The Blind Driver Challenge: Steering using Haptic Cues

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ABSTRACT
Loss of vision significantly impairs mobility, with blind individuals often relying on sighted individuals or public transportation to get around. Self-driving vehicles could significantly improve the mobility of blind people, but current legislation often requires a legal driver to be present in the vehicle who can take over in case of a malfunction. To enable blind people to eventually use a self-driving car independently, we present a steering interface that allows for steering a vehicle using haptic cues. User studies with six blind and sighted subjects identify what accuracy is required and possible using our interface to steer a vehicle on a track using a simulator. We investigate whether driving experience affects haptic steering performance and perform a qualitative study into the usability of our haptic steering interface.

Categories and Subject Descriptors
H.5.2 [HCI]: User Interfaces—Haptic I/O

Keywords
Haptics, Visual Impairment, Mobility, Steering.

1. INTRODUCTION
Reduced mobility and subsequent loss of independence severely reduces the quality of life for blind individuals and often leads to social isolation, depression, limited access to education, and fewer employment opportunities [14, 23]. Though various outdoor [28, 29] and indoor navigation systems [13, 17] have been developed, mobility is significantly constrained as these systems only support walking. To travel larger distances blind users often rely upon public transportation. Though public transportation is widely available in urban areas, in rural areas access may be limited. Blind individuals may also experience significant barriers due to a lack of accessible information pertaining schedules and announcements of stops [19]. Though more expensive, cars are considered a more usable form of transportation as they are not constrained to a fixed route and schedule.

In 2004, the Jernigan Research Institute posed the National Federation of the Blind’s “Blind Driver Challenge” [11], which challenged researchers and innovators to develop interface technologies that can empower blind people to drive a car independently as to increase their mobility. In recent years, several autonomous vehicles have been developed [10, 27], most notably, Google’s driverless car. In recent trials, autonomous vehicles have successfully been used by blind people to get groceries or food [6]. The blind driver challenge, however, aims to be more ambitious by including a role for a blind individual as a pilot beyond being a passenger who just provides a destination. This challenge aims to spur innovation by enabling a blind driver to make informed driving decisions, such as steering and maintaining speed, using a nonvisual interface that can convey real-time information about the environment [11]. There is another important reason to investigate how blind people can drive a vehicle: current legislation doesn’t allow blind people to use autonomous vehicles independently. Laws in both California and Florida require an licensed driver to be in the vehicle to take over control in case of a malfunction [1].

This paper makes the following contributions: (1) we improve a haptic steering interface developed in prior research [30] such to enable blind individuals to independently steer a vehicle on a track; (2) a comparative study with sighted and blind subjects identifies what accuracy is required for steering and what accuracy can be achieved with our haptic steering interface; and (3) we investigate whether prior driving experience affects steering performance.

Figure 1: A blind subject steering a vehicle in our simulator. Haptic actuators are placed on top of the hands that indicate either to steer to the left or right.
2. RELATED WORK

As part of the blind driver challenge [11], a team from Virginia Tech modified an autonomous vehicle developed for DARPA’s Urban Challenge [15] to allow for a blind user to drive this vehicle [24]. This system relies on an autonomous vehicle capable of determining its position on the road using GPS and a map of the environment with drivable roads. How much to steer is indicated using audio provided using a headset, e.g., sonification using frequency indicates the direction and magnitude of a turn. A modified massage chair provides haptic feedback to indicate speeding up or slowing down using a series of vibrotactors. A recent video shows their interface has been refined to convey steering cues using haptic feedback provided to the hands using an array of vibrotactors implemented in haptic gloves [7]. Beyond a number of public demonstrations, no results on the accuracy or usability of their interface are presented. This approach has a number of limitations: (1) many states ban the use of headsets that cover both ears while driving [3]; (2) audio provided using a speaker may be annoying for passengers to hear; and (3) haptic gloves are expensive to construct as these generally are not commercially available [31]. Haptic gloves also require the driver to be tethered using cables, which may not be desirable when the driver needs to exit the vehicle quickly, i.e., in case of an emergency.

