The use of noise cancelling headphones to improve concurrent task performance in a noisy environment

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\textbf{A B S T R A C T}

The main aim of the present study was to examine the effect of noise cancelling technology (e.g., headphones) on concurrent task performance within an aviation environment, namely the cabin of commercial operations. In addition, the present research sought to determine if price comparable noise cancelling headphones deliver similar performance outcomes. Thirty-six participants (23 male), all with normal hearing and with an average age of 20 years (SD = 2.12) were asked to listen to six different audio files under six different experimental conditions. The six experimental conditions were presented in a balanced Latin squares experimental design, while the audio files were presented in a counterbalanced order. Each audio file contained information about a specific aircraft that was a combination of both factual and non-factual information. The secondary task consisted of a simple mathematical exercise. Wideband noise played at 65 dB(A) and filtered to simulate aircraft noise featured in each experimental condition. At the conclusion of each audio file, participants were provided a written multi-answer test. In relation to the main aim (recognition of audio information), a series of planned comparisons revealed no differences in terms of performance between the two price comparable noise cancelling headphones. However, performance when using noise cancelling headphones was significantly better in both the single-task and dual-task condition compared to using no headphones. As expected, performance in the single-task noise cancelling condition was also superior to the dual-task noise-cancelling condition. Of particular note, there were no differences between the dual-task noise cancelling condition and the single-task no headphone condition. These results highlight the benefits of noise cancelling technology in an aviation setting.

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1. Introduction

One industry that has benefited from noise cancelling technology is the aviation industry. Pilots and passengers on commercial operations are exposed to low frequency noise generated by the aircraft engines. For a commercial aircraft powered by a jet turbine engine, this low frequency sound can typically range from 60 dB(A) to 88 dB(A) \cite{1}. For older aircraft as well as propeller driven aircraft, the decibel range can be much higher \cite{2}. Noise cancelling headphones are designed to attenuate external noise at the ear and the technique is more effective at reducing low frequency sounds. This has the effect of reducing confounding noise, thereby allowing the user to better understand speech transmitted to the headphone \cite{3,4}.

The safety implications for pilots in reducing unwanted low frequency noise are numerous, none more than allowing pilots to hear radio transmissions clearly \cite{5,6}. In a recent study investigating communication problems within general aviation, pilot to pilot transmission where the engine noise was at its highest posed the greatest threat to safety \cite{5}.

For commercial passengers of airliners, noise within the aircraft cabin poses less of an immediate safety threat, but nonetheless has the ability to adversely affect performance, as well as comfort level and health state. Moreover, research examining the causal impact of noise on performance reveals noise increases the likelihood of experiencing fatigue \cite{7}, decreases individuals’ ability to recall information \cite{8} and causes higher levels of both self-reported stress \cite{9} and perceived workload \cite{10}. In the most extreme cases, prolonged exposure to unwanted noise can cause sleep deprivation and even insomnia, hearing loss, as well as increased blood pressure \cite{11–13}.

In a recent study investigating the benefits of noise cancelling headphones for passengers during the taxi phase of flight in terms of word recognition, Molesworth and Burgess \cite{14} found comparing to using no headphones or when the noise cancelling feature of the headphones was switched off, noise cancelling technology...
improved individuals’ ability to hear the information provided. During the taxi phase of flight, airlines deliver their pre-flight safety brief to passengers; therefore being able to hear and comprehend this information better prepares the passenger in the event of an emergency. However as most frequent flyers can attest to, not all passengers attend to the pre-flight safety brief. Therefore, the present study was to extend the research conducted by Molesworth and Burgess [14] and investigate the benefits of noise cancelling headphones under conditions reflective of a situation where a passenger chooses not to focus solely on the pre-flight safety brief. Specifically, the present study sought to determine if the use of noise cancelling headphones during the taxi phase of flight could facilitate word recognition (e.g., safety brief or other information) during a concurrent task (i.e., dual-tasks) compared to a condition involving passive noise attenuating headphones.

