Systems Science & Control Engineering: An Open Access Journal, 2014
Vol. 2, 699–706, http://dx.doi.org/10.1080/21642583.2014.924083

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REVIEW

Development of safe-driving-system features for elderly drivers

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(*Received 13 February 2014; final version received 10 May 2014*)

As the overall population ages, elderly drivers will become a larger percentage of the driving population. However, driving-related accidents and injuries associated with elderly drivers are also on the rise. To determine the causes of this trend, we researched existing vehicle systems that use different sensors and signals to promote safe driving. We found that although the systems alert drivers to potential collisions and assist them in finding a location easily, they were not practical enough to protect elderly drivers. For the most part, they were not created by people with driving difficulties caused by health problems, which in turn often afflict the elderly. To address this issue, we analysed the drawbacks of the current systems and used a focus group of people with body conditions that have declined due to age to discover the problems they encounter while driving. With the focus group, we used diverse research activities, such as surveys, observations, and interviews, to demonstrate how new system features (concepts) could be developed for the elderly. Finally, we proposed that adequate system features for the elderly would improve driving safety and provide a more enjoyable driving environment for this population.

Keywords: elderly; driving-system design; design and technology for elderly

1. Introduction

With the average age of the world's population increasing, caring for the growing elderly population is going to be an important service in the coming decade. Specifically, the automotive industry is facing a new challenge to provide new systems for the growing population of elderly drivers due to the number of traffic accidents caused by elderly drivers and their higher fatal injury rates than young driver in crashes on the road (Tefft, 2008). According to the National Highway Traffic Safety Administration's report (2009) on safety, traffic accidents involving elderly drivers have soared by 49.5% over the past five years, with thousands of fatalities. Also, fatal crash rates have increased noticeably starting at age 70–74 and are highest among drivers 85 and older, per mile travelled (NHTSA, 2009). Even in two-vehicle fatal crashes involving an elderly driver and a young driver, an older person has an injury rate nearly twice that of a younger driver, i.e. 58% and 35%, respectively (NHTSA, 2009). Due to the growing issue, developing adequate vehicle systems for elderly drivers' safety on the road has become critical, and many companies have tried to discover and design a new vehicle system in order to mitigate the elderly's accidents and injuries.

However, the elderly are unsatisfied and feel unsafe with the currently developed systems. The systems are not effective enough to protect the elderly because most operating systems fail to consider the body conditions afflicting the elderly, such as decreased vision and hearing, as well as various health conditions and the fact that they might be taking medications (National Centre for Injury Prevention and Control, 2013). Additionally, many countries have merely chosen to train elderly groups about safe driving on the road, such as how to avoid potential injuries and protect themselves during collisions. Therefore, first, this paper will investigate elderly people's driving problems based on their ageing body conditions. It will also emphasize the significance of vehicle system design for the elderly by analysing current vehicle systems and suggesting possible in-vehicle developments for the elderly based on focus group observations and interviews. Finally, it will provide proper vehicle system feature concepts for the elderly throughout the focus group evaluation.

2. Understanding health-related issues with elderly drivers

To develop proper vehicle systems for elderly groups, it is necessary to understand how their ageing body conditions can affect their driving. An effective system cannot be created without first considering the functions this specific group requires in order to be able to drive safely and comfortably. Here are some general health problems associated with the elderly.

- Eyesight

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Some eye conditions can interfere with the elderly's ability to focus their peripheral vision, or can cause them to experience extra sensitivity to light, trouble seeing in the dark, or blurred vision (Saisan, White, & Robinson, 2013). With imperfect visual acuity, they have difficulties in detecting and judging the location of objects correctly (Park & Lim, 2011). Elderly people drive more slowly in darker conditions, and may have pathological narrowing of the visual field in addition to a narrowed visual field while driving (Park & Lim, 2011). Glaucoma is a disease that increases with age, and one symptom is difficulty seeing in one part of the visual field. It is reported that symptoms of open-angle glaucoma are present in about 3.9% of people aged 40 years or older in Japan (Morita & Sekine, 2013). Iwase et al. (2004) reported that when these glaucoma patients drive, they have an increased likelihood of having an accident.

- Hearing

Decreased hearing is a key symptom of ageing. Sometimes, the elderly do not even realize that they are missing important auditory cues, such as emergency sirens and honking horns when they are driving (Saisan et al., 2013).

