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Abstract

Safely operating vehicles require significant visual attention. While attention can be divided, cognitive resources are not limitless. Deaf and hearing participants engaged in a simulated driving task while simultaneously engaging in a conversation in their preferred language. Results indicated that hearing drivers may have a performance advantage over deaf drivers, though it is so minor that it will not likely be seen outside of the laboratory setting. The results also indicated differing cognitive processing among hearing and deaf drivers. The results may inform policy, reduce stigma, and serve as the base for future research on deaf-specific cognitive factors of driving.

Keywords: suicide, substance use disorder, mental illness

Introduction

Research in driver distractibility provides valuable information on driving safety in the general population. While this has been a well-covered area in the literature over the past decade (see National Transportation Safety Administration, 2009), few studies have explored the impact of multiple driving distractions on individuals with hearing loss. This lack of empirical attention has created misinformation about the driving abilities of persons who are deaf and subsequent stigma against deaf drivers and extraneous traffic policies (Hersh, Ohene-Djan, & Naqvi, 2010). A goal of the current study was to address this gap in the literature. The results may inform policy and industry regulations regarding the abilities of deaf drivers and reduce stigma against drivers with hearing loss.

Most drivers engage in casual spoken conversations with their passengers. However, unlike individuals with average hearing abilities who typically converse through spoken language, many deaf individuals rely on visual-manual communication (e.g., American Sign Language [ASL]), when communicating with their passengers. Is conversing with a passenger in sign language more distracting for a driver than conversing with a passenger in a spoken language? Until now, the impact of using a signed language while driving has not been empirically investigated.

It is generally accepted that deafness is not a significant risk to driving as it is a primarily visual task (Sivak, 1998). In fact, although driving ability may be augmented by the auditory, olfactory, and tactile senses, vision is the dominant sense and accounts for about 90% of driving behaviors (Hills, 1980). Indeed, the Department of Transportation (1993) found that situations where hearing may be important (e.g., exterior warning sounds, such as sirens or mechanical failures within the vehicle) are considered atypical and, even then, are not always attended by drivers with average hearing levels. In fact, some research indicates that deaf drivers may have some advantages over hearing drivers (see Adams, Goodman, Howard, Lee, & Yates, 2010; Songer et al., 1992).

Some differences have been found in visual processing between hearing and deaf individuals. For example, deaf adults appear to allocate their visual resources across a wider range than do hearing adults (Bavelier, Dye & Hauser, 2006; Bosworth & Dobkins, 2002; Sladen, Tharpe, Ashmead, Grantham, & Chun, 2005) and detect the onset of peripheral visual targets faster than do hearing controls (Bavelier et al., 2006; Chen, Zhang, & Zhou, 2006). However, there is debate on whether these differences are solely due to prolonged sensory deprivation (Bottari et al.,, 2008), the combination of exposure to a signed language and sensory deprivation (Bavelier et al., 2006), or whether there exists a significant difference in divided attention abilities between hearing and deaf adults (Bosworth & Dobkins, 2002). These apparent differences in visual processing between hearing and deaf individuals may impact the driving ability of deaf adults, particularly given their heightened sensitivity to peripheral stimuli (e.g., passengers).

The current study examined Treisman's (1964) attenuation model, which described attention as a cognitive process that occurs in a simultaneous manner. Attention can be primarily directed towards one behavior (e.g., scanning the road ahead) while still providing cognitive control towards other secondary behaviors (e.g., shifting gears: Treisman, 1964). Contemporary research supports this model as the predominant means of describing attention (see Wickens, 2002, for a review).

While attention can be divided, cognitive resources are limited. Treisman and Davies (1973) found that the limits of attention are reduced when multiple channels of information are presented to one sensory modality. Cognitive resources are taxed if one must attend to two tasks using the same modality (e.g., dialing a cell phone while maintaining focus on the road). A similar task that allows for more cognitive control would be to focus on the road (visual-spatial modality) while using voice recognition software to dial a number (verbal-aural modality). To compensate for this reduced cognitive control, drivers may utilize a variety of techniques while dividing attention, such as reducing the vehicle's speed or increasing the distance between them and the car ahead to maintain adequate driving performance (Rakauskas, Gugerty, & Ward, 2004; Strayer & Drews, 2004).