Concurrent tasks, commonly referred to as dual-task, involves engaging in two (or sometimes more) tasks/activities simultaneously [15–17]. Concurrent task performance is common and has a number of benefits, the most notable being improvements in efficiency. However, not all tasks synchronise harmoniously. Using undergraduate students to illustrate this, Fox and colleagues [18] asked students to complete a reading comprehension task while concurrently holding an instant messaging (IM) conversation, or a reading comprehension task uninterrupted. The results revealed that students who were engaged in both tasks (i.e., dual-task) took significantly longer to complete the reading comprehension task than students who completed the reading comprehension task uninterrupted. A negative relationship was also evident between time spent messaging and reading comprehension scores.

Other detriments in performance when engaging in concurrent tasks include: physical stability [15], forgetting an action and/or the commission of errors in well practiced tasks [16,17], a reduction in the ability to detect stimuli, as well as a degraded response to stimulus [19]. However, what remains unknown is the relationship between noise and performance on concurrent tasks. Based on the findings of Ljung et al. [8], it would be reasonable to expect a positive relationship between listening condition and performance during concurrent tasks. Therefore, in the present research it is hypothesised that the use of noise cancelling headphones will improve performance on a signal detection task in the dual-task condition, compared to the use of passive (non-noise cancelling) headphones.

A secondary aim of the present study was to investigate differences in performance between different models of noise cancelling headphones. Due to the applied nature of the Molesworth and Burgess [14] original study, they tested only one noise cancelling headphone product. Hence it remains unclear if all devices deliver a comparable level of performance. Therefore, the present research sought to answer the following research question: Do price comparable noise cancelling headphones provide a similar level of performance outcome in a situation akin to a pre-flight safety brief (i.e., audio brief) simulation?

2. Method

2.1. Participants

Thirty-six participants (23 male) were recruited for the study and the mean age of the participants was 20 (SD = 2.12) years. All participants, as determined by an auditory screening procedure, had hearing within what is considered the ‘normal’ range (i.e. any loss in either ear at any frequency considerably less than 20 dB(A)). Each participant was reimbursed for his or her time in the form of a $20 bookshop gift voucher. The research, including all stimuli was approved in advance by the University of New South Wales Ethics Panel.

2.2. Design

The study comprised a single (main) factor with six levels repeated measures experimental design presented in a balanced Latin square 6 x 6 design. In addition, the study featured one task variable – the presence or absence of a secondary task (mathematical task versus no concurrent task). The single factor that consisted of six different audio briefs was systematically varied within the design to ensure equal pairing with each condition. For example, the first six participants (and every six thereafter) were presented stimuli in the following order – condition 1, 2, 6, 3, 5, 4 as per the Latin square design. However for the first participant, the audio files were presented in the following order – A (Embraer 190), B (Airbus A330), C (Boeing 767), D (Saab 340), E (Bombardier Dash 8), F (Sukhoi Superjet 100), while the second participant received audio files in the following order, B, C, D, E, F, A, the third participant received audio files in the following order, C, D, E, F, A, B and so on. The six levels of the single factor were:

1. No headphones, audio brief played through external speaker, and external wideband noise.
2. No headphones, audio brief played through external speaker, mathematical task (2nd task), and external wideband noise.
3. Noise Cancelling Headphones 1, audio brief played through headphones and external wideband noise.
4. Noise Cancelling Headphones 2, audio brief played through headphones and external wideband noise.
5. Noise Cancelling Headphones 1, audio brief played through headphones, mathematical task (2nd task) and external wideband noise, and
6. Noise Cancelling Headphones 2, audio brief played through headphones, mathematical task (2nd task) and external wideband noise.

The main dependent variable in this experiment was number of correct responses on a multiple-answer audio test (maximum possible 12). In relation to the secondary task, the number of correct responses on the mathematics questions featured as an additional dependent variable.

2.3. Material

The laboratory equipment comprised: Bose® QuietComfort 3® Acoustic Noise Cancelling® Headphones (headphones 1), Sennheiser® Noise Cancelling Headphones PX2450 (headphones 2), two personal computers (one with internet access), Sennheiser HD265 linear headphones, one audiometric screening procedure (Digital Audiometer-Screen v6.2), Casella sound level metre (model CEL-240), Sound Power Source – type 4205, and a Logitech 5.1 surround speaker system.

