Next generation automobile haptic seat: in inclusive way

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Abstract

Autonomous Vehicles will change the present driving paradigm and the car will be considered a 3rd living space, contributing to the social inclusion of the visually impaired.

This study aimed to develop a haptic seat to alert and inform passengers about certain situations on the road and define the perceived minimum, optimal and uncomfortable vibrational values to be considered when designing guidelines for the development of haptic devices.

An instrumented car seat with 10 actuators was developed, and an experiment was designed and applied to 39 participants, to determine the Ascending Minimum Threshold (AMT); Descending Minimum Threshold (DMT); Optimal Vibration (OV) and Discomfort (D), and study the relationship of these variables with gender, anthropometric characteristics, and age. Software for data collection was also developed.

This research found significant differences between men and women, regarding the MAT (female :24%, male: 26%), OV (female: 34%, male: 40%), and D (female: 47%, male: 60%), concluding that women showed greater sensitivity to haptic stimulation. Anthropometric measures and age also showed a correlation with the variables mentioned above. Therefore, this study suggests that differences between gender, anthropometric measures, and age of users, should be considered when designing haptic devices for car seats.

Keywords: Haptic seat; Human–Machine Interfaces; Haptic Perception; Autonomous Vehicles; Assistive Technology

1. Introduction

Autonomous Vehicles (AVs) will change the present driving paradigm, and the car will also be considered a 3rd living space due to the possibility of their passengers undertaking activities during commutes (such as reading, online meetings, or watching a movie) that were not possible to perform while driving.

Recent studies estimate that 1.3 billion people have some kind of visual impairment worldwide, 36 million are blind and 216 million have moderate to severe visual impairment. Although it has been suggested that the majority of visual impairment is avoidable, other factors such as the aging of the population might considerably increase the number of blinds and moderately or severely vision impaired up to 115 and 588 million people, respectively, by 2050 (Leo, Cocchi, Ferrari, & Brayda, 2020). This growing population may encounter several difficulties in their activities of daily living since we operate in highly visual contexts. Difficulty and fear of independent travel are one of the greatest disabling consequences of blindness. With time, this may cause fear of going out, leading to social problems such as isolation, anxiety, and depression (Ribeiro et al., 2015; Senra et al., 2015).

To ease these circumstances, in recent years, a variety of assistive devices have been proposed, such as refreshable Braille displays, screen readers, audiobooks, or smartphones with voiceover/talkback functions. In this context, technologies with haptic feedback have received increasing attention in the last years, since touch stimuli do not block or distort the sounds coming from the environment, which represent an essential input for blind users (Kim & Harders, 2020).

Haptic interfaces in the seat have been mainly targeted at conveying spatial information, warning signals, and coded information. Due to the efficacy of using the driver’s back as a receptor of spatial information, tactile applications in augmented seats have been greatly focused on providing navigational information (Van Erp and Van Veen, 2001; Hogema, De Vries, Van Erp, & Kiefer, 2009; Fitch, G. et al., 2012; Hwang, Ryu, & Chung, 2012; Breitschaft et al., 2019; SCHROTH Safety Products, 2020).

During this project, the representativeness of individuals with visual impairment, as well as the need to integrate this group with the future transport reality were considered. The aim of this study was to develop a haptic seat capable of alert and informing passengers about certain situations on the road and understand the perceived minimum, optimal and uncomfortable vibrational values, so that this information can be replicated to the visually impaired and constitute guidelines for creating these types of devices.

2. Materials and Methods

2.1. Research steps

This study was divided into four steps: I) Definition of the problem, II) Development of the Haptic Car Seat, III) Software development; IV) Experimental procedure and data collection and V) Data analysis.

