Logopedics Phoniatrics Vocology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ilog20

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To cite this article: K. Jonas Brännström, Viveka Lyberg-Åhlander & Birgitta Sahlén (2020): Perceived listening effort in children with hearing loss: listening to a dysphonic voice in quiet and in noise, Logopedics Phoniatrics Vocology, DOI: 10.1080/14015439.2020.1794030

To link to this article: https://doi.org/10.1080/14015439.2020.1794030

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Published online: 22 Jul 2020.

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LOGOPEDICS PHONIATRICS VOCOLOGY
https://doi.org/10.1080/14015439.2020.1794030

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Perceived listening effort in children with hearing loss: listening to a dysphonic voice in quiet and in noise

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ABSTRACT

Aim: The present study investigates the effect of signal degradation on perceived listening effort in children with hearing loss listening in a simulated class-room context. It also examines the associations between perceived listening effort, passage comprehension performance and executive functioning.

Methods: Twenty-four children (aged 06:03–13:00 years) with hearing impairment using cochlear implant (CI) and/or hearing aids (HA) participated. The children made ratings of perceived listening effort after completing an auditory passage comprehension task. All children performed the task in four different listening conditions: listening to a typical (i.e. normal) voice in quiet, to a dysphonic voice in quiet, to a typical voice in background noise and to a dysphonic voice in background noise. In addition, the children completed a task assessing executive function.

Results: Both voice quality and background noise increased perceived listening effort in children with CI/HA, but no interaction with executive function was seen.

Conclusion: Since increased listening effort seems to be a consequence of increased cognitive resource spending, it is likely that less resources will be available for these children not only to comprehend but also to learn in challenging listening environments such as classrooms.

ARTICLE HISTORY
Received 17 December 2018
Revised 23 June 2020
Accepted 3 July 2020

KEYWORDS
Children; executive function; dysphonic voice; multi-talker babble noise

Introduction

In a previous study, we examined the effect of voice quality and competing speakers on perceived effort in children with normal hearing and found that background listening condition affected ratings of perceived effort but not ratings of voice quality [1]. In the present study using a similar experimental set-up we investigate the effect of signal degradation on perceived effort in children with hearing loss listening in a simulated class-room context. It has been suggested that speech signals can be degraded at for example the source, during transmission or due to receiver limitations [2]. Source signal degradation can occur when the speaker has a speech disorder. Transmission degradation can be caused by the presence of background noise or reverberation. Receiver limitations may be caused by peripheral deficiencies such as a peripheral hearing loss or limitations in cognitive capacity or an incomplete or impaired language model. Any of these degradations alone or in combination may make it harder for a listener to recognize speech, direct attention and use the individual memory capacity optimally. Thus, perceptual learning may become limited or impaired. When listening to a degraded speech signal, more cognitive capacity is required to explicitly process the incoming signal [3–6].

Explicit processing of degraded signals requires use of cognitive resources which manifests itself for the listener as an increased perceived effort [7]. According to Rönnberg [3–6] the listener relies on an automatic and rapid process when listening to speech while it is presented under ideal listening conditions. In their model, the listener matches the speech input to its' phonological representations. After a speech sound has reached the speech sound identification threshold, their representations are matched to the phonological representations available in the sematic long-term memory [3–6]. This process provides the means to identify their lexical representations and also their meaning. Rönnberg [3] considered this process to be implicit as it is both automatic and fast. In contrast, explicit processing which is required when listening under degraded listening conditions, for example speech presented in background noise, as the match between the input representations and the stored representations becomes imperfect. Rönnberg and colleagues [3,5,6] suggested that more cognitive resources are required to perform explicit processing which in turn means that less are available for the listener to encode information into, and retrieve information from long-term memory representations. The increased use of cognitive resources to explicitly process the mismatch also presents itself as an increased perceived effort which can be assumed to represent increased cognitive demands [7].

