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The relationship between noise and mode of delivery on recognition memory and working memory

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ABSTRACT

The present research sought to investigate the effect of noise, comparable to that experienced in an aircraft cabin, on cognitive performance in terms of working memory and recognition memory. In addition, and since advancements in technology have long permitted the exchange of information via various media, the present research also sought to investigate the effect of in-cabin aircraft noise on the medium in which the target signal is delivered. Thirty-two participants (19 female), half non-native English speakers with an average age of 21.84 years (SD = 3.16), and all with normal hearing were asked to complete four different memory tasks under two different experimental factors. The first independent variable was noise, with two conditions: no noise versus wideband noise at 80 dBA. The second independent variable was mode of presentation, with two conditions: target signal presented aurally or visually. With the presentation of stimuli presented in a counterbalanced order, the results from a series of mixed repeated measures analyses revealed that working memory appears largely immune from the effects of wideband noise at 80 dBA. In contrast, recognition memory is most vulnerable to the effects of this noise. In terms of mode of delivery, presenting the target signal visually improves recall performance on the recognition memory task and two of the three working memory tasks (not the linguistics working memory task). Also noise had a greater effect on non-native English speakers on the recognition memory task. These results highlight the varying effect of noise on memory, and the benefits of considering alternate methods of presenting information in noisy settings, such as aviation.

1. Introduction

In safety critical industries, optimising human performance is a key to accident prevention. Crucial to this is to ensure the work environment is suitable for the tasks and those tasks are designed with human limitations in mind. Noise is one aspect of the work environment that affects workplace safety.

It is well established that excessive noise can cause noise induced hearing loss. To reduce the risk of hearing loss, most countries have legislation to limit workplace noise exposure. The European Union Directive [38] includes a daily noise exposure level ($L_{EX,8h}$) over 8 h of 87 dBA with an upper and lower exposure action values at 85 and 80 dBA respectively. However noise, or unwanted sound, at levels well below these values can cause annoyance, disturbance and affect cognitive performance (e.g., [24,25]). Consequently there are guidelines and standards for noise levels considered acceptable for many work environments. These can range from around 40 dBA for an office through to 60 dBA for a delivery area (for more detail see [36]).

There are many workers in safety critical jobs that require high order cognitive skills, and those workers are required to work effectively in noise levels higher than those recommended in the design guidelines. For example, the staff entrusted with the safety of the passengers within transportation including: trains, buses and aeroplanes. Pilots, are required to do their highly skilled job while exposed to high levels of noise in the cockpit. Noise levels within the cabin of a commercial aircraft can be close to 80 dBA for long periods during cruise [28,4]. The crew and passengers can be attempting to complete complex tasks in these high noise levels. It is only by understanding the effects of such noise on performance and memory recall that appropriate measures can be implemented in work practices in order to maintain the high level of safety that is required.

The aim of the work presented in this paper is to examine, from a cognitive perspective how noise at levels comparable with those inside a commercial aircraft affects performance, in terms of memory recall.

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1.1. Cognitive effects of noise

All sounds, including both the target and unwanted (i.e., noise) signals are processed cognitively, either consciously or unconsciously [5,21]. The processing of all new information including sounds is considered to occur in working memory [7]. However, the capacity of working memory is not infinite and if exceeded, decrements in performance result [23,7]. Hence, attending to sounds, either consciously or unconsciously, can be cognitively taxing and with limited cognitive resources can adversely affect the performance of other tasks that may be competing for the same cognitive resources. Evidence in support of the effects of unwanted sound (i.e., noise) on performance can be derived from the research investigating the effects of intermittent as well as continuous noise on performance.

Haines and colleagues investigated the effect of prolonged exposure to aircraft flyover noise (intermittent noise) ranging between 53 and 86 dBA on the cognitive performance of school children and found a link between exposure and impaired cognitive performance, such as long term memory, reading ability and reading comprehension [14,16]. Clark and colleagues found the same type of noise (range 32–71 dBA) also affected the working memory and episodic memory of students [8].

According to Clark and Sörqvist [9], background speech and aircraft noise are the two most detrimental types of noise affecting performance. In an attempt to better understand the effect of noise on memory from a neurological perspective, Sætrevik and Sörqvist [31] used fMRI/BOLD neuroimaging with three different background noise conditions; silence, speech, and aircraft noise (overflights). The two noise sources were approximately 70 dBA, as well as being intermittent and time varying; the aircraft noise was from overflights. Using a working memory task, Sætrevik and Sörqvist found that both types of noise activated the prefrontal cortex (PFC); speech noise to a greater extent than aircraft overflight noise. The level of activation also changed as a result of the working memory activity. The dorsolateral prefrontal cortex (DLPFC) showed signs of activity during a working memory substitution task; the prefrontal cortex was more active when the working memory task contained no substitution. Despite these differences, there were no behaviour performance differences between the three noise conditions.