2.2. Participants

During this experiment, the team recruited 39 test subjects, 20 males and 19 females, within the age range of 22 to 57 years old. Before the experiment, participants who had coats were asked to remove them, so that they would not interfere negatively with the results. Each participant signed a consent form agreeing to take part in the experiment. Participants were then asked to sit on the SAV seat, and the shoulder height sitting and the buttock popliteal length (seat depth) were recorded in order to evaluate the correlation between the anthropometric measures of the test subjects and the dependent variables under study. These measures were chosen as they represent the part of the human body that is in contact with the car seat. Participants' sex, age, height, and body mass were also collected.

2.3. Haptic Seat Development

For the experimental preparation a standard seat was used. The vehicle seat consists of seat pan and back support as illustrated in Fig. 1. It is also shown the locations where the vibration actuators were installed, underneath the seat's leader. A total of 10 actuators (motors) were installed throughout the whole seat contact area to produce the vibrations.

All the motors were from Vybronics, model JQ24-35F580C (see left side of Fig. 2), of type ERM, with a rated voltage of 5.0 VDC, rated current of 150 mA, 12.8 G@100g (RMS), and a frequency range of 0 to 42.5 Hz (or 0 to 2550 RPM). To prevent contact with the eccentric mass, a 3D printed shield was used (see Fig. 2 – right).

Fig. 1. Seat with the locations where the vibration actuators were installed (on the left), and the final setup (on the right).

Fig. 2. The motor from Vybronics, model JQ24-35F580C (on the left), and the 3D printed shield used to prevent contact with the eccentric mass.

A total of ten motors were used, controlled using a multi-driver board for ERM and LRA from Texas Instruments (model DRV2605LEVM-MD), in turn controlled by a Raspberry Pi 4, as illustrated in Fig. 3. One of these boards can control up to eight motors, hence, two boards were used: one to control six of the motors (B1 - upper left, B2 - upper right, B3 - upper center, B4 - lower center, B5 - bottom left, and B6 - bottom right, and another to control the remaining four (S1 - distal left, S2 - distal right, S3 - proximal left, and S4 - proximal right).

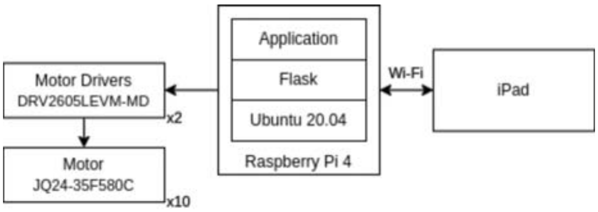

Fig. 3. Haptic Seat's simplified hardware and software architecture.

To measure the surface vibrations and thus have a real amplitude and frequency map of the produced vibrations (see Fig. 4), each actuator was fitted with an accelerometer on top of the seat leader, right above the installed actuator.

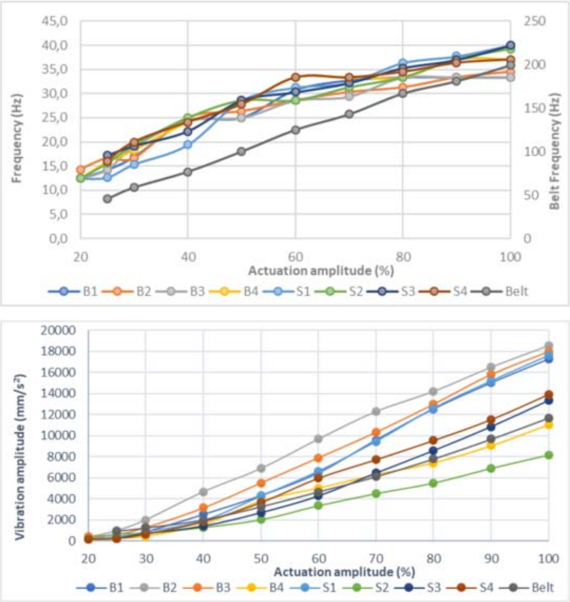

Fig. 4. Vibration frequency and vibration amplitude as a function of the actuation amplitude (0 to 5 VDC).