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Children listen to their teacher's voice throughout the school day in classrooms with often suboptimal listening conditions. Previous studies suggest that signal degradation from both a dysphonic voice and background noise may influence language comprehension and perceived effort in children with normal hearing [8,9]. A dysphonic voice is a common voice disorder among teachers [10]. It is more common than seen in the general population [11,12]. The dysphonic voice is caused by functional changes due to high vocal load [13]. In comparison to a typical voice, it is characterized as being instable, hyper functional (pressed), breathy or rough. In children with normal hearing, previous studies suggest that children have more negative attitudes towards listening to a dysphonic voice compared to listening to a typical voice [14]. More negative attitudes may depend on that this voice quality is more demanding to listen to and hence requires more effort to be able to perform the task at hand. On the other hand, von Lochow et al. [1] found only a close to significant effect of a dysphonic voice on ratings of perceived effort in children with normal hearing. However, it is possible that the amount of signal degradation that the dysphonic voice represented was not sufficient to force the listener to exert explicit processing. In the same study, it was found that multi-talker babble noise increased perceived effort significantly, suggesting that sufficient amount of signal degradation will lead to increased perceived effort.

Speech signals may also be degraded by receiver limitations. Hearing loss represents a receiver limitation. Despite the use of listening devices such as cochlear implants (CI) and hearing aids (HA), a hearing loss still provides speech signal degradation [15–18] that requires more explicit processing. Previous studies suggest that children with hearing loss need more favorable signal-to-noise ratio (SNR) to be able to perform at the same level in listening tasks as children with normal hearing [19,20]. Thus, the combination of source signal and transmission degradation together with receiver limitations may provide sufficient amount of signal degradation to elicit increased perceived effort in children with CI/HA. Furthermore, additional receiver limitations also occur among children with hearing loss with concurrent language disorder or weak school language (i.e. when the school language has been learned a second language, L2), who are challenged by both low level (perceptual) and high level (linguistic) processing limitations.

There seems to be a relationship between task difficulty and perceived effort. According to the motivational intensity theory [21], an increase in task difficulty in a task with known difficulty (the participant has experience with the specific task) will increase the amount of effort an individual is willing to use to solve the task as long as the difficulty of the task does not make it impossible to complete the task successfully. Until this level (called success importance) is reached, effort is proportional to task difficulty [21,22]. That is, the individual continues to expend more and more effort when task difficulty increases, but only until it becomes too excessive so that it is not worth spending any more effort. Although the concept of listening effort is not understood well yet, empirical findings corroborate this reasoning. Ohlenforst et al. [23] found that by decreasing the SNR, adult listeners with and without hearing loss ultimately found that as the tasks demands became too excessive, listening effort measured as pupil dilatation decreased substantially. Assuming a relationship between task difficulty and perceived effort, we expect that as speech signal deterioration increases, i.e. task difficulty increases, perceived effort will increase proportionally from listening to a typical voice in quiet to listening to a dysphonic voice in background noise for children with CI/HA.

Ecological validity of a study is important when assessing the effect of signal degradation on perception and comprehension in children. Experimental tasks and listening conditions should be similar to every day experiences to increase generalisation of the findings. At school, children are exposed to spoken narrative tasks that require the children to listen, understand, comprehend and remember what is said. Auditory passage comprehension tasks may include a narrative read aloud by the examiner with content questions tapping explicit and/or implicit knowledge. This type of task is similar to tasks encountered in the classroom. Listening conditions in the classroom are often degraded due to competing speech and other noises emerging both from the inhabitants of the classroom and from the surrounding classrooms [24,25]. Not only does the sound environment influence the listener, but teachers have to compete with other sound and noise sources to make themselves heard. The increased vocal effort puts strain on their voices which alters their voice quality.

Most previous studies on perceived effort have been made on adult listeners [26]. Therefore, the aim of the present study is to investigate the effect of voice quality and multi-talker babble noise on perceived effort in a passage comprehension task in children with CI/HA. In addition, the relationships between perceived effort and, age, passage comprehension performance and executive functioning were assessed. We hypothesize that listening to a dysphonic voice in quiet and in noise will be perceived as more effortful than listening to a typical voice in these background listening conditions in children with CI/HA. In a similar manner, we hypothesize that listening in quiet will be less effortful than listening in noise. Furthermore, we hypothesize that children with higher passage comprehension performance and executive functioning would be less susceptible to the effect of voice quality and background noise in their ratings of perceived effort.

Materials and method

Participants

Twenty-four children with hearing loss attending schools throughout Sweden were recruited to the study. Fourteen children were recruited through their schools while 10 children were recruited at a summer camp for children with cochlear implants or hearing aids organized by the Swedish Organisation for Children with Cochlear Implants or Hearing Aids (Barnplantorna). To be included, a child had

Table 1. Descriptive information on all children with cochlear implants (CI) and hearing aids (HA).

