Original Article

Listening effort at signal-to-noise ratios that are typical of the school classroom

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Abstract

Objective: The aim of the study was to measure listening effort at typical classroom signal-to-noise ratios (SNRs). **Design:** Listening effort was measured using a dual task paradigm. Participants repeated monosyllabic words presented in a background of children's chatter (primary task) at SNRs that are considered typical of the school classroom environment (quiet, +4, 0, -4 dB) while simultaneously rehearsing sets of five digits for recall (secondary task). High listening effort requires greater cognitive resources and is associated with reduced performance on the secondary task. **Study sample:** Thirty one normal-hearing children (9-12 years). **Results:** Performance was generally maintained on the listening task when multitasking; however, performance decreased on the secondary recall task, especially at the more negative SNRs. **Conclusions:** This demonstrates that considerable listening effort is required when listening at SNRs that are typical of the school classroom.

Sumario

Objetivo: El propósito de este estudio fue medir el esfuerzo para escuchar en un salón de clases con un nivel señal/ruido típico. **Diseño:** Se midió el esfuerzo para escuchar utilizando un paradigma de doble tarea. Los participantes repitieron palabras monosilábicas presentadas sobre un ruido de fondo de niños hablando (tarea primaria) con una tasa señal/ruido considerada como típica del ambiente en un salón de clases (silencio, +4, 0, -4 dB) mientras que simultáneamente se ejercitaba la memorización de grupos de cinco dígitos (tarea secundaria). El esfuerzo elevado requiere grandes habilidades cognitivas y se asocia con un desempeño pobre en la tarea secundaria. **Muestra:** Treinta y un niños normoyentes (9 a 11 años de edad). **Resultados:** El desempeño generalmente se mantuvo en la tarea de escuchar durante la realización de varias tareas; sin embargo, el desempeño disminuyó en la tarea de recordar, especialmente en el extremo negativo de SNR. **Conclusiones:** Esto demuestra que se requiere un esfuerzo considerable para escuchar cuando hay un SNR típico del salón de clases.

Key Words: Listening effort, Dual task, Signal to noise ratio, Children, Cognitive resources, Top down processing, Multitasking

In everyday life, we are frequently required to divide our attention across several tasks. The ability to multitask depends on the nature and the difficulty of the tasks. Research on divided attention typically involves a dual-task paradigm in which performance on a single task is compared with performance on the same task when it is performed in combination with a second task. According to the model of limited cognitive capacity proposed by Kahneman (1973), if the primary task becomes more demanding and requires more effort, performance on the secondary task (or both tasks) will deteriorate.

In the educational environment, children are often expected to multitask. For example, they may be required to listen to the teacher while taking notes, consolidating the taught information, or using the internet. In addition, the educational environment is not always optimal for listening: classrooms are frequently noisy environments and it is generally accepted that noise has a detrimental effect upon learning and educational attainment of school children (for review see Shield & Dockrell, 2003). Classroom signal-to-noise ratios

(SNRs) have typically been reported to be in the range, -7 dB to +5 dB (Arnold & Canning, 1999; Crandell & Smaldino, 1995, 2000) and are often close to 0 dB (Arnold & Canning, 1999). Multitasking may be challenging in such noisy environments because greater listening effort is required. Listening effort refers to the cognitive effort exerted by the listener to understand the speech signal. In ideal conditions, where the speech signal is clearly audible, listening is relatively effortless for normal-hearing adults. When conditions become non-optimal, the listener needs to exert an increased effort to understand the signal. While ease of listening can be measured using self-report ratings, listening effort in children has generally been measured using a dual-task paradigm.

Hicks and Tharpe (2002) and McFadden and Pittman (2008) used dual-task paradigms to investigate the effect of SNR on listening effort in children. Hicks and Tharpe (2002) compared a group of 5–11 year old children having a mild hearing impairment with a group of children having normal hearing. The primary task was word

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Abbreviations:

AB words	Arthur Boothroyd words
dB	Decibels
RT	Reaction time
SNR	Signal-to-noise ratio
WM	Working memory

recognition presented at 70 dB(A) in quiet and in babble at a SNR of +10, +15, and +20 dB. The secondary task was reaction time (RT) to a light presented randomly in time. In the dual-task condition, RT was longer in the children with hearing impairment and this is consistent with the notion that children with hearing impairment expend more effort in listening than normal-hearing children. However the increased RT was similar across the different SNRs suggesting that there was no effect of SNR on listening effort. McFadden and Pittman (2008) compared a group of 8–12 year old children with a mild hearing impairment and a group of children with normal hearing. The primary task was to categorize words as animal, food, or people. The words were presented at 65 dB SPL in quiet and in noise at a SNR of 0 and +6 dB. The secondary task measured the completion rate of a dot-to-dot puzzle. Performance on the secondary task fell when performing both tasks and this was similar for both groups. Mean performance was similar for the two SNRs again suggesting that there was no effect of SNR on listening effort.