2.4. Software Development

A graphical user interface was developed, to run on an Apple iPad Pro, for the vibration intensities evaluation (see Fig. 5**Erro! A origem da referência não foi encontrada.**). This evaluation consisted in the identification of: i) the moment when the subject began to perceive the vibration, in a scenario that started with a low intensity but which was gradually increased (Ascending Minimum Threshold or AMT); ii) the moment when the subject stopped perceiving the vibration, in a scenario that started with a high intensity but which was gradually decreased (Descending Minimum Threshold or DMT); iii) the most comfortable vibration intensity to receive a warning (Optimal Vibration or OV); and iv) the vibration intensity considered uncomfortable (Discomfort or D).

As illustrated in Fig. 3, the iPad's web browser was used to access a web page hosted by a Flask web server running on the Raspberry Pi 4. As the subject interacted with the web page, the motors were controlled based on the current scenario. Inputs from the subject throughout the evaluation were saved for later analysis.

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Fig. 5. Graphical user interface developed for the vibration intensities evaluation.

2.5. Experimental procedure and data collection

As shown in Fig. 1 on the right, an experimental setup was developed in which the participant, wearing light clothes, sat on the car seat and evaluated the haptic stimuli. In this way, the steps taken in data collection are presented: 1- Recruitment of individuals of both sexes aged 18-65 years without comorbidities (Diabetes Mellitus, neurological diseases, or injuries) that could influence haptic sensitivity; 2- Signing the consent form to participate in the study (19 women and 20 men were recruited who agreed to participate voluntarily in the study); 3- Measurement of anthropometric data (Body Mass, Height, Acromion-Seat Distance, Gluteo-Popliteum Distance); A one-minute training phase, comprising a set of 4 vibrations with different intensities (15%, 20%, 15%, 20%) presented in random order were delivered by all 10 actuators (4 on the pan and 6 on the back) to the participant, which was instructed to acknowledge vibration by saying “yes” whenever a stimulus was perceived.

In the experimental phase, 10 actuators (4 on the pan and 6 on the back) were active at the same time for each stimuli presentation.

2.5.1. Minimum threshold

Method of limits: for this first part of the experiment, vibration intensity was varied manually by the experimenter to determine minimum thresholds. This procedure will include two tasks (A and B) as presented in Table 1:

Table 1. Task for determining the minimum vibration threshold.

Task A. (5 trials)	The vibration intensity is increased from 15% until the participant responds “detected,” by pressing a key. This procedure is repeated five times.
Task B. (5 trials)	Then, starting from the standard stimulus, intensity is decreased until the participant responds “not detected”. This procedure is repeated five times.

During the performance of Task A, and starting from 15%, the experimenter increases the vibration intensity at intervals of 1% until the test subject identifies orally that had recognized the vibration. Then the experimenter repeats this process five times. During the performance of task B, and starting from 30%, the experimenter decreases the vibration intensity at intervals of 1% until the test subject communicates that he/she no longer feels the vibration. The process was repeated five times. After the above-mentioned 10 trials (five trials for task A and five for task B), the average point was considered as the absolute minimum threshold of vibration intensity.

2.5.2. Optimal vibration intensity

The participant was introduced to a tablet interface where vibration intensity could be self-regulated through a slider (see Fig. 5). Then, the experimenter asked the participant the following question: “Which vibration intensity would be the most appropriate to alert a passenger that he/she must prepare to leave the vehicle, considering that he/she is close to the destination?”. The participant manually regulated the intensity of the haptic actuators and whenever he/she felt that an optimal vibration intensity was delivered, the confirm button was pressed on the tablet. The slider returned to the starting position and the participant repeated the procedure five times. No time constraints were applied.

2.5.3. Maximum comfort threshold

Using the previous setup, the participant was introduced to the maximum comfort threshold determination task. The experimenter triggered the task with the question: “Which vibration intensity will you describe as the maximum intensity you consider comfortable? Please adjust the slider to the vibration that you find comfortable and from which it becomes uncomfortable.”