In recent years there has been increasing interest in improving automotive safety using haptic interfaces. For example, lane keeping [18] or lane changing [26] systems are commercially available where haptic cues warn the driver of impeding danger. Haptic feedback has some desirable properties over other modalities in that it is private and doesn’t distract any passengers. Haptic feedback provided through a seat [21] or a belt may be impeded by the driver’s clothes, as receptors in a driver’s hips and back are not sensitive enough to distinguish complex stimuli [22]. Hands are very sensitive to haptic feedback due to an abundance of tactile receptors in the fingertips [8]. Haptic feedback provided through a steering wheel allows for robust and efficient communication of rich tactile information [24] as the driver is always holding it. Receiving feedback from the steering wheel itself may be more intuitive, as it may allow the driver to control the wheel using an associated physical mapping [24].

A number of haptic steering wheels have been developed. Enriquez [16] was one of the first to implement a tactile display in a vehicle context. Different types of warnings are conveyed through pulsations of varying frequencies on the driver’s hands by embedding inflatable pads in the steering wheel. User studies show a significant decrease in response time and demonstrate the feasibility of using frequency to convey different warnings. Griffiths and Gillespie [21] developed a driving simulator where the steering wheel is both held by the driver and motorized for automatic control. The motion of the steering wheel is a response to the sum of forces acting from the human grasp, from the automatic control motor, and from the steering linkage. Feeling the actions of the wheel, the driver can either comply with it or override it by applying more force. User studies show significant increase in the user’s lane keeping ability while decreasing the visual demand and reaction time. Kern et al. [24] present a steering wheel with six integrated vibrotactors to convey navigation information to the driver. Spatial cues on the wheel indicate to turn left or right. User studies evaluated the effectiveness of supplemental directional information in different modalities (audio/tactile) and found that haptic feedback impedes driving performance, with no significant effect for the other modalities. They further explored using dynamic patterns for conveying the steering direction, by sequentially activating vibrotactors in the direction the wheel needs to be turned. Qualitative results are reported with users preferring audio over haptic feedback. The “haptic steering wheel” [22] embeds 32 linear vibrotactors in a steering wheel, which allows for communicating information regardless of where the drivers hold their hands and further allows for displaying tactile illusions, such as sensory saltation. Spatial and temporal patterns (clockwise/counter-clockwise activation) are used to indicate whether to steer left or right, as well as to convey various types of alerts. User studies evaluate the user’s ability to distinguish different spatial encodings, stimulus times and tactile illusions. Kim et al. present a haptic steering wheel with 20 vibrotactors [25]. Turning directions are indicated using clockwise or counterclockwise activation of vibrotactors. User studies evaluate multimodal feedback for younger and elderly drivers and found significant improvement in performance for haptic feedback.

Previous Work. Glare significantly diminishes visual perception, and is a significant cause of traffic accidents. Existing haptic steering interface only communicate warnings or high level navigation instructions. In previous research [30] we developed a haptic steering interface that enables safe steering when visibility is temporarily blocked. Our interface consists of a vibrotactor implemented on the left and the right side of a steering wheel that conveys how far the steering wheel needs to be turned; a value that we calculate a priori for a given curve. Three user studies with 12 sighted subjects were performed, the first study tried to develop a better understanding of driving using visual feedback, the second study evaluates steering using haptic cues (no visual feedback) with two different haptic encoding mechanisms. A third study evaluates the supplemental effect of haptic feedback when used in conjunction with visual feedback. Studies demonstrated this steering interface to safely steer a vehicle through curves up to 45°. We also demonstrated that a driver’s lane keeping ability is improved when this interface is used in conjunction with visual feedback.
Figure 3: Steering cues are provided through a vibrotactor integrated in the left and right of the steering wheel. Drivers steer away from a cue felt in either hand, in order to find a dead-band window that indicates the target orientation of the wheel, which changes as the car drives through the curve.