- Reflexes

As reaction times slow with age, the elderly may be slower to spot vehicles emerging from side streets and driveways, or to realize that the vehicle ahead of them has slowed or stopped. Also, it has been found through in-car observations that older drivers have a very difficult time responding to traffic signals and performing left and right turns due to pain or stiffness in their necks, which prevents movement (Saisan et al., 2013).

- Memory

Keeping track of so many road signs, signals, and markings, as well as all the other traffic and pedestrians can also become more difficult given the fact that the elderly often have decreased memory capabilities and a decreased attention span. The elderly drivers often find themselves missing exits that used to be second nature, or find themselves getting lost frequently (Saisan et al., 2013).

3. Analysis of current vehicle systems

Different sets of systems for safe driving have been produced. The following systems can minimize the elderly's injury risks related to their common health problems.

3.1. *Night-vision system*

Night-time driving is accompanied by low visibility along with sleepiness and high levels of fatigue (Bugalia, 2013). This leads to increased risk of accidents, which in turn is one of the main reasons for on-road pedestrian fatalities. One of the most common complaints of elderly drivers is the difficulties they have driving at night. At roughly 45 years of age, eyes lose some of their ability to see low-contrast objects (Tefft, 2008). Also, they recover more slowly from exposure to glare (Tefft, 2008). These difficulties can shorten the distance at which drivers can detect and recognize objects. One type of technology that promises to extend the range of driver vision and improve safety is the infrared (IR) night-vision system (Stuart, Kyle, Nicklin, & Komos, 2001).

Current night-vision systems increase the visibility of objects by presenting a high-contrast image of the forward scene on an interior visual display (Stuart et al., 2001). The images are acquired either from a far-infrared (FIR) camera that is sensitive to the heat radiated from objects on the roadway or from a near-infrared (NIR) camera that detects reflected IR radiation from an IR source on the vehicle (Stuart et al., 2001). The NIR system can show roadway objects that are not detected in an FIR system, such as road signs and lane markings (Stuart et al., 2001). With this system, the elderly can drive without nervousness and increase their mobility at night.

3.2. *Lane-departure warning systems*

When elderly drivers unintentionally leave their lanes, their crash risk increases. If they are warned as their cars begin to veer out of their lanes, some crashes could be avoided. For elderly drivers with slower reaction times, such warnings give them the extra time needed to avoid a crash.

Lane-departure warning (LDW) systems are designed to minimize accidents by addressing the main causes of collisions, such as driver error, distractions, and drowsiness (Williams, 2008). They use a camera system to analyse roadway markings and provide a warning to alert a driver when his or her vehicle has moved out of the lane (Williams, 2008). LDW sufficiently warns elderly drivers if they doze off or are inattentive at any time (Williams, 2008).

3.3. *Lane-change collision-avoidance systems*

All vehicles have blind spots that cannot be seen in the side- or rear-view mirrors. This blind zone presents a risk for drivers of all ages but can be a particular concern for those elderly drivers with decreased neck flexibility and decreased ability to turn and look directly into blind zones (Hakamies-Blomquist, 2004). To help prevent lane-change crashes, the lane-change collision-avoidance system (CAS) was developed to detect and warn drivers of vehicles in their blind spots (Svenson, Gawron, & Brown, 2009). A CAS can detect surrounding vehicles that are in zones on the sides and behind the vehicle and notify the driver through the use of a warning signal such as an auditory message or a visual symbol in the side- or rear-view mirrors (Svenson et al., 2009). If the warning systems enable elderly drivers to spend less time looking to the side when changing lanes, the drivers can focus more on the forward scene and reduce the risk of a rear-end crash due to the unexpected deceleration of a leading vehicle.

3.4. Adaptive cruise control

Adaptive cruise control is a radar-based system that can monitor the vehicle in front of the equipped car for up to a 600-ft distance and adjust the speed of the equipped vehicle to keep it at a pre-set distance behind the lead vehicle, even in most fog and rain conditions (Burgett, Srinivasan, & Rangunathan, 2008). The system measures distance as a function of speed and can monitor the traffic ahead while ignoring stationary objects such as road signs and telephone poles (Burgett et al., 2008). It also can determine how fast the equipped vehicle is approaching the vehicle in front of it (Burgett et al., 2008). For example, when approaching a lead vehicle at a high rate of speed, the system will activate sooner than it would if the equipped vehicle were approaching slower (Masaki, Yoshimi, & Yasuhiro, 2008). When an elderly driver is following another vehicle as these cars are doing, adaptive cruise-control systems can help maintain a safe distance from the vehicle ahead.