Applying the Treisman and Davies (1973) results to the current study, individuals who communicate using a signed language (visual-spatial modality) while operating a vehicle (visual-spatial modality) should perform less well than individuals who communicate using a spoken language (verbal-aural modality) while operating a vehicle (visual-spatial modality). That is, drivers who use a signed language will be dividing cognitive resources within the same modality and be more cognitively taxed than drivers communicating with a spoken language. The objective of the current study was to examine Treisman's (1964) attenuation model and investigate how a visual-manual mode of communication (i.e., ASL) impacts the driving performance of deaf drivers. Using a simulated driving task and computerized tests of visual attention, the current study represents a significant leap forward from previous research that primarily utilized anecdotal information to explain differences between deaf and hearing drivers.

Method

Participants

All information pertaining to inclusion and exclusion criteria were obtained by participant report. The inclusion criteria for all participants were: a) between 18 and 30 years of age; b) a valid driver's license from any U.S. state; and c) right-hand dominance. The exclusion criterion for all participants was any biological disorder that affects motor coordination (e.g., macular degeneration, retinopathy, Usher Syndrome).

The inclusion criteria for deaf participants were: a) a conductive or sensorineural hearing loss of 70 dB or greater in the better ear before the age of seven years; b) acquisition of a signed language before the age of seven years (i.e., ASL, Signed Exact English, or Manually Coded Language); and c) ASL as the primary mode of current communication.

The inclusion criteria for hearing participants were: a) acquisition of spoken English before the age of seven years; and b) spoken English as the current primary mode of communication. The exclusion criteria for this group were: a) any documented hearing loss; and b) history of using any form of signed language to communicate.

Materials

The Useful Field of View Test (UFOV), developed by Visual Awareness, Inc. (2007) and the U.S. Department of Transportation, is a valid and reliable computerized test that measures speed of visual processing and the ability to attend to stimuli through tasks that become increasingly more difficult and rapid in presentation. The test provides data to help predict driving safety and measure crash risk. The UFOV is a reliable measure of crash risk prediction in that crash risk increases as the visual field decreases (Ball, Owsley, Sloane, Roenker, & Bruni, 1993).

SimuRide Commercial Edition is a driving simulation software program produced by AplusB Software Corporation. An Acer laptop computer with an Intel Dual-Core i5 Chipset, running at 2.25GHz, with 4 GB of DDR3 RAM (1066 MHz), and a 500 GB SATA hard drive operated the SimuRide program. The system utilized the 64-bit version of Windows 7 and had a 15.6 inch CineCrystal HD widescreen display, with dimensions of 1366 X 768 pixels. The SimuRide software comes equipped with a steering wheel, gas pedal, and brake pedal. It consists of software that allows drivers to independently interact and maneuver through a virtual driving environment. SimuRide produces a report of data at the end of each session with minute-by-minute information regarding driving errors (e.g., exceeding the speed limit, not stopping at posted stop signs).

Select items from the Reading Fluency subtest of the Woodcock-Johnson-III Tests of Achievement were utilized for the present study. For the purpose of the current study, 30 yes/no sentences from the Reading Fluency subtest were used. The researchers, fluent in English and in ASL, selected the sentences based on the ease with which they could be translated into ASL. The sentences were converted from the standard paper assessment to an actor who spoke the sentences in spoken English or signed the sentences in ASL. During the administration, the actor was seated to the right of the participant to simulate the positioning of a driver and passenger.

Procedure

Participants first completed a brief demographic and driving history questionnaire. They then completed the UFOV or the SimuRide assessment which were counterbalanced to remove priming effects. The examiner presented the instructions to each participant in spoken English or ASL. For the SimuRide assessment, the participants were instructed to position themselves in the driving chair (in front of the computer monitor) as if they were driving an automobile. A paid actor was seated to the right of the participant; the actor was present to administer the distracter stimuli during Phase III of the assessment. Following the instructions, the participants began the 12-minute simulated driving course. Minutes 1 and 2 (Phase I) were used as a practice session where the participant became acquainted with the driving simulation task. Minutes 3 to 7 (Phase II) collected the data under focused attention task (only driving, no distracters). Minutes 8 to 12 (Phase III) collected data under the divided attention task (responding to the actor's yes/no questions while driving). The examiner was present during all tasks in order to note any behavioral observations.