Although the findings were negative, the SNRs used in these two studies were relatively favourable; therefore, the findings may not be representative of the listening effort required in classroom settings. Performance on the secondary task may be considerably poorer at SNRs that typically occur in the school classroom (−7 dB to +5 dB, Arnold & Canning, 1999). In addition, an increase in listening effort (as shown by a larger decrement in performance on the secondary task) may only become apparent at these poorer SNRs.

Stelmachowicz et al (2007) used a dual-task paradigm to investigate the effect of stimulus bandwidth in a group of 7–14 year old children having a mild hearing impairment and a group of children with normal hearing. The primary task was word recognition, filtered at either 5 or 10 kHz bandwidth and presented at 60 dB SPL in speech shaped noise at +8 dB SNR. The secondary task was recall of a string of five digits. Digit recall was poorer when performing both tasks together. Performance on the digit recall was similar across the two groups of children and for the two stimulus bandwidths. This suggests that listening effort was similar across test conditions. Again, the SNR was relatively favourable and not typical of school classrooms (−7 dB to +5 dB, Arnold & Canning, 1999). Choi et al (2008) investigated the ability of normal hearing 7–14 year old children to switch attention between two tasks presented in a dual-task paradigm. The two tasks were word recognition (at 65 dB SPL and SNR of +8 dB) and digit recall. Half of the children were told that word recognition was the primary task and the remainder were told that digit recall was the primary task. Unexpectedly, both groups showed a reduction in digit recall suggesting that the children may not be able to direct their attention to the primary task accordingly. Once again, the SNR was relatively favourable compared to school classrooms.

In summary, studies have used a dual-task paradigm to measure listening effort in children but none have used SNRs that are considered typical of some school classrooms. It is felt that the test conditions in these studies were not sufficiently challenging to identify the greater listening effort of children with hearing impairment.

Therefore, the aim of the present study was to measure listening effort in normal-hearing children, using a dual-task paradigm, at SNRs that are representative of the classroom environment. The validity of the study was increased by using multi-speaker babble recorded from children's background chatter (Hamilton, 2008). It was hypothesized that as the SNR became more negative, listening effort would increase and this would reveal itself as an increasing decrement in performance on the secondary task.

Methods

Participants

Thirty one normal-hearing children (14 male and 17 female) aged 9–12 years (mean 10 years, 8 months, $\pm$ 6.12 months) with no history of hearing, communication, or learning problems (as determined by a questionnaire given to teachers and parents) participated in the study. All children spoke English as their first language. Hearing thresholds (as tested using the BSA recommended procedure, British Society of Audiology, 2004) were $\leq$ 20 dB HL at 0.5–4 kHz in both ears, and middle-ear function was within normal limits on tympanometry. The study received ethics approval from the University of Manchester, School of Psychological Sciences Research Ethics Committee. Written parental consent, as well as verbal consent from the children, was obtained before testing commenced. Data from one child was excluded from the analysis because he/she was unable to perform the secondary task successfully in any condition.

Task stimuli

The primary task was a word recognition task using Arthur Boothroyd (AB) monosyllabic consonant-vowel-consonant words (Boothroyd, 1968), spoken by a male speaker. AB words are often used in speech in noise testing in children and have a recognized scoring system. These were stored digitally on a laptop computer. Words were equated at 65 dB SPL root-mean-square measured in a B&K 4153 coupler, and presented binaurally via KOSS KC50 earphones. Words were presented in sets of five with an onset-to-onset interval of 4 s. Each set was digitally mixed with multi-speaker babble which commenced 2 s before the onset of the first word and ended 2 s after the onset of the fifth word. The level of babble was adjusted to create four conditions: quiet (no babble), +4 dB, 0 dB, and −4 dB SNR. These values were based on SNRs reported for typical classrooms (e.g. Arnold & Canning, 1999). The secondary task involved rehearsing digits and reciting these at a later time. A serial recall task was chosen to compete with word recognition because both tasks are thought to require processing capacity in the phonological loop of working memory (WM) (Baddeley, 2003). Stimuli consisted of randomly-generated sets of five-digit numbers displayed simultaneously on the laptop monitor for 3 s.