3. STEERING INTERFACE DESIGN

Similar to the existing solution for the NFB driving challenge [21], we aim for our haptic steering interface to allow for steering a vehicle on a racetrack. We only focus on on the steering task rather controlling the speed of a vehicle, as steering is considered the most challenging part of driving a vehicle [30]. Though cruise control can be used to automatically maintain speed, a steering task must always be performed by a human driver (in most US states). Allowing blind drivers to adjust speed also makes it challenging to compare the performance of our steering interface between subjects. We therefore solve the steering problem independently from controlling a vehicle’s speed.

Our steering interface extends the interface we developed in prior research [30]. This interface aims to allow for safe steering when the driver is temporarily limited, e.g., due to glare. This interface is inspired by how rumble strips or Bott’s dots work. These raised markers or notches in the road provide a tactile sensation to a driver when they drift from their lane and when a haptic feedback is felt, intuitively drivers steer away from the side of the vehicle the tactile sensations are felt from. This interface exploits this natural mapping by integrating a vibrotactor in the left and the right side of a steering wheel. A preliminary study with steering using visual feedback found a linear relationship between the radius (r) of a curve and how far the steering wheel needs to be turned (T) [30]. For a given curvature we calculate (T) and when the driver enters the curve either vibrotactor is activated and the driver steers away from the side the vibrations are felt form until the haptic feedback stops and T is achieved (see Figure 3). When the driver approaches the end of the curve the target orientation of the wheel is reset to center and haptic feedback is provided accordingly. Because it is challenging to hold the wheel exactly at T, the car’s position will follow the shape of the curve, but not follow the lane’s median as it will deviate. Small lane deviations may be acceptable when the driver is only temporarily blinded and the driver can correct their position on the road when visibility returns.

For letting a blind person steer a vehicle, small deviations will accumulate and rapidly grow unbounded, with the car eventually leaving the track. A self-correction mechanism could help a blind blind driver steer the car back to the median of the track after a deviation occurs due to steering through a curve. In theory, this may allow a blind driver to safely steer a car around the track.

3.1 Self-Correction Mechanism

A self-correction mechanism was implemented as follows. We first calculate the target position X of the vehicle on the track’s median (see Figure 4). The current position of the car is point C, and the orientation of the car is vector \( \vec{R} \). Point P is the projection of C on the median of the track. After finding P, the target position X is found by adding a distance D on the median. When X or P are on a curve, D is the length of the arc between P and X. To keep calculations simple, we constrain the shape of our track to one that includes 180° circular curves. Then the angle \( \alpha \) between \( \vec{R} \) and \( \vec{X} \) is calculated. Haptic cues need to be provided such that the driver will change the current direction of the vehicle \( \vec{R} \) to \( \alpha \). To avoid small oscillations, a dead-band window of size \( \beta \) is implemented around \( \alpha \) (see Figure 4). The way haptic feedback is provided is significantly different from our previous interface [30] as the haptic feedback provision only considers the rotation of the steering wheel and not the actual position of the vehicle on the road. This interface specifically aims to avoid oscillations, where our improved...
interface relaxes this constraint, and we anticipate this will allow a blind driver to more closely follow the median.

If $\alpha$ is outside the window, haptic feedback is provided. We calculate the distance from the front left ($lx$) and front right ($rx$) of the car with point X. If $lx < rx$ we activate the right vibrotactor and otherwise the left vibrotactor. Similar to our prior interface [30] a simple on/off encoding was used as this yielded the best performance.

4. STEERING USING VISUAL FEEDBACK

We first conducted a user study with sighted subjects steering a vehicle on a track using visual information in order to establish a baseline to which the performance of our haptic steering interface can be compared against.