Results

Demographics

Fifty-five participants volunteered for the study, though five were excluded from the data analysis. Two deaf participants were excluded because they indicated that their current preferred language was other than ASL (an inclusion criterion). An additional three deaf participants were excluded because they did not follow the researchers' instructions during the driving simulation assessment. The two groups were composed of 25 hearing and 25 deaf participants (see Table 1).

Table 1
Participant Demographics

		Deaf Group	Hearing Group
Age	Mean (SD)	21.44 (2.8)	19.16 (1.7)
Age of Driver's License Acquisition	Mean (SD)	16.84 (1.5)	16.64 (.7)
Corrective Lenses	Mean (SD)	1.68 (.48)	1.60 (.5)
Gender	Male	4	15
	Female	21	10
Race	Caucasian	21	23
	African American	2	0
	Asian	1	1
	Other	1	0
Auto Accidents	1	6	5
	2+	1	3
Moving Violations	1	6	8
	2	2	2
	3+	3	3
Hours Driven (Week)	Less than 1 hour	6	10
	1-5 hours	14	9
	6+ hours	5	6
Hours Driven (Weekend)	Less than 1 hour	5	10
	1-5 hours	14	13
	6+ hours	6	2
Area Commonly Driven	City	11	10
	Suburbs	8	12
	Small Town / Rural	6	3

Neuropsychological Factors

All participants scored in the "normal" range of functioning on each subtests of attention measured by the UFOV (i.e., Visual Processing Speed, Divided Attention, and Selective Attention), indicating a low likelihood of crash risk. No between-group differences were found in Visual Processing Speed, $F(1,48) = 1.0, p > .05$; Divided Attention, $F(1,48) = .64, p > .05$; or Selective Attention, $F(1,48) = .03, p > .05$: see Table 2, below.

Table 2
UFOV Scores

	Deaf Group Mean (SD)	Hearing Group Mean (SD)
Visual Processing Speed	16.7 (0.00)	20.03 (16.66)
Divided Attention	18.56 (8.65)	21.63 (17.08)
Selective Attention	69.11 (29.48)	67.39 (37.47)

Note: Scores in milliseconds. No significant differences at the $p < .05$ level.

Driving Simulation

The driving simulation was divided into two primary phases. The first phase required the participants to navigate a driving course without distraction. The mean number of driver-performed errors during this phase of the simulation was 1.76 (SD = 1.27) and 1.32 (SD = .85) for the deaf and hearing groups, respectively. No between-group difference in the number of errors performed was found, $F(1, 48) = 3.14, p > .05$.

The second phase of the driving simulation required participants to engage in a conversation with a mock passenger while navigating the driving course. The mean number of driver-performed errors during the second phase of the driving simulation was 1.72 (SD = .79) and 1.16 (SD = .89) for the deaf and hearing groups, respectively. A between-group difference in the number of errors made was found, $F(1, 48) = 0.28, p = .02$. This result indicates that the participants in the hearing group made significantly fewer errors than the participants in the deaf group, supporting the study hypothesis. However, the data indicated a very minor effect size, $\eta p = .10$, indicating that the between-group difference was quite small and would be unlikely to occur outside of a laboratory setting.

A review of the data indicated that deaf participants appeared to make more speeding violations than the hearing drivers during the second phase of the driving simulation, $F(1, 48) = 5.47, p < .05$; see Table 3. It appears that the driving simulation's auditory speeding cues (i.e., a high-pitched engine roar as the vehicle's speed increased) may have been a factor in this difference because the deaf participants were unable to hear this sound. To examine this observation, the speeding errors were removed from the driving simulator error record and the groups were compared again. The results indicated no significant difference in driver errors between the groups, $F(1, 48) = 0.95, p > .05$.

Table 3
Speeding Errors by Group

	Frequency Deaf Group	Frequency Hearing Group
1 Error	6	8
2 Errors	5	0
3 Errors	1	0
Total Errors	19	8*

Note: * Indicates significant difference at the $p < .05$ level.

The difference in driver errors between the first and second phases of the experiment was examined to assess for within-group differences. No significant differences were found for the participants in the deaf group, $t(24) = 0.13, p > .05$, or for the participants in the hearing group, $t(24) = -1.95, p > .05$. These results indicate that driving and communicating to a passenger in one's preferred language (ASL or spoken English) is no more distracting than driving alone.