The test documentation comprised: an information sheet, a consent form, a demographics questionnaire, six audio briefs and their respective multiple-answer written audio test and four mathematical tests (secondary task stimuli), each with 76 items. Each audio brief and written audio test was a replication of each other except in the form presented (e.g., audio versus written). Specifically, each audio brief contained information about a particular aircraft (e.g., Embraer 190, Airbus A330, Boeing 767, Saab 340, Bombardier Dash 8 or Sukhoi Superjet 100) that was a mixture of both factual and non-factual information. The audio briefs were designed to reflect, as opposed to replicate the pre-flight safety briefs provided by commercial airlines since any prior exposure to these pre-flight safety briefs may have adversely affected the results. Similarly, a combination of both factual and non-factual information was employed to minimise the effect of prior
knowledge on the results. Importantly, the audio brief reflected in length the pre-flight safety brief, and the specific information in each of the six different audio briefs was balanced so that they each contained 22 pieces of numerical information. This was also reflected in the multiple-answer written tests where 3 from the 12 multiple-answers related to numerical information.

The written test reflected the audio file except with the addition of the multi answer options for one word in some sentences. For example, one sentence in the Embraer 190 audio file, which is based on accurate (factual) information stated:

“It has a double-bubble fuselage design and according to the manufacturer this provides passengers with an extraordinary amount of personal space”.

The same sentence appeared in the written test except with three options for one word as shown below:

“It has a double-bubble fuselage configuration/ design/ uncertain and according to the manufacturer this provides passengers with an extraordinary amount of personal space”.

So in completing the multiple-answer written test, participants had to choose one of the options (i.e., word recognition) and were given the specific instruction “if you do not know the word, circle uncertain”.

In relation to the mathematical tests, there were four in total – all paper based tests. The first test was conducted prior to any experimental condition and from here forward is referred to as the baseline test. The three other tests featured in the dual task conditions (conditions 2, 5, and 6; see Procedure section below). Each test comprised 76 random mathematical questions relating to either an addition, subtraction or multiplication between two numbers totalling no more than 20 (e.g., 9 + 7, 19 – 4, 3 × 4). Preliminary tests prior to the actual experiment revealed 76 questions were sufficient, in terms of the time taken to complete the maths question relative to the audio briefs. All tests were randomly allocated to audio conditions, including the baseline, and no two tests were the same.

2.4. Procedure

Participants were recruited using the careers website at the University of New South Wales. Participants initially completed the consent form, followed by demographics questionnaire (age and gender), baseline maths test, and a computer controlled audiometric screening procedure using the Sennheiser non-noise cancelling headphones. Following this, participants were provided with the noise cancelling headphones and presented with the six different audio briefs under the six audio conditions.

During all conditions involving the maths tests (baseline, conditions 2, 5, and 6), participants were instructed that their primary objective was to complete the series of simple mathematical questions. In all cases, these questions were presented to participants on a single A4 page, where the participant had to write their answer directly next to the question. They were to always complete this task as “quickly as possible”, however it was stressed that accuracy was more important than speed (i.e., “… however it is more important to ensure that you do not make any mistakes”). In all conditions involving dual-task exercises, participants were reminded that their performance on the mathematical task should be similar to that of the baseline task. Participants were also reminded about the contents of the audio brief, namely that it was derived from both factual and non-factual information. This served to reinforce the point that participants should focus on the content of each brief, rather than any prior knowledge they might have about the aircraft. At the conclusion of each audio brief, all participants were asked to complete the respective audio multiple-choice test. This test was presented in paper format, with no conflicting audio, and without the use of any headphones.

The study was conducted in a quiet research laboratory. The typical noise level inside the room without any participants or experimental generated noises (only computers operating) was found to be, in terms of L_{eq,1min}, 38 dB(A).