4.1 Instrumentation

![Figure 6: Layout of the Bristol Motor Speedway Track](image)

We created a simulator by modifying an open source driving simulator created in Microsoft XNA [5]. Drivers see a vehicle from a 3rd person perspective on a track (see Figure 6). We use this view as opposed to an overhead view as this view yields a significantly better driving performance [9]. We implemented the Bristol Motor Speedway [2], as shown in Figure 6. This track was chosen due to its relatively small size. We did not include any banking or speeding zones and used a fixed track width. Instead of using elliptic arcs, we used circular arcs, to avoid complex calculations for our self-correction mechanism. The four different segments of the track are illustrated with four different colors in the figure and henceforth the name of each cardinal direction is used to indicate each segment. Our track needs three parameters to be formed: (1) the length of the straight section L; (2) the width of the road W; and (3) the radius (R) of the circular sections E, W. To make it similar to the Bristol Motor Speedway, the parameters, L, W, and R, are assigned the values 200m, 6.1m, and 75m, respectively. The resulting track is 871m measured from its median, slightly longer than the 858m Bristol track. Barriers are placed in the inner and outer edge of the track.

For our user study, we use a constant speed to allow for a performance comparison between subjects. For a curve radius of 75m the department of transportation recommends a speed of 48km/h [4] but since our simulator doesn’t take into account friction, we set the speed of the car in the simulator to 50km/h. This value was also chosen as to have approximately 17 seconds of steering input required from the driver, while steering through the circular sections. For input, we used a simulator grade racing wheel, the Logitech G27 Racing Wheel, with an 28 cm diameter (see Figure ??) that was attached to a desk. Every 10ms, we log the position of the car and the position of the steering wheel. Drivers don’t control the speed of the vehicle but start the vehicle by pressing the gas pedal peripheral once with their foot which will cause the car to immediately drive at the target speed. To indicate whether car is moving or waiting for a subject to push the gas pedal, an engine sound is used. We use a short audio file that is played in a loop, and which does not convey any information about the performance of steering.

4.2 Participants

We recruited six sighted individuals (3 females, average age 31.3, SD=12.5). All were right handed and none reported any non-correctable impairments in perception or motor control. On average, participating subjects had 12.3 years (SD= 13.3) of driving experience.

4.3 Procedure

Subjects were invited into our lab and seated in front of the steering wheel with the pedals placed under their feet. A 27” display was used to show the simulator in fullscreen mode. Subjects were asked to drive on the median of the track, but we did not render any stripes to indicate the median. Subjects were allowed to try a few laps for practice as to minimize any learning effects and when they felt comfortable enough, the trial would start. The start of the track is located in the middle of the north section. The car is po-
Table 1: Steering using visual feedback (stdev)

<table>
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<th>DIRECTION</th>
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<th>DEVIATION (M)</th>
<th>AVG CRASHES</th>
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<td>Straights</td>
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sitioned in the middle of the start line, facing east or west. Initially the car stops and as soon as the driver hits the gas pedal once, it accelerates to 50 km/h. After 4 laps, the car is stopped and teleported to the start position but facing in the opposite direction from which it started. When the car hits the barrier, a crash sound is played and the car stops and turns to the target point calculated in the last frame before the crash. When car is stopped due to a crash or when changing directions, the driver is required to hit the gas pedal again to get the car driving again, which is indicated using speech. Subjects completed 8 laps; which included 4 clockwise and 4 counter-clockwise laps. The order of direction was randomized between subjects. It took ±10 minutes to complete the trial.

4.4 Results

For every single trial, we calculated the standard deviation of the vehicle from the median of the track, for the curve, the straight part as well as the complete track, split up by clockwise and counterclockwise laps. Table 1 shows the result of this experiment. In addition to the standard deviation, we also list the average number of crashes per subject. We achieve an overall average standard deviation from the median of .63 meters (SD=.08). For an α of .05, there was no difference in standard deviation between curves and straights \( t_{10} = 1.027, p = .33 \) and between clockwise and counterclockwise laps \( t_{10} = .978, p = .35 \). None of the sighted subjects crashed.

5. STEERING USING HAPTIC CUES

A second user study with blind and sighted users focused on analyzing the performance and accuracy of our steering interface and to determine whether prior driving experience of sighted users would lead to a difference in performance. A brief qualitative study was performed with blind users to understand the usability and usefulness of our steering interface and to collect suggestions for improvements.

