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Cognitive workload and driving behavior in persons with hearing loss

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ABSTRACT

Purpose: To compare the effect of cognitive workload in individuals with and without hearing loss, respectively, in driving situations with varying degree of complexity.
Methods: 24 participants with moderate hearing loss (HL) and 24 with normal hearing (NH) experienced three different driving conditions: Baseline driving; Critical events with a need to act fast; and a Parked car event with the possibility to adapt the workload to the situation. Additionally, a Secondary task (observation and recalling of 4 visually displayed letters) was present during the drive, with two levels of difficulty in terms of load on the phonological loop. A tactile signal, presented by means of a vibration in the seat, was used to announce the Secondary task and thereby simultaneously evaluated in terms of effectiveness when calling for driver attention. Objective driver behavior measures (*M* and *SD* of driving speed, *M* and *SD* of lateral position, time to line crossing) were accompanied by subjective ratings during and after the test drive.
Results: HL had no effect on driving behavior at Baseline driving, where no events occurred. Both during Secondary task and at the Parked car event HL was associated with decreased mean driving speed compared to baseline driving. The effect of HL on the Secondary task performance, both at Baseline driving and at the lower Difficulty Level at Critical events, was more skipped letters and fewer correctly recalled letters. At Critical events, task difficulty affected participants with HL more. Participants were generally positive to use vibrations in the seat as a means for announcing the Secondary task.
Conclusions: Differences in terms of driving behavior and task performance related to HL appear when the driving complexity exceeds Baseline driving either in the driving task, Secondary task or a combination of both. This leads to a more cautious driving behavior with a decreased mean driving speed and less focus on the Secondary task, which could be a way of compensating for the increasing driving complexity. Seat vibration was found to be a feasible way to alert drivers with or without HL.

1. Introduction

Driving a car is one of the most complex and safety critical everyday tasks in modern society (Groeger, 2000). The Task Capability Interface (Fuller, 2000) describes driver control as when the demands of the driving task are less than the capability of the driver. Consequently, loss of control arises when the demands of the driving task exceed the driver's capability. The level of difficulty in the driving task is thus the inverse of the spare capacity and also connected to the cognitive

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workload (Fuller, 2005). Driving effort is dynamic as the cognitive demands can change back and forth from very low to extremely high, sometimes within fractions of a second (Michon, 1985; Peters & Nilsson, 2006). Among the factors determining the driving task demand, of which the driver has immediate and direct control, driving speed is the most significant (Fuller, 2005). It has been demonstrated that when a threshold of a certain preferred driving speed is exceeded, experienced task difficulty, effort and feeling of risk is affected (Lewis-Evans, de Waard, & Brookhuis, 2011). Normal driving can be considered as a cognitive and controlled task, and thus one approach to understand driving behavior is using cognitive psychology. This approach attempt to describe internal processes involved in making sense of the environment, and deciding what action might be appropriate (Eysenck & Keane, 2010; Neisser, 1976). Hearing loss (HL) means loss of auditory information, which may affect road user behavior in specific traffic situations and might reduce traffic safety (Ivers, Mitchell, & Cumming, 1999; Schmolz, 1987).

The working memory plays a central role in processing of information. The phonological loop is one component in Baddeley's multicomponent model of the working memory (Baddeley, 2012; Repovs & Baddeley, 2006). Within this loop, a phonological store holds memory traces in phonological form, and an articulatory rehearsal process recodes information from other modalities (Baddeley, 1983; Repovs et al., 2006). Andersson (2002) demonstrated that specific aspects of the phonological system deteriorate as a function of poor auditory stimulation in individuals with HL. Specifically, the phonological representations are deteriorating and this deterioration also affects the ability to rapidly perform phonological operations (i.e., analyze and compare letters) (Andersson, 2002). Thus, it is reasonable to assume that a Secondary task during driving, which includes performing phonological operations would affect drivers with HL more than normal hearing (NH) drivers.

The prevalence of age-related HL is increasing, due to populations becoming progressively older and thus presenting symptoms of reduced sensory function. These may be physiological or caused by additional factors damaging the hearing function (e.g., harmful noise in the environment). The prevalence increases for all ages, although the most common category of HL is presbycusis, which refers to the physiological age-related changes of the peripheral and central auditory system leading to HL. The prevalence of HL in Europe is roughly 30% for men and 20% for women at the age of 70 years, and 55% for men and 45% for women at the age of 80 years (Roth, Hanebuth, & Probst, 2001). A consequence of the increasing prevalence of HL, is that the number of road users (not only drivers) with HL will also increase.

Relatively few studies have focused on HL and driving previously, and the knowledge is thus rather limited. However, the importance of a hearing capability for road users has been examined by Schmolz (1987), who revealed that HL is associated with higher degree of inattention and that traffic education for older adults should be bound to hearing ability. There are also some studies with either self-reported accidents or medical record data, pointing to connections between HL and higher risks of traffic accidents (Ivers, Mitchell, & Cumming, 1999; McCloskey, Koepsell, Wolf, & Buchner, 1994; Picard et al., 2008).

Thorslund, Peters, Lyxell, and Lidestam (2013) showed that among individuals with HL there are fewer license holders and that the prevalence of driving license decreases with an increasing degree of HL. However, those drivers who have HL drive to the same extent as NH drivers (Thorslund et al., 2013). The results also revealed that drivers with HL may develop compensatory strategies, since the number of incidents or accidents is not related to HL (Thorslund et al.). The interest in a warning system for inattention was high among all participants regardless of HL or not (Thorslund et al.). This further stresses the importance of research on drivers with HL, to examine driving behavior and possible compensatory strategies, and also on feasible warning modalities and design of support systems accessible for drivers with HL.

Due to a more complex in-vehicle environment of systems for infotainment (e.g., navigation system, mobile phone), there is an increased risk of distracting the driver from the driving task. Hickson, Wood, Chaparro, Lacherez, and Marszalek (2010) reported a significant interaction between HL and distractors, such that people with moderate to severe HL had significantly poorer driving performance in the presence of distractors than had individuals with NH or mild HL. This further supports that it is important to design driver support systems also for drivers with HL.

According to Fuller (2005), the driver selects a range of workload and then drives in such a way as to maintain the experienced difficulty within that range. Manipulation of driving speed along with degree of engagement in Secondary tasks is claimed to be the primary mechanisms for this maintenance (Fuller, 2005). Simulator studies have demonstrated that distraction tasks (both visual and cognitive) lead to decreased speed and a difficulty in maintaining a certain speed (Engström, Johansson, & Östlund, 2005; Lewis-Evans, de Waard, & Brookhuis, 2011). Tsimhoni and Arbor (2003) found, in a driving simulator study with a Secondary task and varying complexity of the road condition, that the total time allocated to the Secondary task increased significantly with a more complex driving task (sharp curves vs. straight road vs. parking). Even though the participants seemed to adapt their glance behavior to the road conditions, driving performance still deteriorated with a more complex environment (more lane departures), and at the same time more errors were made in the in-vehicle task (Tsimhoni & Arbor, 2003).

The purpose of the present simulator study was to compare the effect of cognitive workload, in individuals with and without HL, respectively, in driving situations with various complexities. We specifically examined, during three different driving conditions, two levels of difficulty in terms of load on the phonological loop. A tactile signal, provided as a vibration in the seat, was evaluated for effectiveness when calling for driver attention. A comparison was made between drivers with moderate HL and drivers with NH. All participants experienced Baseline driving with low cognitive effort, Critical events with a need to act fast, and a Parked car event with the possibility to adapt the workload to the situation (e.g., give less priority to the Secondary task). The Secondary task was present at all driving conditions.