3.5. Vehicle-navigation systems

Vehicle-navigation systems enable the car's owner or a third party to track the vehicle's location, collecting data from the field and delivering it to the base of operation (Claburn, 2009). Since the introduction of navigation systems in the 1990s, they have become very popular, particularly for elderly drivers, who often refrain from travelling on unfamiliar roads due to their fear of getting lost (Band & Perel, 2007). Vehicle-navigation systems can extend elderly drivers' mobility by giving them more confidence when travelling in unfamiliar locations (Band & Perel, 2007). For elderly drivers who have difficulty searching for street signs, the voice directions can also help lower their visual workload. In fact, the NHTSA (2009) says in its article "Exploratory Study of Early Adopters, Safety-Related Driving with Advanced Technologies" that approximately 73% of the elderly drivers with such a navigation system in their vehicles felt that it increased their willingness to drive in an unfamiliar area, and 98% of the drivers felt that using a navigation system is better than using a paper map.

3.6. Pre-safe crash-avoidance system

Pre-safe crash-avoidance is a new system to protect an occupant from a frontal crash (Ito, Ejima, Sukegawa, Antona, & Ito, 2013). When the risk of an accident is recognized, the belt buckle retracts about 1.6 in., increasing belt-tensioning on passengers by up to 3 in. to better protect them in an accident (Ito et al., 2013). The buckle also branches off at a lower point at the occupant's hip to reduce the chance of the pelvis pushing through the belt (Sanchez, 2012). The seatbelt extends upwards when the rear doors are opened (Sanchez, 2012). This system is developed in a tactical way by using the seatbelt for safety. If elderly drivers with weak visibility and hearing use this system, they would lessen the likelihood of unexpected collisions on the road because the seatbelt would notify the elderly's body when a collision is likely.

Such systems have been developed for safe driving on the road, but they are ideal for the elderly, as they inspire them to drive with confidence. However, there are some drawbacks in each system when used by the elderly with declining health conditions. For example, the night-vision system is very useful for elderly people driving at night, but what about those people with vision problems that are driving during the daytime? The LDW system works well for most people, but would be useless for most people with decreased hearing. The lane-change CAS would not be a good fit for elderly people with reflex problems, since they likely could not focus well on both visual and auditory signs and, as such, their reaction times could be slowed.

4. Development procedure of system features for the elderly

4.1. Method

To propose adequate system features for the elderly, surveys, observations, and interviews were conducted with elderly groups and a focus group. These short research activities were conducted in Seoul, Korea, because many elderly drivers actively drive around the city.

First, to better understand the elderly's driving behaviour changes, the survey was conducted with 30 participants aged 60–70 with at least 30 years of driving experience and age-related health issues, such as hearing loss, decreased sight, and slower reaction times. The survey questions asked about their current medical conditions and specific driving situations. Once the surveys were returned, the data were analysed (see Table 1).

From the survey data, we learned that elderly drivers tend to drive an average of one to three times per week for less than an hour each time. They have difficulty easily recognizing visual signs, and their necks and shoulders feel tired. Particularly, a lapse in recognizing visual signs is often reported in other studies. According to a report from Parker, Reason, Manstead, and Stradling (1995) about driving errors, elderly respondents reported more lapses than other full-age-range samples of drivers in the recognition of the visual signs. This fits in with what is known about the declining cognitive capacities of older people and the increasing likelihood of problems with attention. Holland (1998) said in his study about older drivers that indeed one of the frequently reported individual behaviours of older drivers was a lapse in accurately reading signs, and Villalba, Kirk, and Stamatiadis (2001) also stated in their study that head-on crashes requiring driver's visual recognition and search capabilities occurred most in the elderly group.

In addition, due to decreased visible capabilities and slow reaction times, the elderly respondents of the survey have experienced minor accidents driving at night and while

Table 1. Survey data from 30 elderly drivers.

