye (ten years). She also has comorbidities including high blood pressure (40 years), arthritis in hips and lower back (10 years), cataract in right eye (5 years), sciatica (45 years), clinical depression (2 years), and sleep disorder (10 years). She is taking therapeutically prescribed dosages of eye drops for glaucoma, hydrochlorothiazide, and lisinopril for blood pressure, multivitamins, and glucosamine chondroitin. She wears prescription lenses, is medically stable, and reports some side effects, i.e., lightheadedness, from the blood pressure medication. She has a doctoral degree, and lives alone in a single story condominium in a residential neighborhood. She still drives five days a week, drives mostly alone, and she maintains her vehicle well. She is active in her community by participating in a garden club, doing her own shopping, and volunteering for work at the local hospital. She avoids driving in rain, rush hour traffic, nighttime driving, and interstate and highway driving. She has had no crashes or citations in the past three years. She has taken a classroom-based driving refresher course, more than three years ago. Table 10.3 summarizes Elizabeth's strengths and challenges.

Based on clinical assessments (content not discussed in this chapter), Elizabeth shows impairment in depth perception, recall, visual-motor perceptual skills, gait speed, and neck range of motion.

On-road assessment. Elizabeth has completed an on-road assessment administered by a CDRS, with the following results:

TABLE 10.3
Strengths and Challenges for Elizabeth

Strengths	Challenges
1. Regulating her driving	1. Neurodegenerative nature of PD
2. Avoiding potential hazards	2. Chronic and degenerative visual conditions
3. Living alone—independent in Activities of Daily Living (ADLs) and possibly most Instrumental Activities of Daily Living (IADLs)	3. Side effects of blood pressure medication (lightheadedness, dizziness)
4. Having higher education	4. Limited support network
5. Wearing prescription lenses	5. Effects of the comorbidities, e.g. stiff joints, depression, potential for daytime sleepiness
6. Having a good driving record	

- Stops over stop lines at intersections (potentially due to depth perception impairment)
- Makes wide turns at curves and turns into the furthest lane (potentially due to impairments in depth perception, visual-motor perception, and set shifting)
- Not scanning adequately to the left and right before crossing intersections (potentially due to impaired neck range of motion)
- Not reacting appropriately to cars in her blind spot (potentially due to impaired set shifting and neck range of motion)
- Not maintaining lateral lane position as she drifts to the left (potentially due to impairments in visual-motor perception, and set shifting)
- Not using turn signal consistently (potentially due to impairments in recall and set shifting)

The CDRS Has Made the Following Recommendations

- Continue with driving utilizing self-identified restrictions
- Restrict driving: no driving in challenging environments (new areas, poor weather, city driving); no highway driving; avoid rush hour traffic;
- Provide client with education on
  - use of reference points, i.e., vehicle features that align with lane markings and stop line;
  - planning the driving routes to include protected left turns; and
  - consistent use of turn signal;
- Use of AV technology to mitigate impairments related to functional declines as described in Table 10.4.
- Expose the client to three visits, for one month, for 60–75 minutes. The visits will entail in-clinic client education and instruction; skill training on the use of AV technology in the parking lot; and in-car residential and city (light traffic) driving skill retraining.
- Follow-up with the client in one year to monitor the neurodegenerative effects of PD on her fitness-to-drive abilities.

Elizabeth's long-term goal is to enhance her fitness-to-drive skills and to competently perform routine driving tasks, mainly dependent on tactical skills, in the restricted driving environment, while compensating for the effects of her medical conditions, i.e., depression and PD that can cause functional declines. The CDRS's recommendations and employment of strategies will help Elizabeth to achieve these goals. The CDRS discharges Elizabeth after three successful sessions and recommends that she maintains her regular medical appointments, including visits to the ophthalmologist, and a follow-up visit with the CDRS in one year (due to the degenerative qualities of PD), or if her health condition changes sooner. The CDRS reports the outcome of the comprehensive driving evaluation, as well as the success of the interventions, and the discharge plan to Elizabeth's primary care physician.

TABLE 10.4
Use of AV Technology to Mitigate Impairments Related to Functional Declines

Impairment in Driving Behaviors (Strategic/Tactical/Operational)	AV Technology to Offset the Driving Impairments	Benefits for Elizabeth
Makes wide turns at curves and turns into the furthest lane (tactical)	Lane-keeping assist	Lane departure warning systems use visual/auditory or vibrational (haptic) stimuli to alert a driver that they are drifting out of the lane and the lane-keeping assist centers the vehicle to its lane to overcome the notion of making wide turns.
Not scanning adequately to the left and right before crossing intersections (tactical)	Intersection assistant	Scans the environment for oncoming traffic and warns drivers of vehicles approaching from the sides at intersections, highway exits, or car parks to overcome the inadequate scanning behaviors of the client.
Not reacting appropriately to cars in her blind spot (tactical)	Blind spot detection	Alerts the driver through auditory and visual cues of approaching vehicles in the blind spot to overcome the impairment related to blind spot detection.
Not maintaining lateral lane position as she drifts to the left (tactical)	Lane departure warning and correction system	As described above.
Not using turn signal consistently (tactical)	Lane departure warning and correction system	As described above.

10.4 CONCLUSION

In this chapter the authors discussed deskilling, visual disorders, and neurological and neurodegenerative disorders. Specifically, the authors focus on the core clinical characteristics, associated functional performance deficits, the effect on driving behaviors, and potential of automated vehicle technologies (SAE Levels 0–2) to mitigate the effects of the functional performance deficits, and to enable the driver to resume control. The content discussed is tied together through the illustration of two case studies.

Although the empirical literature supports most of the sections in the chapter, the last section (i.e., deployment of automated vehicle technologies to resume control) represents a conceptual amalgamation of collective thinking on the possibilities of vehicle automation. This section is based on conjecture, informed by the authors' collective best clinical reasoning, understanding the medically-at-risk driver's functional performance deficits, as well as the potential possibilities that automated vehicle technologies hold for the driver to resume control.

The authors hope that this chapter lays the conceptual foundation for engineers, clinicians, rehabilitation scientists, and other transportation professionals to recognize the vulnerabilities of medically-at-risk drivers, as well as the opportunities that automation holds to enable these populations to be independent and safe in their driving tasks. The authors also hope that this chapter will prompt scientists, to empirically test the assumptions related to automated vehicle technologies, for at-risk drivers.

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