Procedure

All testing was carried out in a quiet room in the child's school using a counterbalanced design. To obtain baseline values for each test condition, two sets of five AB words were presented at each SNR. The participant's task was to verbally repeat each word exactly as heard, even if this sounded incorrect. A maximum of three points were assigned to each word, one for each phoneme, so that each test condition was scored out of 30. A correctly recalled word scored three points and lower scores were given if only some phonemes were correct.

A baseline measure of digit recall was recorded for each participant. A random string of five digits was presented on the laptop screen for 3 s. Before presentation a visual and audio prompt of 'Look at the numbers' was given. Participants were instructed to remember the digits in the exact order they occurred until a visual and audio prompt of 'Say the numbers' appeared 20 seconds later. Each digit was considered as an individual item and only digits in the exact serial position were scored as correct. During the memorizing period, the AB(S) words were presented in all conditions, using a balanced design, but participants were instructed to ignore these. Four sets of digits were used so that the recall task was scored out of 20.

In the dual-task condition, a string of five digits were presented for 3 s. In the subsequent 20-s period, a set of five words were presented and scored. The participant was then asked to recall the rehearsed digits. This procedure was repeated until there were four sets of words and four digit recall trials. The importance of the primary speech recognition task was emphasized in the instructions and this was reinforced by providing a reward for each word repeated correctly.

Results

The data are summarized in Figures 1 and 2. For both figures, performance on the single baseline condition is shown as filled columns, and performance on the dual-task condition is shown as open columns.

Mean performance on the speech task reduced from 97–98%, when the words were presented in quiet, and to 47–53% at a SNR of -4 dB. A two-factor repeated-measures ANOVA on the speech recognition scores revealed a statistically significant effect of SNR [$F(3,90) = 481.03$; $p < 0.001$] and task combination (single vs. dual) [$F(1,30) = 14.91$; $p = 0.001$]. There was also a significant interaction between SNR and task combination [$F(3,90) = 8.39$; $p < 0.001$]. Pair wise comparisons for the SNR conditions were performed on the single and dual-task data separately using t -tests with Bonferroni correction for multiple paired comparisons ($0.05/6 = 0.008$). All comparisons for both the dual-task and single task conditions were statistically significant ($p < 0.001$).

Mean baseline performance on the digit recall task was 80–90%. Performance was reduced in the dual-task condition, especially at the more negative SNRs. A two-factor repeated-measures ANOVA on the digit recall scores revealed a statistically significant effect of SNR [$F(3,90) = 16.53$; $p < 0.001$] and task combination [$F(1,30) = 124.13$; $p < 0.001$]. There was also a significant interaction between

SNR and task combination [$F(3,90) = 20.62$; $p < 0.001$]. Again, pair wise comparisons were carried out with Bonferroni correction for multiple paired comparisons ($0.05/6 = 0.008$). For the single task condition, the mean differences in performance between quiet and $+4$ dB SNR, and quiet and 0 dB SNR were significant ($p < 0.002$). None of the remaining single task comparisons were significant ($p > 0.138$), presumably because the children were ignoring the noise as instructed. For the dual-task condition, there was a statistically significant difference for all comparisons ($p < 0.002$) except for 0 dB vs. -4 dB and for quiet vs. $+4$ dB SNR, neither of which survived correction ($p > 0.002$).

Discussion

As expected, mean performance reduced on the speech recognition task as the SNR became more negative. In general, the children were able to provide a similar level of mean performance on the speech recognition task when this was presented in the dual-task condition; however, greater listening effort was required and fewer cognitive resources were available for the secondary task, as shown by the poorer mean performance on the digit recall task, especially at the more negative SNRs. This is consistent with earlier dual-task studies involving normal-hearing adults (e.g. Downs & Crum, 1978) that showed a decrease in RT when noise was added to the primary listening task. Mean performance on the secondary digit recall was relatively poor for the speech-in-quiet condition. During data collection it was noted that the children appeared more relaxed and less vigilant in this condition, perhaps because it did not require many cognitive resources and was less of a challenge (this may be a problem with the artificial nature of the experiment). When noise was added, vigilance appeared to increase and the children were more focused on the task. This leads us to speculate that fewer cognitive resources may have been used for this dual-task condition and this could explain the relatively poor performance on digit recall at a high SNR. The conditions were counterbalanced and every time a word appeared in quiet, the general trend was that children appeared less vigilant, irrespective of when this condition appeared.

