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Aging effect on detectability, criticality and urgency under various auditory conditions

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ABSTRACT

The objective of the study was to investigate the relationship between different components of an auditory warning signal and determine elderly driver's detection, criticality and urgency perceptions under varied auditory warning conditions. A laboratory study was conducted involving 28 younger and 28 older adults. A pure-tone audiogram was administered for quantification of the participant's hearing level (in dBHL) prior to the test protocols. Audiogram was conducted in a sound isolated booth. The main experiment investigated the effects of frequency, temporal characteristics, aging, and noise on detectability, caution and perceived urgent levels. Method of adjustment was used by the subjects to adjust the sound pressure level (dBA) till they detected, or felt caution or urgent. Overall, the results indicated that elderly had higher sound pressure threshold than younger individuals in all the sessions (i.e., detectability, caution and urgency). Elderly were found to have higher hearing thresholds especially at 4000 Hz. Higher frequencies were also seen to require less sound pressure thresholds to convey feeling of caution and urgency. Sound pressure threshold to convey the feeling of urgency was the lowest for 2000 Hz and 4000 Hz with 1000 Hz requiring the highest threshold intensity. In conclusion, current study findings suggest frequency, temporal and spectral components to influence a person's criterion. We would recommend the use of complex tones (multi-components) having high frequency around 2000 Hz for detection, warning and urgent conditions.

1. Introduction

Elderly population is growing rapidly with expectation to double and reach 72 million by the year 2030 (He, Sengupta, Velkoff, & DeBarros, 2005). In comparison to drivers of 25–69 years of age, elderly are nine times more likely to experience fatal accidents. In 2005 alone, 191,000 elderly drivers were involved and injured in vehicular crashes (NHTSA, 2006). Thus, it is of paramount importance to design vehicular systems taking vision, cognitive and physical limitations of elderly drivers in mind.

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Aging related physiological and cognitive changes start happening around 40–50 years of age (Glasser & Kaufman, 2003). Presbycusis is an age related hearing loss whose severity can vary from mild to severe (Gates & Mills, 2005). About 40% of the elderly population (above 65 years of age) suffer from this debilitating hearing loss which has been seen to seriously hinder communication (Ries, 1994). This decline is gradual and slowly increases the detectable hearing threshold level and is more pronounced above 2000 Hz frequencies.

Patterson (1982) suggested that in order for a warning signal to be useful, it has to be detectable, reliable and initiate the correct response. Kuwano et al. (2000) stated the following requirements of a warning signal – ease of understanding among all age groups including elderly who have hearing loss in any noisy environments. The warning signal should be easily understood by all individuals irrespective of their country of origin or language.

A number of studies have been conducted in the paradigm of collision warning systems using different sensory inputs (Gray, 2011) – visual icons given on a dashboard display (Lee, McGehee, Brown, & Reyes, 2002), auditory warnings in the form of tones or speech (Graham, 1999), tactile signals in the form of vibration presented through driver's seat or seatbelt (Ho, Reed, & Spence, 2007), and multimodal warnings (Ho & Spence, 2005; Lee et al., 2002; Politis & Pollick, 2013). There still does not exist a consensus among researchers as to the most effective way of presenting warning stimuli (Engstrom & Victor, 2009). Driving being mainly a visually intensive task, auditory is seen to be one of the most robust modality to convey critical and time sensitive information (Belz, Robinson, & Casali, 1999). Previous research indicate auditory warning signals to significantly improve driving by alerting the driver (Lin et al., 2009) and resulting in faster mean brake reaction times compared to visual warnings (Scott & Gray, 2008). Additionally, a number of studies found auditory and vibrotactile warning signals to improve a driver's reaction to possible front-to-rear-end collisions (Ho, Reed, & Spence, 2006; Ho & Spence, 2005; Ho, Tan, & Spence, 2006; Kiefer et al., 1999; Lee, Hoffman, & Hayes, 2004; Lee, McGehee, Brown, & Marshall, 2006; Suzuki & Jansson, 2003). In one of their earlier studies, Ho and Spence (2005) found warning systems that convey both symbolic and spatially predictive information is most suited for collision avoidance systems. They however noted, that usage of cell phone or other linguistic activities that happen during driving reduce the usefulness of verbal warning signals. Previous studies indicate auditory icons with solid connections to their referents initiate quick accurate reactions than abstract arbitrary sounds in laboratory research settings (Keller & Stevens, 2004; McKeown & Isherwood, 2007; Perry, Stevens, Wiggins, & Howell, 2007; Stephan, Smith, Martin, Parker, & McAnally, 2006).

The primary objective of an auditory signal is to alert the individual of an impending danger (Nakatani, Suzuki, Sakata, & Nishida, 2009). Nakatani et al. (2009) pointed out in his research the two main issues faced while comprehending an auditory warning signal – culture related perception gap and the ability to isolate the critical alert from other varied signals. The time required to recognize and respond to critical warnings would be influenced by driver's perceived urgency of the situation (Marshall, Lee, & Austria, 2007).

Fundamental frequency, spectral and temporal variations, duration and impulsiveness of sound, signal intensity all have been seen to affect perception and effectiveness of warning signals (Gelfand, 1998; Haas & Casali, 1995; Kryter, 1994; Saifuddin, Matsushima, & Ando, 2002). A void exists in literature about the effects of acoustic parameters on the perceived urgency of elderly drivers. The current study attempts to investigate the relationship between different components of an auditory warning signal and determine elderly driver's detection, criticality and urgency perceptions under varied auditory warning conditions.

2. Methods

2.1. Experimental design

Frequency (500, 1000, 2000, 4000 Hz), Temporal characteristics (continuous, 0.2 s, 0.5 s, 1.0 s-all having a duty cycle of 50%), Age (young, elderly) and background noise (yes and no) were the independent variables. The temporal characteristic indicates the pulse duration and silent interval of the specified value, except for continuous signal. Detectability, urgent and caution levels (dBA) were the dependent variables. Sound pressure level (Pulse Intensity) was used as the dependent variable, since earlier studies indicated it to influence both detection and perception of urgency (Edworthy, Loxley, & Dennis, 1991; Haas & Casali, 1995). The auditory signal was provided with background noise at 65 dBA. The background noise level was provided in dBA, a weighting network which deemphasizes low frequencies and to a small measure, the higher frequencies (Casali & Robinson, 1999). The inverted dBA scale attempts to provide an approximation of normal human hearing acuity for moderate sound levels.

2.2. Participants

A laboratory study was conducted involving 28 younger (age(mean/SD) = 23.6/4.8 yrs) and 28 older adults (age(mean/SD) = 73.6/4.4 yrs). The participants were screened for visual acuity, the ability to see red color, and by audiogram tests. The participants were also required to have a valid driver's license and be an active driver (drive at least 4 times a week). Both the age groups had equal number of male and female participants. Informed consent form detailing the objectives, procedures and risks involved in the experiment was approved by local Institutional Review Board and obtained from each participant prior to data collection.