	N	%
Monaural CI	1	4%
Binaural CI	11	46%
Monaural HA	2	8%
Binaural HA	6	25%
Bimodal fitting	4	17%
Mainstreamed in typical class	21	88%
Attending school for children with hearing loss	3	13%
Requiring special services at school	11	46%
Current SLP contact	8	33%
Previous SLP contact	18	75%
Non-native Swedish speakers (Multilingualism)	4	17%

SLP: Speech and language pathologist. ($N = 24$).

to be a regular cochlear implant or hearing aid user or using a combination of both (bimodal fitting), be able to understand and speak Swedish at a good-enough level to participate in class-room activities and follow school curriculum and aged between 6 and 13 years. All recruited children (11 boys and 13 girls) were included. They had an average age of 09:03 (years: months) with a range from 06:03 to 13:00. Descriptive information on the children is provided in Table 1. It can be noted in the table that eight children had ongoing and 18 children had had previous speech and language pathologist contact. In Sweden, speech and language pathologist contact is mandatory for children with hearing loss. The Regional Ethics Committee in Lund, Sweden (application 2014/408) approved the project.

Passage comprehension task and listening conditions

Five passages were selected from a subtest in the Swedish version of the Clinical Evaluation of Language fundamentals–Fourth Edition (CELF-4) [27]. The passages were used as an auditory passage comprehension test. One passage was used as exercise to familiarize the child with the task. Four passages were used to test passage comprehension in four different listening conditions. Each passage has a unique topic content, for example a short story on a reading contest in a school. Since the topics are not universal, language skills along with cognitive and social skills also influence performance on CELF-4. The passages had slightly different durations ranging from about 40–55 s. The children were instructed to first listen to a passage, then answer five questions (e.g. "What were the school children supposed to do?") on the passage content and finally rate the perceived effort of the task (see below).

Using recorded material, four listening conditions were created for the passage comprehension task. The listening conditions were: listening to a typical voice in quiet, to a dysphonic voice in quiet, to a typical voice in background noise and to a dysphonic voice in background noise. These four listening conditions were created for all four passages in order to be able to counterbalance both listening condition and passage content across the children to minimize order and fatigue effects on the results.

The five passages (one exercise and four actual test passages) were recorded once with a typical voice and once with a provoked dysphonic voice. The same female speaker (49 years old and one of the authors) was used for all recordings. A vocally loading procedure was used to provoke the dysphonic voice quality [28]. A background noise was presented at 85 dB SPL Leq (the equivalent continuous sound level as verified using a Brüel and Kjaer integrating-averaging sound level meter, type 2240 with a 60 s integration time) in a sound treated booth. The speaker was instructed to read aloud while making herself heard over this noise at all times. The background noise (the International Speech Test Signal, ISTS; [29] was presented using a laptop computer and a Fostex SPA 12 loudspeaker (Fostex Corporation, Tokyo, Japan). The vocal loading procedure made the speaker emit speech at about 90 − 95 dB SPL for 20 min. Thereafter, without allowing for any rest, the passages were immediately recorded for the dysphonic voice.

The passage comprehension passages were recorded in the same manner for the typical and the dysphonic voice. All recordings were made while the speaker listened to a background noise presented at 55 dB SPL Leq (presented using the same equipment and verified with the same equipment as in the vocally load procedure). The recordings were made when the speaker read the passages aloud while making herself heard over the noise. Here ISTS was also used but it had been time-shifted and duplicated eight times to get a less modulated noise signal with the same spectral content [14]. The resulting speech levels were approximately 60–65 dB SPL as monitored using a head-mounted microphone MKE 2, no 09_1 (Sennheiser, en-de.sennheiser.com/). Recordings were made with a Lectret HE-747 microphone connected to a Zoom H2 (Zoom Corporation, Tokyo, Japan) using 44.1 kHz/16-bit sampling frequency. After removing pauses and other silent sections, all passages were normalized offline to the same average root-mean-square in dB Adobe Audition (version 6; Adobe Systems, San José, Ca). After the normalization, the original pauses and sections were added to the passages again.