5.1 Instrumentation

We used the same steering wheel and setup as for our first experiment. For haptic feedback provision, we used a commercially available wireless motion-sensing controller (Sony Playstation Move), which has an integrated vibrotactor that allows for frequency modulation with a perceivable range of 91 to 275Hz. Similar to our prior interface, a controller was attached to each side of the steering wheel using tape. Preliminary trials with using this setup showed that it was sometimes difficult for users to interpret which vibrotactor was active due to resonation problems. Tactile resonance may be avoided by modifying the steering wheel and embedding vibrotactors in each side using a proper amount of insulation. We ended up with an alternative solution that mitigates the resonance problem by mounting the Sony Move controllers to the back of the subjects’ hands using straps. The simulator communicates with the Sony Move controllers using a Bluetooth connection. When connected, the Move controllers LED light up using a different color as to distinguish each controller, but this does not convey any other visual information. For the self-correction mechanism a number of parameters, such as \( D, \beta \) were determined experimentally. For \( D \), we experimented with different values of \( D \) and found that a tradeoff needs to be made between requiring very fast responses from the driver (as it will steer quickly to the median) versus significantly increasing the average deviation from the median (as it takes longer for the car to reach the median). We ended up choosing a value (15.9m) based on how far the car travels in 1 second (13.9m) plus some small offset (2m) to accommodate for the length of the car as we calculate the position of the car from the center of the car. Using a number of preliminary trials with different values, a value of \( 6^\circ \) for \( \beta \) was found to yield the smallest average deviation. Because there is a small delay before each vibrotactor is activated, haptic cues are provided 380ms ahead of when the user must steer in order to accommodate this delay. This value was determined experimentally. We use a simple on/off cue with haptic feedback provided at a frequency (275Hz) that the human skin is most sensitive to. Every 10ms, we log the position of the car on the track, the position of the steering wheel and when a vibrotactor is active.

5.2 Participants

A between subject study was performed with sighted and blind subjects to test whether there was a difference in performance due to driving experience. We recruited six sighted individuals (2 females, average age 26.3, SD=2.0). All were right handed and none reported any non-correctable impairments in perception or motor control. On average, participating subjects had 5.8 years (SD=3.8) of driving experience. Our second group of subjects included blind individuals recruited through a local chapter of the National Federation of the Blind. An inclusion criterion for our study was that subjects were blind with no prior driving experience. We recruited six subjects (2 females, average age 46.0, SD=12.5). Five subjects were totally blind with one being legally blind. All were right handed with no impairments in tactile perception or motor control. None of the blind subjects had any driving experience or had used a driving simulator before.

5.3 Procedure

Subjects were invited into our lab and seated in front of the steering wheel and the pedals of the racing wheel kit were placed under their feet. A Sony Move controller is attached to each backhand using their fabric straps (see Figure 1). The display was turned 180° and was only visible to an observer who was present during the trial. Prior to the trial, we explained to subjects how to interpret the haptic feedback, e.g., feel a cue on your left turn right, and we gave feedback on their performance during the familiarization phase. We encouraged subjects to steer using small turns and immediately steering back to neutral as not to oversteer. Both
subject groups were allowed to try a number of laps for practice as to minimize any learning effects and when they felt comfortable enough, the trials would start. Subjects completed a total of 8 laps; which included 4 clockwise and 4 counter-clockwise laps. The order of direction was randomized between subjects.