The auditory conditions were presented in a counterbalanced order, as per a balanced Latin squares experimental design while the audio files were systematically varied to ensure within each audio grouping (e.g., six audio conditions) all audio pairs (i.e., condition and audio file) were equal. During each audio condition, continuous wideband noise was produced from the sound source placed out of view of the participant. Consistent with previous research [14], the sound level measured in the vicinity of the participant’s head was, in terms of L_{eq,1min}, 65 dB(A). This level was consistent with that reported by Ozcan and Nemlioglu, [1] typically reflective of that in the taxi phase of flight.

In all of the headphone conditions, the audio brief was played through the headphones under examination at a level determined by the participant. Specifically, participants were instructed prior to the commencement of the experiment to set the auditory volume at a level that facilitates extracting the most information from the audio file. This was performed with a test audio file (a short segment from the audio file which would be presented to them last) for no more than five seconds and in the presence of the background noise. This condition reflected that of the operational environment where passengers on commercial airlines are free to select their desired audio volume level (i.e., real life situation under investigation). In the remaining two conditions, the audio briefs were played through the Logitech speakers at 70 dB(A). Consistent with Molesworth and Burgess [14], this level was 5 dB(A) greater than the wideband noise level, as determined by a subject matter expert (i.e., flight attendant with 16 years experience on task). Following the six audio conditions, participants were thanked for their time and provided the bookshop gift voucher. The total time taken to complete the experiment was approximately 45 min.

3. Results

Since the main aim of the present study was to compare different auditory conditions as a result of different headphones and tasks (i.e., dual vs single task), a series of planned comparisons, opposed to a series of repeated measures analyses were employed. According to Tabachnick and Fidell [20], this approach maximises power since it restricts analyses to those of theoretical interest. For all analyses, the statistical package ‘PSY’ developed by Bird, Hadzi-Pavlovic, and Isaac [21] was employed.

The first planned comparison sought to determine if performance using the two different noise cancelling headphones varied in the single-task condition (i.e., no mathematics task), while the second planned comparison examined this same variable in the dual-task condition (i.e., with mathematics task). With alpha set at .05, and assumptions of normality met, the results of the first planned comparison examining scores in the single-task condition between Headphones 1 and Headphones 2 failed to reveal a statistically significant difference, F(1, 35) = 1.22, p = .276. This result closely reflected the result of the second planned comparison examining scores in the dual-task condition between the same headphones, F(1, 35) = .048, p = .494. Combined, these results indicate that participants performed similarly irrespective of the headphones used.

Having established that performance was similar irrespective of headphones, these two groups in each condition (single-task and dual-task) were collapsed, leaving four groups (see Table 1).
order to determine if performance under each of these conditions (single and dual task) varied as a result of employing noise cancelling headphones, a series of planned comparisons were conducted. With assumptions of normality satisfied, alpha was set at .025 in order to control for family-wise error (Bonferroni-adjusted \( \alpha = .05/2 \)). As illustrated in Table 2, the mean number of correct answers on the written audio test in condition 1 (noise cancelling headphones in single-task condition) was 7.85 (SD = 1.76). This was significantly different from condition 2 (brief through speaker (i.e., no noise cancelling headphones) and single-task condition; mean correct 5.72, SD = 2.94), \( F(1, 35) = 14.93, p < .001 \).

The same analysis was employed to determine if a difference existed in the dual-task condition between the ‘noise cancelling headphone group’ (condition 3) and ‘brief through speaker group’ (condition 4). However, since the objective of this condition was to examine performance with competing stimuli, it was first important to establish if groups performed in accordance with instructions. Remember participants were told their priority was to complete the maths based task and their performance during the dual-task conditions should reflect that on the baseline maths test. As a result, an examination of the data from the baseline maths test revealed participants answered an average of 61 questions (SD = 12) and made an average of 1 mistake (SD = 1.10). During the three experimental conditions (Headphones 1, Headphones 2 and no headphones) they answered fewer questions, 52 (SD = 14.01), 54 (SD = 12.62), and 54 (SD = 13.96) respectively as determined by a series of planned comparisons with alpha set at .017 (Bonferroni-adjusted \( \alpha = .05/3 \)), smallest \( F(1, 35) = 13.616, p = .001 \). However, between the three experimental conditions with alpha set at .017 (Bonferroni-adjusted \( \alpha = .05/3 \)), no differences were noted, largest \( F(1, 35) = 4.842, p = .034 \).