Three clinical speech and language pathologists judged the voice quality authenticity in the recordings of the typical voice and the dysphonic voice. Judgements were made regarding the parameters instability, pressure (hyper function), breathiness and roughness. An overall judgement of the voice quality was also made. These judgements were made in an analysis software, *Visual sort and rate–Visor* [30]. The speech and language pathologists judged the degree of voice disorder in each parameter on a visual analogue scale ranging from 0 (no occurrence) to 10 (maximum occurrence). They made their assessments together at the same time. The final judgement was made in consensus. In clinical practice, a score higher than 5 is deemed pathological. The typical voice was judged as a 1 regarding hyper function while the dysphonic voice was judged as a 7. The speech and language pathologists judged the remainder of the parameters as 0. In an overall assessment of the degree of voice disorder, the typical voice was judged as 0 and the dysphonic voice as 4.

The background noise used in the listening conditions with noise consisted of the combination of the individual recordings of four girls (9 – 11 years old) reading separate chapters in an age appropriate book [31]. More details are available in von Lochow et al. [8]. The girls were recorded individually at separate sessions in a sound treated booth using a Zoom H2 (Zoom Corporation, Tokyo, Japan; 44.1 kHz/16-bit sampling frequency) with a portable microphone JTS (UT16HW) and a JTS (US800ID) receiver. These recordings were normalized offline to the same average root-mean-square in dB using Adobe Audition (version 6; Adobe Systems, San José, Ca). Normalization was made after removing pauses and other silent sections. These pauses and other silent sections were added again and the four resulting sound files were combined into one file representing a multi-talker babble noise. This noise was added to the passage recordings to create the listening conditions with background noise with a 10 dB SNR. The rationale for using this SNR was to provide challenging listening conditions without compromising audibility. In the passages with background noise, the background noise begun 1 s before the beginning of the speech signal and ended 1 s after the end of the speech signal.

Procedures and ratings of perceived effort

Testing took place in a quiet room either at their school or at camp. All children were tested by an examiner. The examiner instructed the children verbally. The instructions were to listen to four passages sometimes presented in quiet and sometimes in noise. After listening to a passage, the child was instructed to first answer five questions on the passage content and then rate his/her perceived effort. A visual analogue scale of 100 millimeters was used to assess the perceived effort of the passages. The left-handed endpoint of the scale was visualized using an unhappy emoticon. The right-handed endpoint was visualized using a happy emoticon. The children were used to these types of judgements as they are commonly used in Swedish schools for different types of evaluations. They rated their perceived effort based on the question "*How strenuous was the test?*" by ticking the scale using a pen. The distance from the left-handed endpoint to the tick was measured in millimeters. Thus, a longer distance represented a lower perceived effort. The ratings ranged from 0 to 100 where a score of 0 represents the highest amount of perceived effort and a score of 100 represented the lowest amount of perceived effort. To familiarize the child with the task, an exercise passage with the typical voice in quiet was made before the actual testing commenced. During the actual testing the four passages representing the different listening conditions were presented one at the time.

The speech presentation level was set to 70 dB SPL in all listening conditions. In the two listening conditions with background noise, a 10 dB SNR was used. The passages were presented using a laptop computer *via* a Bose Companion 2 loudspeaker. The loudspeaker was placed 1 m in front of the child (0 degree azimuth) at with an elevation approximately equal to the child's head. A Brüel and Kjaer integrating-averaging sound level meter (type 2240) was used to verify presentation levels. Verification was made using a 1000 Hz tone with a root-mean-square in dB equal to the speech signals. The passage content and listening condition order were counterbalanced across subjects to minimize any order or fatigue effects. The test session durations were about 1–1.5 h.

Assessment of executive function

Following the passage comprehension test, the children were tested on Elithorn Mazes (EM). EM can be used to assess executive functions in children aged eight to 16 years old (Wechsler Intelligence Scale for Children–Fourth Edition; [32]. EM can be used to assess the relationship between executive function and voice quality effects [1,8,33]. More specifically, EM assesses organization, planning skills, inhibitory control, and processing. The examiner instructed the child verbally to draw a path out of a maze. The path needed to cross a certain number of predefined dots located within the maze. The maze was presented on paper and the child used a pen to complete the task. Three exercise mazes were presented initially to familiarize the child with the task. The actual testing consisted of the child trying to complete seven mazes, one at a time, with increasing complexity. The scoring was made in the following manner; For each maze, the child has to complete the trial within 120 s. A second trial is allowed if the child is unable to complete the task during the first trial. A correctly completed maze receives a score of four [4]. A time bonus of four [4] is added if the child completes the maze using shorter time. If the child fails the first trial, no time bonus is awarded. Thus, each maze can be awarded a score of eight [8] and the seven mazes can yield a maximum score of 56.