5.4 Results

The standard deviation from the track’s median was calculated and reported in the same way as for our first study. Table 2 and Table 3 shows the results for the sighted and blind subjects, respectively. In addition to the standard deviation, we also list the average number of crashes per subject. For the sighted subjects, one subject crashed three times, one subject twice, one subject once and three subjects did not crash. Crashes seemed uniformly distributed over the laps, with 83% of crashes occurring in curves. Two blind subjects crashed twice, and three subjects only once and one didn’t crash. 57% of crashes occurred in the first lap and 71% were in curves. Only a single crash occurred in the last three laps. For the standard deviation, no significant difference (sighted/blind) between the curves and the straight parts \((p = 0.173/0.454)\) and between directions \((p = 0.269/0.077)\) was detected. For the average number of crashes, no significant difference (sighted/blind) between the curves and the straight parts \((p = 0.128/0.383)\) and between directions \((p = 0.173/0.705)\) was detected. Because of these results our analysis focuses on the combined standard deviation and the average number of crashes for the whole track. A one-way MANOVA found no statistically significant difference in steering performance (standard deviation, crashes) between sighted and blind subjects \((F_{2, 9} = 0.616, p = 0.562, \text{Wilk’s } \lambda = 0.880, \text{partial } \varepsilon = 0.120)\). There was homogeneity of variances, as assessed by Levene’s Test \((p > 0.05)\). A statistically significant difference in standard deviation \((t_{10} = 4.433, p = 0.0013)\) was found between blind subjects and sighted subjects driving using visual feedback, e.g., the results from our first study.

We also analyzed reaction time between both groups of subjects, e.g., the time between when a haptic cue was provided and when the driver started to turn the steering wheel or adjust the direction in which it was turned. Using the log files, we calculated an average response time of 269 milliseconds (SD=52) for blind and 350 ms (SD=50) for sighted subjects. There was a statistically significant difference between these response times \((t_{10} = 2.734, p = 0.021)\).

5.5 Qualitative Results

Qualitative experiences from blind subjects were collected after the trial using non-directed interviews. The usability and effectiveness of our haptic steering interface was evaluated using a 5-point Likert scale that ranged from 1 (strongly disagree) to 5 (strongly agree). All subjects expressed that they really enjoyed using the driving simulator \((M=4.83, SD=0.41)\) with three of them stating that this was the first time they had ever driven a simulator. Five subjects found that our haptic steering interface was easy to learn to use \((M=4.50, SD=1.89)\) with one subject stating that the haptic interface by itself was difficult to learn to use, but that the verbal instructions were essential in learning how to use it. All subjects agreed that our interface allows for accurately steering a vehicle on a track \((M=4.67, SD=0.52)\). All subjects agreed that the haptic mapping used to convey steering directions was intuitive and comfortable \((M=5.00, SD=0.00)\), though one subject noted that an inverse mapping could also have been used. Another subject stated that using a stronger vibration could probably improve performance. All subjects thought our interface could eventually be used for steering a real vehicle \((M=4.67, SD=0.52)\), but two subjects admitted they were unsure how to answer this question, as they had never driven a vehicle.

Open-ended questions were used to collect suggestions for improvements, which included \((\# \text{ of subjects that made this comment})\): (a) Allow for controlling the speed of the car and shifting gears \((3)\); (b) Support driving in more realistic \((\text{non-track})\) environments, e.g., a city \((3)\); (c) Use frequency modulation to indicate how far to steer \((1)\); (d) Add opponents to race against \((2)\); (e) Add more tracks with more difficult curves that include hairpins and chicanes \((2)\); and (f) Verbally announce the lap time or a score \((2)\). The last three suggestions seem to imply that we turn the driving simulator into a racing game, in which two subjects were very interested in.

6. DISCUSSION

Comparison. we are unable to make a performance comparison between our approach and the existing solution for the Blind driver challenge [21] as no quantitative results on the accuracy of their steering interface are reported. However, public demonstrations have demonstrated it to be effective in a real vehicle. Our previous haptic steering interface [30] achieved an average standard deviation of 2.97m (SD=1.720) for a 180° curve. Our improved interface achieves an average standard deviation of .97m (SD=.17), which demonstrates that a self-correction mechanism significantly reduces deviation. Our first study with sighted drivers steering using visual feedback yields an average standard deviation of .63m (SD=.08) which was significantly
lower than the average standard deviation achieved using haptic feedback. Sighted drivers that drove using visual feedback did not crash at all, where blind drivers mostly crashed in the first laps (only 1 crash in the last 3 laps) and this number could further decrease when blind drivers become more proficient with our interface over time. Given that in the US lanes have an average width of 3.7m and that cars have an average width of 1.83m, we believe the standard deviation achieved with our haptic steering interface would allow for safe driving. Regular roads rarely involve curves and steering through smaller curvatures should reduce deviation.