The participants' accuracy of responding to the mock passenger's statements was examined. The total number of errors made was 85 and 13 for the participants in the deaf and hearing groups, respectively. The mean number of response errors made by the participants in the deaf and hearing groups were significantly different, $F(1, 48) = 10.57, p < .001$, indicating that the hearing participants were paying more attention to the passenger's questions than were the deaf participants.

Discussion

The objective of the current study was to investigate the performance effects of engaging in a conversation while driving; the focus was to examine differences in driving performance between deaf drivers who communicate in a signed language and hearing drivers who communicate in a spoken language. Results indicated that driving performance does not appear to differ between deaf drivers who engage in signed conversations with their passengers and hearing drivers who engage in spoken conversations with their passengers.

Sample Distribution

The small sample sizes of each group did not allow this study to assess for differences using any statistical procedures; however, the two groups appeared to be mostly similar, though different in a few areas. A brief driving history was collected from each participant to assess for differences in collisions, moving violations, age of driver's license acquisition, hours driven per week, and areas commonly driven. The results revealed no clear differences in any of these variables between the deaf and hearing groups. Differences were found regarding the gender of the two groups. The participants in the deaf group were more likely to be female when compared to the hearing group. This was not surprising given the composition of the deaf population at the university research site which has a female majority (Gallaudet University, 2009). Lastly, one of the most important determinants of the sample distribution was the UFOV assessment, which aims to predict driving performance (Visual Awareness, Inc., 2007). The results of the current study showed no differences on any of the three UFOV subtests between the deaf and hearing groups. Further, the results indicated that no participants met the critical level for automobile crash risk. These results suggest that the two groups showed no significant differences in their predicted driving performance, consistent with previous research on deaf and hearing drivers (Adams et al., 2010).

Driving Performance

The primary focus of the current study was the performance effects of deaf drivers who engage in signed conversations with their passengers.

It was hypothesized that the hearing drivers would produce significantly fewer errors than the deaf drivers during the distraction phase of the driving simulation. This was based on Treisman's (1964) theory of attentional capacity and supported by the research conducted by Treisman and Davies (1973), which found that attentional capacities are reduced when competing stimuli are presented in the same sensory modality. During the distraction phase in the current study, hearing drivers were dividing their attention between two sensory modalities, auditory and visual. Conversely, the deaf drivers were utilizing just the visual modality during this phase of the study. Following Treisman's (1964) parameters and the results of Treisman and Davies (1973), the deaf drivers who were asked to use just one sensory modality to process two channels of information (i.e., driving and conversing) should have performed less well than the hearing drivers who were asked to use two sensory modalities to manage the two channels of information.

The results initially supported the study hypothesis, indicating that the hearing participants performed significantly fewer driving errors while engaging in a pseudo conversation with a mock passenger. However, the practical significance, as measured by the partial eta squared statistic, revealed an effect size so low that the between-group difference is unlikely to be noticed during a real-world driving task. Further investigation of the data revealed a potential confound that may have bolstered the hearing drivers' performance. As outlined above, the participants in the deaf group made significantly more speeding errors than the participants in the hearing group. It appears that the driving simulation's auditory speeding cues (i.e., a high-pitched engine roar as the vehicle's speed increases) may have been a factor in this difference. When driving a real automobile, deaf drivers have tactile cues (e.g., the feel of the engine accelerating) and visual cues (e.g., moving through a three-dimensional world) to help them monitor their speed. The absence of these cues during the driving simulation coupled with the simulation's auditory speed cues likely placed the deaf participants at a disadvantage. To eliminate this potential confound, the current study purged the speeding errors from the driving record of each participant. Differences in driver performance between the deaf and hearing drivers were not significant when this potential confound was controlled. That is, signing while driving appears to be no more distracting than speaking while driving.

In addition to providing data to examine the current study's main hypothesis, the distraction phase of the study yielded a significant amount of information on how deaf drivers communicate with their passengers while driving an automobile. One of the most interesting findings was how deaf drivers utilize their cognitive resources. To test Treisman's (1964) theory of attentional capacity, the current study attempted to force the participants to divide their attention between the road and the conversation by requiring them to respond to the mock passenger's statements as soon as they were uttered. The results of the response error assessment (i.e., participant accuracy during the true/false simulated conversation) indicated that such a division of attention occurred for the participants in the hearing group, though not for the participants in the deaf group. The difference in errors made by the hearing group and the deaf group was so great that it appears that deaf participants alternated their attention between driving and responding. This result suggests that deaf drivers do not divide their visual attention between concentrating on the road and participating in a conversation; rather, they alternate their attention. Additionally, it indicates that deaf drivers prioritize this cognitive shifting such that they prioritize attending to driving over attending to a conversation.