There was also no difference in the number of mistakes participants committed between the baseline maths condition and the three experimental conditions (Headphones 1, Headphones 2, and no headphones). .94 (SD = 1.07), 1.06 (DS = 1.09), .67 (SD = .76) respectively as determined by a series of planned comparisons with alpha set at .017 (Bonferroni-adjusted \( \alpha = .05/3 \)), largest \( F(1, 35) = 2.593, p = .116 \). No differences were also noted between the three experimental groups in terms of number of mistakes committed as determined by a series of planned comparisons with alpha set at .017 (Bonferroni-adjusted \( \alpha = .05/3 \)), largest \( F(1, 35) = 2.952, p = .095 \). Based on these results it is reasonable to conclude that the slower rate at which the participants completed the maths based task during the experimental conditions could be as a result of attending to stimuli both implicitly as well as explicitly [22]. Once noise is attended to (either implicitly or explicitly) it appears to disrupt the effective storage of the target information in working memory [23]. As a result, it can be concluded that participants performed similarly during the baseline and experimental conditions.

Comparing performance using a planned comparison with alpha set at .025 (Bonferroni-adjusted \( \alpha = .05/2 \)) between the noise cancelling group (condition 3) and control (condition 4) in the dual-task condition, participants were able to identify more words correctly when using noise cancelling headphones (6.47, SD = 1.24) than without (5.36, SD = 2.18), \( F(1, 35) = 13.18, p = .001 \). This result is consistent with those from the single-task condition and reflects favourably on the use of noise cancelling technology.

| Table 2 | Mean number of correct responses and standard deviation on the audio brief exercise distributed across the four revised experimental auditory conditions (max score 12). |
| --- | --- | --- | --- | --- |
| Experimental Group | Mean score | SD |
| Condition 1 (single task + noise cancelling) | 7.85 | 1.76 |
| Condition 2 (single task) | 5.72 | 2.94 |
| Condition 3 (dual task + noise cancelling) | 6.47 | 1.24 |
| Condition 4 (dual task) | 5.36 | 2.18 |

The final two analyses were designed to examine the relationship between audio condition (noise cancelling or no headphones) and concurrent task performance. Of particular importance is the second analysis that compares the single task condition without noise cancelling headphones (condition 2), a condition that reflects existing practices in commercial aviation, and the dual-task condition with noise cancelling headphones (condition 3). However prior to this it was important to compared performance using noise cancelling headphones in the single task condition (condition 1) with performance using noise cancelling headphones in the dual-task condition (condition 3). With a corrected alpha of .025 (Bonferroni-adjusted \( \alpha = .05/2 \)), the results of a planned comparison revealed a statistically significant difference (mean score 7.85 and 6.47 respectively), \( F(1, 35) = 27.32, p < .001 \). This result reflects favourably on performance in a single task condition with the use of noise cancelling headphones.

Recall the second analyses was designed to compare performance when no headphones are being used (brief through speaker) in the single task condition (condition 2) to a situation where noise cancelling headphones are used in a dual-task condition (condition 3). With a corrected alpha of .025 (Bonferroni-adjusted \( \alpha = .05/2 \)), the results of a planned comparison failed to revealed a statistically significant difference (mean score 5.72 and 6.47 respectively). \( F(1, 35) = 1.89, p = .184 \). Combined, the results from these two analyses support the hypothesis. As expected, performance during concurrent tasks when using noise cancelling headphones was inferior to a single task condition when using these headphones. Somewhat unex-
pected was the finding that performance during concurrent tasks when using noise cancelling headphones is no different to a situation involving a single task and no headphones (i.e., present situation in commercial aviation). The results of the present study also found no differences, in terms of performance between the two price comparable noise cancelling headphones under examination.