Limitations. Our haptic steering interface was tested in a simulator and not in a real vehicle. However, for designing a suitable interface, a simulator has a number of benefits as it allows for accurately measuring the position of the vehicle on the track and we don’t have to worry about serious consequences when a driver crashes their vehicle. Because we were interested in testing whether prior driving experience would affect haptic steering performance, subject recruitment was restricted to recruiting blind subjects without any driving experience, which we found were difficult to recruit. Driving a vehicle involves much more than just steering and we did not evaluate controlling the speed of the vehicle or the detection and avoidance of obstacles (e.g., other cars/pedestrians).

Differences. We detected a significant difference in response time to haptic cues between sighted and blind drivers, which confirms the observation that blind individuals have a greater sensitivity to haptic feedback, due to the so called plasticity effect [12]. No significant difference in haptic steering performance between sighted and blind users was found, which seems to support our claim that prior driving experience has no effect on using our steering interface. However, because steering using haptic feedback is significantly different from steering using visual feedback, it could be that there are no transfer effects between these modalities. Alternatively, prior driving experience does affect haptic steering performance but this effect is neutralized by that blind drivers responded faster to haptic steering cues. It is difficult to answer this question, as individuals that are blind that have recent (< 5 years) driving experience may not have developed a greater proficiency to haptic feedback as cross-modal plasticity typically takes years to develop [12]. Users studies with blind drivers with recent driving experience may or may not show a significant improvement in steering performance when compared to blind drivers without prior driving experience.

7. FUTURE WORK

We will focus on integrating and evaluating our haptic steering interface in an autonomous vehicle and in more realistic driving environments, but this requires solving a number of problems. Currently our interface enables a blind driver to steer using small oscillations, which helps the vehicle stay close to the median. To an outsider however, the vehicle looks like it is swerving and the driver may appear inebriated, which may be socially undesirable. This study only focused on steering but we also need to inform drivers when to adjust their speed or stop the vehicle. Driving a vehicle on a track is a relative simple task for an autonomous vehicle and driving a vehicle in traffic is much more challenging as this requires detecting other cars and pedestrians.

Autonomous vehicles are capable of detecting other cars and obstacles but current legislation requires a legal driver who can take over in case of a malfunction [1]. If an autonomous vehicle breaks down, we may not be able to use its sensors to determine the vehicle’s position and other traffic. To allow a blind driver to drive their car to a service point, we can imagine our haptic steering interface to evolve into a rudimentary backup system that uses its own set of sensors. A benefit of our system it is relatively low cost to install: vibrotactors do not need to be embedded in the steering wheel but external vibrotactors, i.e., such as those available in motion sensing controllers could be used that can be worn by a blind driver. An approximate orientation of the steering wheel can also be found using the controllers’ internal gyroscopes, which avoids having to fully integrate our system with the car’s system.

The suggestions posed by two blind subjects to develop our simulator into a fully-fledged racing game is something that we will consider for future research, especially considering that very few games are accessible to blind gamers [12]. In addition to adding different tracks, adding controls for speed and allowing the driver to shift gears, (multiplayer) opponents could be added, but this would require conveying much more information than steering information alone.

8. CONCLUSION

The development of a vehicle that can be driven independently by blind users has great potential to significantly increase their mobility and quality of life. Current legislation, however, requires a licensed driver to be present in the vehicle to take over control in case of a malfunction. This paper presents a haptic steering interface that allows blind people to steer a vehicle on a track. Our work innovates over existing work, in that we improve an existing haptic steering interface and we identify what accuracy is required—and possible– for steering using our haptic interface. We identify that prior driving experience does not affect the performance of haptic steering with no difference in performance found between sighted and blind subjects. Blind drivers respond faster to haptic cues than sighted drivers. Results of this research could eventually allow for blind people to use autonomous vehicles independently.

9. ACKNOWLEDGEMENTS

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10. REFERENCES