Additional support for the study's conclusion that deaf drivers who engage in signed conversations with their passengers are no more distracted than hearing drivers who engage in spoken conversations with their passengers can be found in the between-phase group driving performance comparisons. To examine this, each participant was administered a non-distracted driving simulation as a baseline driving record. As predicted, no significant differences in driving performance were found between the participants in the deaf and hearing groups during this phase of the current study. This result indicates that no significant difference exists for deaf drivers and hearing drivers on driving performance and that the two phases of the driving simulation (i.e., non-distracted and distracted), could be compared for each group of participants. The between-phase driving performance for each group revealed no significant differences. This supports the conclusion that drivers made no more errors during the distraction phase of the experiment than they did during the non-distracted phase of the experiment. That is, driving and conversing does not appear to be any more distracting than driving alone for hearing or deaf drivers.

Study limitations, future research, and concluding remarks

Previous research on the driving performance of deaf individuals had focused predominately on driving history and cognitive measures (e.g., Adams et al., 2010; Murphy, Brandt, Brownfeld, Klein, & Miller, 2007; Schien, 1968). However, a goal of the current study was to extend previous research through the design of an applied experiment as a means of bridging the laboratory and the real world. Naturally, applied studies reduce control and increase confounds, both of which limit the generalizability of the results. The current study utilized a driving simulation which is more realistic than a cognitive measure of driving performance, but less realistic than a real-life driving course. Such an approach was taken to maintain the safety of the study participants. While a simulator is a useful measure of driving performance, it is not ideal because participants remain aware that a mistake made during the simulation has fewer consequences than a mistake made during actual driving. Additionally, use of a simulator relies on the reproduction of the driving environment; simulators still do not fully recreate the multi-sensory driving experience (e.g., a three-dimensional environment and the feel of the roadway). Moreover, the current study utilized a true/false approach to mimic a conversation. Although dissimilar from a traditional conversation, it was used to assess whether participants were dividing or alternating their attention. Lastly, the study groups differed on the basis of gender. This was expected given the compositions of the two research settings, though does increase the possibility of type one or two error.

It is important to note that the current study focused on the performance of deaf drivers whose preferred mode of communication is ASL. The results of the current study cannot be used to support or oppose the performance effects of driving and performing other tasks (e.g., talking on a cellphone). Additionally, these results are not generalizable to deaf persons who prefer and predominately use a different form of communication (e.g., lip reading and speaking). The deaf participants in the current study are unique in that their use of a manual and visual form of communication is as natural to them as it is for most hearing people to speak and listen.

The next step in this field of research is a design that is truer to life, such as a road test, though the results of this study have triggered further questions about how deaf individuals attend to stimuli while driving. For example, during the distracted phase of the driving simulation, deaf participants exhibited a variety of attending behaviors. Some participants appeared to keep their eyes on the road and used their peripheral vision to respond to statements while others turned their heads slightly towards the mock passenger. Further research may help to determine whether this difference in behavior has any influence on the driving performance or conversation attention of deaf individuals.

The current study was the first applied assessment of driving ability among deaf drivers. As described above, several studies have aimed to compare deaf and hearing drivers (e.g., Adams et al., 2010; Murphy et al., 2007; Schien, 1968), though none have used an applied design; rather, most have focused on driving history and cognitive factors. The most significant finding from the current study is that the driving performance of deaf drivers who engage in signed conversations with their passengers is comparable to that of hearing drivers who engage in spoken conversations with their passengers. The results also showed that deaf drivers utilize alternating attention when driving and conversing and allocate cognitive resources for driving rather than for conversing. Lastly, the current study showed that non-distracted driving performance was comparable between deaf and hearing drivers. This information will hopefully reduce the stigma against deaf drivers, inform policy and industry regulations regarding the abilities of deaf drivers, and serve as a base for future research on the deaf-specific cognitive factors of driving.

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