The results of the present study lend further support to the notion that noise, as an environmental stressor in aviation is real. They also highlight the beneficial effects of employing counter-measure such as noise cancelling headphones to reduce the negative impact of noise in the aircraft cabin. The results also suggest that noise cancelling technology can mediate between noise and performance on concurrent tasks. As many commercial aviation passengers can attest to, a large number of passengers fail to attend to the pre-flight safety brief when commuting. Therefore, increasing the quantity of information individuals are able to recognise from this safety brief has real safety implications, none more than in an emergency when this information needs to be both recalled and applied.

Noise cancelling headphones are not permitted during the pre-flight safety brief due to the category they fall within, namely Personal Electronic Device (PED) since they, or more specifically Transmitting-PEDs (T-PEDs) may interfere with communication or navigation equipment [24]. While there is limited evidence to support this ban [25,26], it is important to ensure unequivocally that they do not cause interference prior to advocating their use and/or lifting this ban. In the absence of any evidence to support the claims of interference with communication or navigation equipment, the results of the present research combined with that from Molesworth and Burgess [14] suggest aviation authorities and airlines need to revisit the prescribed use of this technology in the cabin.

It is well established that concurrent tasks [15–18] as well as noise [7–10] produce performance detriments. While the present study demonstrated the beneficial effects of reducing unwanted noise in both a single and dual-task situation, only one type of concurrent task was examined. Specifically, individuals were asked to complete a mathematical based task. What remains unknown is the effect of other concurrent tasks which are more closely aligned to the primary task such reading or completing a word exercise (e.g., crossword). Research examining the effects of various concurrent tasks on performance, has found that when the noise shares similar properties to the target stimulus in terms of meaningfulness, then the disruption is greater than if it was considered less meaningful [23]. Therefore, future research should examine the effect of concurrent tasks such as crosswords on participants’ ability to recall auditory information when using noise cancelling headphones.

Future research could also be directed to investigate age related effects of noise cancelling technology. It is well established that there is a positive relationship between age and the effects of noise on performance [27]. Therefore, it is assumed that the older generations would benefit even more from employing such technology. However since this remains untested, it is potentially a limitation of the present research in terms of applying the results to the population generally.

Since the main aim of the present research was to improve the recognition of information contained in a pre-flight safety brief, alternate methods other than providing every commercial passenger noise cancelling headphones need to be explored. Having knowledge that reducing noise facilitates word recognition, engineering solutions can be employed to improve the noise insulating properties of aircraft as well as their engines. Molesworth and Burgess [14] propose alternate methods to improve word recognition such as increasing the salience of the pre-flight safety brief to better engage the listener. It may also be feasible to perform the pre-flight safety brief at an earlier time in the journey when the aircraft engines are at idle or even prior to start-up. Considering most safety briefs take less than 2 min, the benefits gained should be outweighed by any (if at all) time lost.

Finally, the present study focused on only one aspect of a pre-flight safety brief, namely the audio component. It is possible that the supplementary information provided by the accompanying video or live briefing compensates for the detrimental effects of the noise in the cabin; this remains to be tested. However, if passengers are engaged in a secondary task other than the supplementary safety information provided such as reading a newspaper or completing a puzzle, then it would be assumed that this safety related supplementary information (e.g., reading safety card) would have little if any affect. This excludes situations where passengers listen to their own audio source such as an mp3 player where such behaviour has been demonstrated to be detrimental to performance [14].

5. Conclusion

Noise cancelling technology in the form of noise cancelling headphones facilitates in creating an improved environment to hear auditory information such as a pre-flight safety brief on an aircraft. The benefits of this technology extend to those situations where the listener may be otherwise distracted or engaged in a task other than the target task. In isolation, these results provide a compelling argument for aviation governing authorities and airlines to reconsider the conditions under which this technology can be used. However, prior to advocating such a move, careful consideration needs to be afforded to the transmitting interference characteristics of this technology plus the potential for it to be misused (i.e., passengers listening to external audio sources).

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