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Gaze behavior and human error in distracted driving: Unlocking the complexity of articulatory rehearsal mechanism

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ABSTRACT

This study reports development of an experimental paradigm named as 'Direction Following in Distracted Driving - Suppression of Articulatory Rehearsal Mechanism (D3-SARM)'. It investigates the effect of suppressed articulatory rehearsal mechanism (ARM) on gaze behavior and driving performance in a naturalistic driving environment. Drivers ($N = 45$) voluntarily participated in the study and drove an instrumented vehicle on a two-lane track. They were required to follow certain directions displayed on the direction signboards that were installed along the track. There were three levels of suppression of ARM namely, non-suppression (NS), simple suppression (SS), and complex suppression (CS). Equal number of participants were randomly assigned to each level of suppression. The results demonstrate that there are significantly lesser fixation durations and fixation counts under CS of ARM as compared to the other two levels. Overall driving error analysis revealed that there are more significant errors under CS as compared to SS and NS. Moreover, drivers committed more slips than lapses irrespective of the levels of suppression. On the whole, this study suggests that suppression of ARM affects gaze behavior and compromises driving performance. Also, even in the case of drivers being unable to have fixation on target visual information irrespective of non-suppressed ARM or suppressed ARM, drivers paid visits.

1. Introduction

Issues related to distraction is a critical aspect of automotive human factors research. Despite the fact that development of cognitive tasks (Cohen et al., 1994; Gronwall, 1977) in the context of working memory (WM), researchers have not approached the complexity of suppression of Articulatory Rehearsal Mechanism (ARM) and the underlying dynamics of gaze behavior and performance compromise. This aspect of WM in the context of driving requires development of a new experimental paradigm for scientific investigation. Studies on distracted driving have majorly focused on issues related to effects of distractions caused by using mobile phones during driving (Horrey & Wickens, 2006; Strayer, & Drews, 2007); effects of roadside advertising on attention and road safety (Herrstedt, Greibe, & Andersson, 2013); and effects of phone type and messaging on gaze behavior while driving (Young, Rudin-Brown, Patten, Ceci, & Lenne, 2014). However, there is limited evidence for its relationship with driving errors (Young & Salmon, 2012).

Drivers get driving related information mainly through visual, auditory, and haptic receptors but it is predominantly based on the information received through visual senses (Sivak, 1996). The process of storing the visual information and

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at the same time manipulating it in order to be used in current task has been best explained by WM Model (Baddeley & Hitch, 1974; Baddeley, 2000, 2007). An important aspect of WM in this context is that of ARM which recodes visual information into phonological information and rehearses it in order to prevent it from decaying (Baddeley, 2000).

2. Literature review

2.1. Articulatory rehearsal mechanism (ARM) of working memory (WM) and visual information in driving

Baddeley and Hitch's WM model (1974) is a multi-component system consisting of three components namely, central executive, visuospatial sketchpad, and phonological loop. Central executive, also known as the real brain of WM, controls attention and allocates resources to the two subsystems. The primary responsibility of central executive is to select information from the environment and retrieve information from long term memory (LTM) (Baddeley, 1992). Visuospatial sketchpad holds visual and spatial information that is received through senses or retrieved from LTM. The second storage system, the phonological loop, temporarily stores information related to sounds and consists of a mechanism of rehearsing the phonological information called as articulatory rehearsal mechanism (ARM) in order to prevent its rapid decay (Baddeley, 1986). Due to various criticisms, the original WM model was revised by adding fourth component to the model, known as the episodic buffer (Baddeley, 2000, 2002) which acts like an interface between memory subsystems (visuospatial sketchpad and phonological loop) and LTM. In other words, episodic buffer integrates the information from all other systems of WM and offers a unified information in order to meet the demands of the task in hand.

Phonological loop consists of a phonological store and an ARM (Baddeley, 2012). Phonological store stores speech-based information for short periods of time after which the information fades away rapidly (Baddeley, 2007). This time limitedness of the phonological store is overcome by ARM which is used to recite the information in order to prevent its rapid decay in the phonological store (Baddeley, 2007). ARM recites the phonological information making it to re-enter into the phonological store, where it starts to decay again immediately. Baddeley, Thomson, and Buchanan (1975) described ARM as a time-based tape of fixed length which refreshes phonological information after every 2 s. By constantly refreshing the information, the recitation process prevents it from decaying. The process of refreshing the information is called as verbal rehearsal or articulatory rehearsal and it does not need to be overt, as people who have lost their articulation capability due to any reason may also show the signs of sub-vocal articulation (Baddeley & Wilson, 1985). The ARM does not recite or rehearse phonological information only but serves another important function of phonological/verbal recoding of visual information (Baddeley, 2007). Therefore, in driving, phonological recoding ought to play an important role in terms of processing information presented in visual form. This is primarily critical for the visual information which has a verbal label (e.g., road signboard with a right headed arrow can be labeled as right turn). Information presented in a visual form is named or labeled and the phonological information produced from this labeling process then gets access to the phonological store where it is recited again and again to stay for a longer duration. Information received through auditory senses gains direct (obligatory) access to phonological store and in order to retain the information received through visual sense for a longer time (more than 0.5–1.0 s) it gets access to phonological store, otherwise it fades away. This makes the access of visual information to phonological store optional (Baddeley, 1983). Information once in the phonological store, verbal rehearsal operates in the same manner irrespective of the means of entrance, i.e., direct or the optional route.

Phonological coding is beneficial in the sense because remembering visual information is more difficult than remembering phonological information and that in the situations when the delay is more between encountering the information and recalling it (Henry, 2011). Last decade has seen proliferation in the use of new wireless nomadic devices that have made their way into automobiles giving rise to many new sources of distractions (for e.g., using internet, watching videos, etc.), it is highly possible that visual information might be getting suppressed from entering into phonological store for articulatory rehearsal and remembered acoustically. It makes sense to explore when the visual information is blocked from entering into the phonological store (by means of distraction) how it influences drivers' gaze behavior and driving performance.

Effect of suppression has been studied in the context of interactions with phonological variables like the *phonological similarity effect* (consonants with similar sounding names such as b, g, c, v, t, p are harder to remember than dissimilar sets such as h, w, y, k, r, I); *word length effect* (memory span decreases as word length increases) and *the unattended speech effect* (memory for visually presented items gets impaired by the simultaneous presentation of spoken material). Due to suppression of ARM the unattended speech effect disappears, the word length effect gets insignificantly reduced, and the phonological similarity effect gets abolished (Baddeley, 1983). For suppressing ARM, Coltheart (1993) has used an irrelevant task in the context of phonological similarity effect where the participants were required to remember and later recall a phonemically similar list of words. During presentation of the list of words the participants had to keep counting up to 6 and then restart counting. Other studies (e.g., Richardson & Baddeley, 1975) studied the effect of suppression of ARM on free recall of list of words. In these studies, participants are instructed to say irrelevant words during the presentation of the list of words. The nature of these ARM suppression tasks is that (a) it requires minimal attentional resources and (b) the purpose is to ensure that the ARM becomes unavailable for either phonological coding or verbal rehearsal. Relevant studies concerning WM in the context of driving include effects of distraction induced by WM load on driving performance (Engström & Markkula, 2007); impact of cognitive distraction on visual behavior and braking performance (Harbluk, Noy, Trbovich, & Eizenman, 2007); relationship between WM capacity and driving performance (Mäntylä, Karlsson, & Marklund, 2009; Ross et al., 2015).