As mentioned earlier, listening effort in children has been investigated in dual-task studies by Hicks and Tharpe (2002), Stelmachowicz et al (2007), and McFadden and Pittman (2008). These showed the expected decrease in secondary task performance; however, performance on the secondary task (reaction time, digit recall, and puzzle completion speed, respectively) did not deteriorate as the primary task was made more difficult (poorer SNR or low pass

Figure 1. Mean performance (percent correct) on the speech recognition task. Filled columns, single task baseline condition; open columns, dual task condition. Error bars show 95% confidence intervals.

Figure 2. Mean performance (percent correct) on the digit recall task. Filled columns, single task baseline condition; open columns, dual task condition. Error bars show 95% confidence intervals.

filtering). The most likely explanation is that the primary test conditions were not differentiated sufficiently in terms of demands on cognitive resources. The present study shows a clear and unambiguous deterioration in secondary task performance as SNR became less favourable. Choi et al (2008) has also shown listening effort to increase in children when using a dual-task paradigm (digit recall). Interestingly, the findings of Choi et al (2008) were the same when the children were instructed to give priority to either the listening task or the digit recall task; therefore, the listening task received preferential allocation regardless of task instructions. The authors suggest that children had immature attention control and may have reverted to the relatively easier listening task. A different finding may have been obtained with a less demanding secondary task and this may be an important methodological consideration in future studies. In the current study there was no evidence of lack of persistence at the higher SNRs, a future study could include some less favourable SNR conditions to see if this happens.

It is also important to consider the limitations of the present study. First, the study could not control how the children remembered the digits. They may have rehearsed them verbally (as was intended) or they may have relied on remembering the visual representation only. If they used the later, the lack of verbal rehearsal may have meant there was less competition for resources (due to the task involving cross-modality processing in visuo-spatial WM and auditory-verbal WM). Second, it has been shown that different types of interfering noise may affect performance differently. For example multi-speaker noise can have a more adverse effect than pink noise on speech discrimination scores (Papso & Blood, 1989). It is possible that different types of noise may have a different level of interference with demands on attention and on listening effort. However multi-speaker babble was chosen in this study to increase validity and simulate real life classroom listening. For future studies it may be worth recording the actual sound level of the test room. Third, reverberation time is something that is often not considered in studies of listening effort but is another factor that would influence listening effort in real life classroom situations. Fourth, the present findings might be limited due to the artificial nature of the test environment and the fact that the words were presented over headphones using a mixed (and not separated spatially) competition noise. Future studies could consider if the results are replicated when a sound-field signal is spatially separated from noise just as a teacher's voice would be separated from ambient sounds, and also consider the reverberant characteristics of a typical classroom. This will be required in studies involving hearing aids.

Despite these limitations, the findings may have important implications for educational environments and are particularly concerning when considering a child's learning. Classroom activities involve listening and learning and successful performance on a secondary task to listening is important. If a child is spending increased effort in listening, they will have limited resources available for additional tasks and so their learning may be compromised. It is well known that children who are hearing-impaired are more seriously affected by noise (Crandell & Smaldino, 2000) and this is also likely to be the case when, for example, children are not being taught in their first language (Mayo et al, 1997), or have with learning difficulties (Crandell et al 1995), or speech and language difficulties (e.g. Crandell et al, 1995; Shield & Dockrell, 2003).

Many studies have considered the effects of noise on cognitive, motivational, and physiological measures. For example, studies have found that children or adults with normal hearing give up on a difficult puzzle task more readily when listening in noisy environments than when listening in quiet environments (e.g. Cohen et al,

1980). Listening in noise may affect the rate of learning and the cognitive resources available to perform at an expected pace. It has been shown that children's speed on information processing tasks is reduced when listening in noise (Dockrell & Shield, 2006) and that their personal rate of work decreases (Ando et al, 1975). This suggests that children may give up more readily if listening effort is increased in noise and emphasizes again the need for additional studies considering listening effort in noise in classrooms.

Conclusion

Greater listening effort is required at typical classroom SNRs. As a result, fewer cognitive resources are available to complete other tasks. This finding may have implications for classroom noise levels and the design of classroom learning environments.

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