Again, the participant manually regulated the intensity of the haptic actuators and confirmed a vibration intensity through a button on the tablet. The slider returned to the starting position and the participant repeated the procedure five times.

3. Results

Thirty-nine test subjects, 20 males and 19 females, within the age range of 22 to 57 years old participated in this experiment. The responses obtained are related to the percentage of electrical voltage (from 0 to 5 volts) applied to the motor that produces the vibration in the car seat. Results were analyzed for the minimum ascending threshold, the minimum descending threshold, the optimal vibration intensity, and the maximum threshold (discomfort). Anthropometric and socio-demographic characteristics were also considered (see Table 2).

Table 2. Minimum Thresholds (Ascending: AMT; Descending: DMT), Optimal vibration - OV, Discomfort - D, Anthropometric and Socio-demographic characteristics

Gender		AMT (%)	DMT (%)	OV (%)	D (%)	A* (years)	S* (cm)	BM* (kg)	ASD* (cm)	GPD* (cm)	BMI* (kg/m^2)
Female n:19	Average	23.7	16.4	35.5	48.4	38.0	161.9	57.4	50.8	45.5	21.9
	Median	24.0	17.0	34.0	47.0	36.0	161.0	56.0	51.0	44.0	20.8
	IR*	7.0	9.0	29.0	47.0	31.0	23.0	7.0	7.0	13.0	10.9
Male n: 20	Average	25.2	17.2	41.8	65.3	29.5	178.2	77.1	55.4	46.3	24.2
	Median	26.0	18.0	40.0	60.5	27.5	180.0	78.0	47.0	47.0	23.8
	IR	4.0	9.0	30.0	60.0	25.0	27.0	50.0	14.0	10.0	15.12

*Interquartile Range (IR); Age (A); Stature(S); Body Mass (BM); Acromion Seat Distance (ASD); Gluteo Popliteum Distance (GPD); Body Mass Index (BMI)

Data related to the minimum and maximum threshold as well as optimal vibration sensation did not show a normal distribution (Kolmogorov-Smirnov/Shapiro-Wilk, $p \leq 0,05$). Therefore, a non-parametric comparison test (Mann Whitney U Test) was performed in order to verify the differences between men and women for the variables Ascending Minimum Threshold, Descending Minimum Threshold, Optimal Vibration, and Discomfort. For the evaluated group, it was found that there was a difference in the following variables: Ascending Minimum Threshold ($p=0.005$), Optimal Vibration ($p=0.01$), and Discomfort ($p=0.001$). It was also noticed that the female group showed greater sensitivity to haptic stimuli in general.

Using Spearman's non-parametric correlation test, it was possible to identify in females a strong inverse relationship between the acromion-seat distance and the indication of optimal vibration (Cc: -0.700; $p = 0.001$) and moderate correlation for discomfort (Cc: -0.528; $p = 0.02$). Therefore, the greater this measure, the lower the percentage value of vibrations by the car seat. For males, there was a moderate positive correlation between height and the minimum ascending threshold (Cc: 0.577, $p = 0.015$), therefore, the higher the male individual, the higher the percentage value of vibration to start being noticed.

We also sought to understand the relationship between anthropometric data and haptic sensitivity, in which, for both genders, stature was shown to be the variable that exerted the greatest influence, with emphasis on the ascending minimum threshold ($p=0.001$) and descending minimum threshold ($p=0.034$).

This analysis demonstrated that there was a tendency for the influence of body mass on the sensitivity of the vibration produced by the car seat in an ascending way (p=0.058). However, a larger number of participants would be needed to identify the impact of this measure on vibratory sensitivity.