Q1: How many times do you drive per week?	
① 0	0
② 1–3 times	20
③ 3–6 times	9
④ Everyday	1
Q2: What is your average time per driving?	
① Below 30 min	15
② 30 min to 1 h	10
③ 1–2 h	4
④ Over 2 h	1
Q3: What is the first symptom after starting driving?	
① Tired eyes	10
② Neck pain	9
③ Shoulder pain	9
④ Headache	2
Q4: Do you feel afraid when you drive?	
① Yes	25
② No	5
Q4-1: If yes, what makes you nervous to drive?	
① Low eyesight	12
② Slow body movement	10
③ Decreased hearing	4
④ Low memory: when finding a new place	4
Q5: Have you had any accidents on the road after you became 60 years old?	
① Yes	14
② No	16
Q5-1: If you have, what kind of accident have you had?	
① Night driving	3
② Lane changes	7
③ Turn left or right	3
④ Merging situation	1

changing lanes. Even in the Parker et al. (1995) study, their accident analysis of older drivers showed higher error rates in failing to notice pedestrians at night, checking rear-view mirrors before pulling out, and changing lanes because of the same visibility and reaction problems. Moreover, most elderly respondents from the survey said that they do not want to drive at night, and more than 50% of them have difficulties changing lanes in the proper manner.

From the survey data, it appears that the elderly group has shown similar driving problems and behaviours based on their ageing health conditions for a long time, as well as in the different studies. And although many studies have looked at how the elderly have different driving behaviours than other age groups, their problems have not been decreased yet. This means that current systems are not effective enough to allow the elderly to drive safely.

After analysing the elderly's driving behaviours, the focus group observations and interviews were conducted to establish a vehicle-design system for them. The focus group members were three of the previous survey respondents and all three were male. One was 65 years old with 30 years of driving experience, another was 70 years old with 32 years of driving experience, and the third was 60 years old with 32 years of driving experience.

Table 2. Common problems for elderly drivers.

Driving time	Common symptoms at day and night times of driving
10 min	Tired eyes
20 min	Neck pain and tired eyes
30 min	Blurred vision
	Neck and back pain
	Decreased hearing capabilities

First, to discover the focus group's common driving problems, we observed their driving for 30 min during the day and during the night. Every 10 min, we tracked their common problems (see Table 2).

Furthermore, an interview was conducted to evaluate the usefulness of the existing vehicle systems. Also, the focus group was asked if they had suggestions for other design systems that would be more beneficial to their driving.

4.2. Concept proposal of system features for the elderly

Based on the research, identical system concepts specifically for the elderly could be considered with diverse system methods, unlike the currently developed systems that concerned systems based on a single system method.

Here are some system feature proposals based on the previous research data.

First, driving eyeglasses or a vehicle window comprising anti-fatigue glass would prevent some of the elderly's eye fatigue. The focus and survey groups indicated that the main problem experienced while driving is eye fatigue and that it increases their driving difficulties, and as driving time increases, eye fatigue often causes headaches. Anti-fatigue glass is already produced in the current market, and it can lessen fatigue and prevent irritation and burning. If such a glass were applied to vehicle windows, it would lessen eye fatigue and reduce collision risk in elderly drivers.

Second, providing a massage seat within the vehicle can relieve neck and back pain. The focus group indicated that they experience decreased energy after driving for more than 30 min, and this was often caused or exacerbated by neck and back pain. Some people might say that young people have the same problem after a long period of driving. However, young drivers have higher basal-metabolic rates than the elderly and are generally less tired from excessive environmental situations like long-distance driving. Currently, few people are using the massage seat due to its significant cost and, as such, it is mostly only available in luxury vehicles. For example, in an Audi A8L, the massage seat adds $2000 to the price, and in a Jaguar XJL Supersport it adds $4000 (Gall, 2012). In order for the elderly to have an enjoyable and safe driving experience, car manufacturers need to offer the seats at a cheaper price point.

Third, an entertaining or soothing warning sound would be helpful for elderly people with hearing problems. The elderly focus group indicated that current warning systems sounds are confusing or jarring, often causing disorientation and increasing accident risk. However, a voice with detailed direction regarding how to proceed or what is wrong, or a unique sound for each warning, would reduce these risks.

Fourth, a steering wheel that vibrates when an accident is imminent would be beneficial for the elderly with reaction problems. The elderly group said that their late reactions caused accidents although current vehicle systems were installed in their cars. With this system, the elderly might be able to avoid dangerous situations.