The authors explained the lack of differences on the performance measure due to the differences in brain activity; increased mental effort compensated for the interference from the different background noises [31]. They also note, it is possible that a change in the performance measure may yield different results. Moreover, the working memory substitution task, conducted in the presence of speech, activated a cluster in the occipital lobe more than when the same task was undertaken with aircraft overflight noise. Albers et al. [1] note that occipital activation is common with visual processing. Had the performance measure relied more on visual imagery or more complex decision-making, behavioural performance difference may have been observed [31]. It is also possible that the performance may have varied if the target stimuli were presented aurally as opposed to visually.

This is precisely what Kjellberg et al. [20] found when they asked participants to complete a series of working memory tasks; one memory task was presented orally and another memory task presented visually. Recall performance was compared between noise condition: silence and in the presence of synthesised broadband noise from speech material at 60 dBA and with a signal to noise ratio of 4 dB. Recall performance was affected by the noise when the target signal was presented orally, however it remained unaffected when the target signal was presented visually. It is possible however, that the differences in the results were due to the two different working memory tasks employed, or a combination of the task and the modality of presentation.

What is less ambiguous is the masking capability of noise. Helfer and Freyman [15] note noise can mask the target signal in one of two ways: 'Energetic masking' or 'Informational masking'. Energetic masking is the traditional view of masking, where the target is covered-up by the masker, in terms of physical properties. Freyman, and colleagues define Informational masking encompassing features of masking that cannot be explained by energetic masking [12]. These can include elements within the two sound sources that are clearly distinguishable from each other, but difficult to untangle perceptually [13]. Maronne et al. [22] illustrated that by simply improving the signal to noise ratio, the effects of energetic masking can be overcome. In terms of Informational masking, the noise itself can also be manipulated, often by simply altering its properties (e.g., frequency, amplitude, spectrum, etc.) so it more closely resembles the target signal. Cooke et al. [6] found evidence of Informational masking in a study with native and non-native English speakers (native European Spanish speakers), and these effects were more pronounced for non-native English speakers.

The precise reason why noise affects non-native speakers more than native speakers remains unknown. According to Von Hapsburg and Peña [39], it may be the additional cognitive load imposed as a result of searching two or more lexicons that affect performance (i.e., information processing or response time). Sætrevik, and Sörqvist [31] believe similarly the cognitive load is responsible for these differences, however they believe the increase in cognitive load is from the effort expected expelled to compensate for the interference as opposed from searching multiple lexicons. Kilman et al. [19] believe that language proficiency in the non-native language is important in overcoming the masker. High language proficiency allows individuals to inhibit the masking signal better.

Since noise present inside the cabin of an aircraft is wideband and relatively constant, as it is largely from the engine, it is unlikely that theories such as 'Informational masking' can explain any detrimental effects of this noise on cognitive performance. Maronne et al. [22] investigated the effects of continuous noise (steady-state speech-spectrum-shaped) on verbal working memory tasks. The target speech signal was held at 65 dBA and the background noise level presented with signal to noise ratio of −5 and −10 dB. They showed a degradation in performance with an increasing negative signal to noise ratio. However continuous wideband noise, at 65 dBA has also been found to adversely affect recall for information on a free recall working memory task when the information was provided as speech, at a level that was clearly audible above the background noise [24]. A similar result was evident on a recognition memory task, where participants were provided a choice between two plausible options (i.e., Cued-Recall; [27]).

The effects of continuous wideband noise on recognition memory have been found to be more pronounced for individuals whose native language was not the same as the target language [26]. These effects are not new, as other types of noise such as intermittent noise yield similar results [10]. The precise reason why noise affects non-native speakers more than native speakers remains unknown. According to Von Hapsburg and Peña [39] and Schmidtke [34], it is the larger lexicons that are responsible. Non-native speakers need to search both their lexicons in order to determine if the sound, including the noise is familiar, thereby slowing information processing or response time.

1.2. Information presentation modality

In an attempt to mitigate the effect of noise on performance, various mitigation methods have been employed in different