4. Discussion

Some studies have been carried out with the use of vibration in car seats in order to alert the driver to dangerous situations (Telpaz et al., 2015; Chang et al., 2011). However, there is little recent information about the haptic perception of individuals who are seated on these benches (Morioka and Griffin, 2008; Yong et al., 2011). The present study generated information related to this perception, with the objective of presenting a sensory output for individuals with visual impairments, a group of people who make up a high percentage of the world population (Leo, Cocchi, Ferrari, & Brayda, 2020).

Overall, the results obtained from this study seem to reveal important data regarding the perception of a haptic stimulus. Starting with the significant differences found between men and women, when evaluating Minimum Threshold, Optimal Vibration, and Discomfort. The study allowed to find that the female group showed greater sensitivity to haptic stimuli when studying the variables above mentioned. These results converge with the observed findings in haptic appreciation between gender demonstrated by Weinstein S. (1968). According to this author, women were significantly more sensitive than men to pressure sensitivity.

Regarding optimal vibration, the results of this study pointed to a variation between men and women of 34% to 40% respectively. When translating to motor action frequency in Hz (Fig. 4), it was noticed that these values varied between approximately 20 and 25 Hz. These values are in line with those proposed by Yong et al (2011) who demonstrated an optimal motor actuation frequency of approximately 26 to 34 Hz). Morioka and Griffin (2008) demonstrated that below 80 Hz of motor vibration, there is a more effective tactile appreciation on the surface of the body in contact with the seat than on the hands and feet.

Another finding of this study is related to the anthropometric proportion of the evaluated individuals, and it was possible to identify in females a strong inverse relationship between the acromion -seat distance and the indication of optimal vibration (Cc: -0.700; p = 0.001). Therefore, the greater this measure, the lower the percentage value of vibrations by the car seat. In contrast, for males, it was found a moderate positive correlation between height and the minimum ascending threshold (Cc: 0.577, p = 0.015), thus, the higher the male individual, the higher the threshold. These results seem to be aligned with the findings of Weinstein S. (1968) who concluded that males and females may show significantly opposite sensitivities for the same body parts.

This study contributes to the incremental knowledge of haptic perception, aiming to improve users' experience inside autonomous and non-autonomous vehicles. An important accessibility component was included in this study to support users with different types of visual impairments. In the end, the results of this project contribute to the definition of guidelines for the development of assistive technologies to be included in the context of autonomous and non-autonomous cars.

5. Conclusions

The goal of this study was to develop assistive technology to be applied in the context of the 3rd living space that could contribute to the social inclusion of the visually impaired but that at the same time could be used by all users. Following accessibility and inclusive design guidelines, and using multimodal solutions, a haptic seat was developed to determine the minimum and maximum threshold for perceived vibration, and the optimal vibration intensity that should be used in the warning "arrival approach" to be given by the seat to the passenger of the SAV.

Regarding gender, significant differences were found between men and women, regarding the Minimum Ascending Threshold (female: 24%, male: 26%), Optimal Vibration (female: 34%, male: 40%), and Discomfort (female: 47%, male: 60%). Also in the evaluated group, women showed greater sensitivity to haptic stimulation.

Regarding the anthropometric issues of the evaluated group, the greater the distance between the acromion and the bench surface, in the female group, the lower the vibratory percentage to reach optimal vibration and the sensation of discomfort. For men, the taller they are, the higher the percentage value of vibration starting to be noticed.

There was also a tendency towards a negative correlation between the age of the women and the vibration intensity that generated discomfort.

Therefore, this study points to issues to be observed in the construction of haptic stimulation devices installed in car seats, namely: the sensory differences between gender, the change in the perception of the stimulus as a function of the anthropometric characteristic, and the need to assess the age of users of this technology. As suggestions for future works, a study should be conducted in a real environment and with visually impaired participants. Moreover, a study should be conducted to understand the subjective evaluation of the vibration rhythms according to urgency and pleasantness, as well as the perception of the dynamic vibration applied in the seat.

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