4.3. Concept development of system features for the elderly

Based on the previous proposal, we conducted a user-defined system feature development at its concept level for elderly drivers. In this development process, driving eyeglasses and a vehicle windshield comprising anti-fatigue glass were excluded because the anti-glare material currently available in the market is not adequate for the design-development process. Therefore, a massage seat, entertaining warning sounds, and a vibrating-steering wheel were developed with diverse concepts. To determine whether the design concepts would be beneficial to elderly drivers, we asked the focus group to evaluate them by rating them on a scale of 1–5, with 1 being the minimum and 5 being the maximum. We asked them to rate the concepts using the following criterion: ease of use, frequency, and whether it was a good match for its intended user.

Furthermore, an interview session was conducted to evaluate the usefulness of the feature designs. The focus group was asked how often each person would use the design system if it existed and if they had suggestions for other design systems that would be more beneficial to aid safe driving.

5. Results

The data were collected from subjective system-concept ratings from the elderly focus group and the focus group suggestions from the interview. From these data, we finalized fine-design systems for elderly drivers which have the highest ratings in terms of their ease of use, frequency, and whether they are a good match for elderly drivers.

5.1. Designing a set of system features

To be properly designed for elderly drivers, the sets of system features were set by considering the elderly's conditions and with minimized drawbacks of previously proposed system features.

First, the massage seat's functions were designed to be focused on one body part, such as the shoulder, waist, and middle back because using a broad massage system over the entire back side of the user is very expensive. Thus, if we use the current massage system concept, the cost would be higher and possibly cost prohibitive for elderly drivers.

Second, a warning sound concept was divided into two sound options: a singing voice and a big siren sound with detailed directions that the elderly can easily understand.

Third, a vibrating steering wheel concept was systemized with two designs. With one, all wheel parts vibrate, and with the other the left or right side vibrates to indicate the direction of the danger. The potential system feature concepts are listed in Table 3.

5.2. Subjective ratings of the system features

After designing system feature concepts, the focus group rated them based on the defined criterion. The rating results are also in Table 3.

5.3. Finalized user-defined system features

After rating each system feature concept from the focus group, the final preferred system features were suggested. From the final systems, we can see how each system concept has affected the focus group conditions. The final system concepts are shown in Table 4.

First, using a massage seat focused on the shoulder area was selected by the focus group. The elderly focus group said that they mostly feel pain in shoulder or neck when

Table 3. Designed system concept evaluation.

Proposed systems for the elderly	Potential design concepts	Evaluation			
		Ease of use	Frequency	Fit for the elderly	Total
Massage function	Massage function on the shoulder	4	5	5	14
	Massage function on the middle back	4	3	2	9
	Massage function on the waist	4	3	4	11
Entertaining sound	Singing voice with detailed direction	4	3	3	10
	Big siren sound and voice with detailed direction	4	4	5	13
Vibrating steering wheel	Vibrating steering wheel on the whole part	4	5	5	14
	Partly vibrating steering wheel	4	5	4	13

they are driving. If the massage function on the shoulder were applied, they would feel more comfortable and could afford to buy it given its proposed economical price. Also, the massage function on the middle back and waist seemed to be a good fit as well, but the elderly drivers feel more tension and fatigue on their shoulders while driving.

Second, compared with the entertaining sound, a big siren sound and voice with detailed directions were more preferable for the elderly drivers because they would feel more serious about an emergency situation with the big siren sound than the singing voice. Specifically, the big siren sound would be very effective for elderly drivers because decreased hearing is one of the elderly's ageing symptoms. One elderly driver in the focus group said that the singing voice might be effective after using the system longer because they would remember the specific singing voice with a specific emergency situation, and then they would not need to fully listen to the voice explaining the situation.

For the vibrating steering wheel, the whole vibrating steering wheel was chosen from the focus group. The elderly stated that the left/right vibrating option might confuse them. They suggested that if a warning visual LED, directing their eyes to the potential accident location were located on the wheel, they would have safer driving on the road.

After finalizing the system feature concepts, a focus group interview was conducted to obtain their suggestions. During the interview, they suggested that if the massage function on the seat, the vibrating steering wheel function, and the big siren sound were integrated, the integrated system would be more beneficial for them. For example, when a potential collision situation arises, the shoulder massage function would activate along with the big siren sound. If these concepts were working at the same time, they would be more apt to recognize the situation and react faster. However, the elderly focus group said that if both massage and vibrating concepts were used at the same time, they would feel more confused.

Table 4. Finalized concepts.

Proposed systems for the elderly	Finalized design concepts	Feature
Massage function	Massage function on the shoulder	
Entertaining sound	Big siren sound and voice with detailed direction	
Vibrating steering wheel	Vibrating whole steering wheel part	

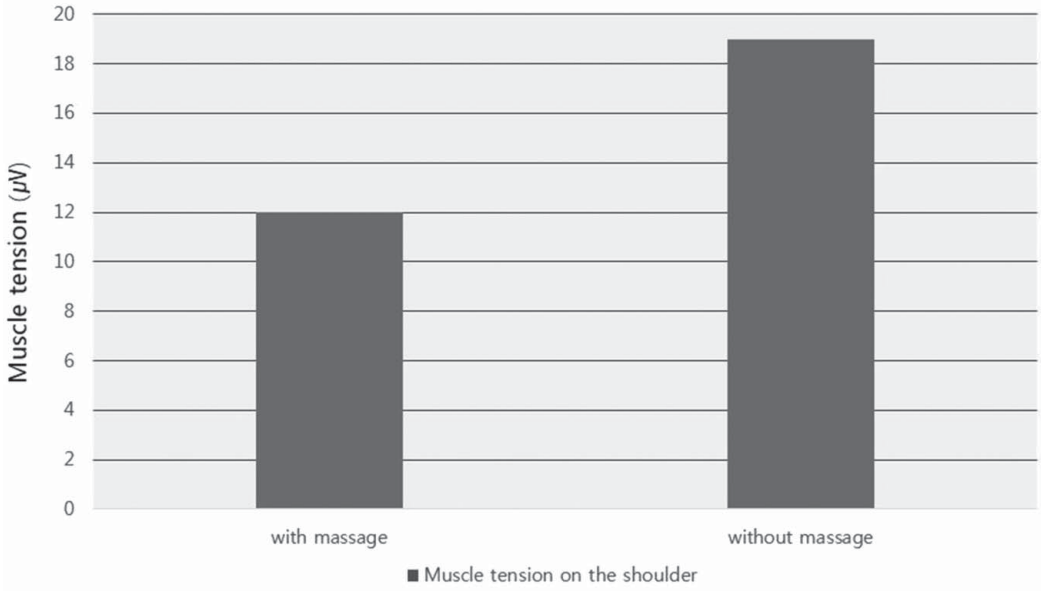

Figure 1. Muscle tension on the shoulder.

6. Validation

To validate how the system feature concepts can be beneficial to elderly drivers, we simulated a massage function on the shoulder area with the focus group members. Vibrating steering wheels and entertaining sound concepts were excluded because we determined that actual prototypes should be developed for this system concept validation since the concepts require a new vehicle-sensing system development.

First, we eliminated massage functions on other areas of the body so only the shoulder massage worked. Then, we asked three focus group members to drive a vehicle for 30 min with the massage seat installed and for another 30 min without the seat. After each test, electromyography (EMG) that evaluated and recorded the electrical activity produced by skeletal muscles was conducted on the focus group members to see how the massage function affected the shoulder and how it might relieve fatigue and pain (Kujit-Evers, 2007). According to Kuijt-Evers (2007), there is a relationship between comfort and EMG because relaxation could result in EMG-amplitude reduction, as the massage system could have a relaxing effect. For this reason, an EMG system was used to measure the elderly's comfort in this study. Additionally, a focus group interview was conducted to ask people how they felt about the massage function on the shoulder.

As a result, significant differences were found in the EMG check of the focus group. In driving with the massage function, the result of muscle tension was significantly lower -12–$19\,\mu V$ (see Figure 1). Also, the focus group said that they felt less pain and fatigue while they were driving, and their driving time could be longer with the massage function. Therefore, the validation result proves that the massage function on the shoulder area contributes to the elderly's driving comfort, and allows them to drive for longer periods of time.

7. Conclusion

In this paper, we analysed the drawbacks of existing systems and highlighted the significance of system design based on a particular user group, i.e. the elderly. We also surveyed 30 elderly drivers, held a specific focus group observation, and interviewed the group to identify their driving difficulties and gain insight into what type of safe driving systems would be most beneficial to them. Finally, we proposed and developed essential system concepts that the focus group needs and that could mitigate the elderly's accidents. However, a limitation of our study was that the user-defined vehicle system concepts for the elderly group were not fully tested with an actual vehicle system. The finalized system concepts could be changed from actual tests. In future work, we would test how the finalized concept works for the elderly group.

Acknowledgements

This vehicle system concept was developed with 30 elderly participants. The authors thank research participants for their contributions to help develop new driving concepts for the elderly.

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