Statistical analyses

The variables were perceived effort for the different listening conditions in the passage comprehension (CELF-4 responses) task, executive function and passage comprehension scores. In addition, four composite variables were derived from the variables for perceived effort for the different listening conditions: average scores for perceived effort with typical voice (average of ratings in quiet and in noise), average scores for perceived effort with dysphonic voice (average of ratings in quiet and in noise), average scores for perceived effort in quiet (average of ratings typical and dysphonic voice) and average scores for perceived effort in noise (average of ratings typical and dysphonic voice). These composite scores were calculated to be able to compare overall effects of voice quality and background listening condition on ratings pf perceived effort. Non-parametric statistics were used as ratings of perceived effort could be considered to be on ordinal scale. An alpha level of 0.05 was considered statistically significant. Friedman test was used to test the effect of listening condition on ratings of perceived effort. If significant, Wilcoxon Signed Ranks test was used to compare between conditions. Wilcoxon Signed Ranks test was also used to compare differences in composite scores. Spearman's rank correlation coefficients (rho) were used to assess relationships between variables.

Results

Initially, a correlation analysis using Spearman's rank correlation coefficients was made between age and all other variables. Age was found not to be not significantly correlated with the other variables (r $< \pm$ 0.33, $p > .11$), although with three exceptions: age showed a significant correlation with passage comprehension scores for the dysphonic voice presented in noise (rho = 0.45, $p = .026$), with perceived effort for the dysphonic voice in quiet (rho = −0.42, $p = .042$) and with composite score of perceived effort in quiet (rho = −0.43, $p = .034$). Since majority of the variables were not correlated with age, age was excluded as a covariate in the following analyses.

The average perceived effort for the four different listening conditions are shown in Table 2(A) lower score indicates higher perceived effort. To test the effect of listening condition Friedman test was used with four within-subject variables: perceived effort when listening to a typical voice in quiet, to a dysphonic voice in quiet, to a typical voice in background noise and to a dysphonic voice in background noise. The results showed a significant within-subject effect for listening condition (Chi2 = 16.961, $p = .001$). Post hoc tests were made using Wilcoxon Signed ranks test. The results are shown in Figure 1. The results showed that the perceived effort for the typical voice in quiet was significantly lower than the dysphonic voice in quiet (Z = −1.964, $p = .049$), the typical voice in noise (Z = −2.677, $p = .007$) and the dysphonic voice in noise (Z = −2.838). All other comparisons were not significant (Z ≤ −1.703, $p \geq .088$).

Using Wilcoxon Signed Ranks tests, the composite scores were used to compare overall effects of voice quality and background listening condition on ratings pf perceived effort. The results are shown in Figures 2 and 3. Perceived effort for quiet was significantly lower than for noise (Z = −2.906, $p = .004$). Perceived effort for the typical voice was significantly lower than for the dysphonic voice (Z = −1.964, $p = .049$). These results indicate that perceived effort was rated higher in noise compared to quiet listening condition and was rated higher for the dysphonic voice compared to the typical voice.

Spearman's rank correlation coefficients were calculated between rating of perceived effort for the different listening conditions, composite scores and executive function. No significant correlations were identified (rho = ≤± 0.17, $p \geq .419$). The results suggest no significant association between ratings of perceived effort and executive function.

Spearman's rank correlation coefficients were calculated between perceived listening effort and passage comprehension performance for each listening condition. No correlation was significant (rho = ≤ ± 0.40, $p \geq .057$). Spearman's rank correlation coefficients were calculated between composite score for perceived listening effort and composite scores for passage comprehension performance (calculated as for perceived effort) (rho = ≤ ± 0.32, $p \geq .123$).

Table 2. Average perceived effort (a lower score indicate higher perceived effort) and performance (a score of five is maximum) on the auditory passage comprehension task (CELF-4) when listening to a typical voice in quiet, to a dysphonic voice in quiet, to a typical voice in background noise and to a dysphonic voice in background noise.

	Typical voice			Dysphonic voice		
	N	Mean	SD	*N*	Mean	SD
Perceived effort						
Quiet	24	78.5	22.2	24	64.0	30.5
Noise	24	50.8	34.5	23	48.7	34.1
Performance						
Quiet	24	3.0	1.2	24	2.7	1.6
Noise	24	1.9	1.6	24	2.0	1.2

Discussion

The present findings showed that children with hearing loss experience a significant increase in perceived effort

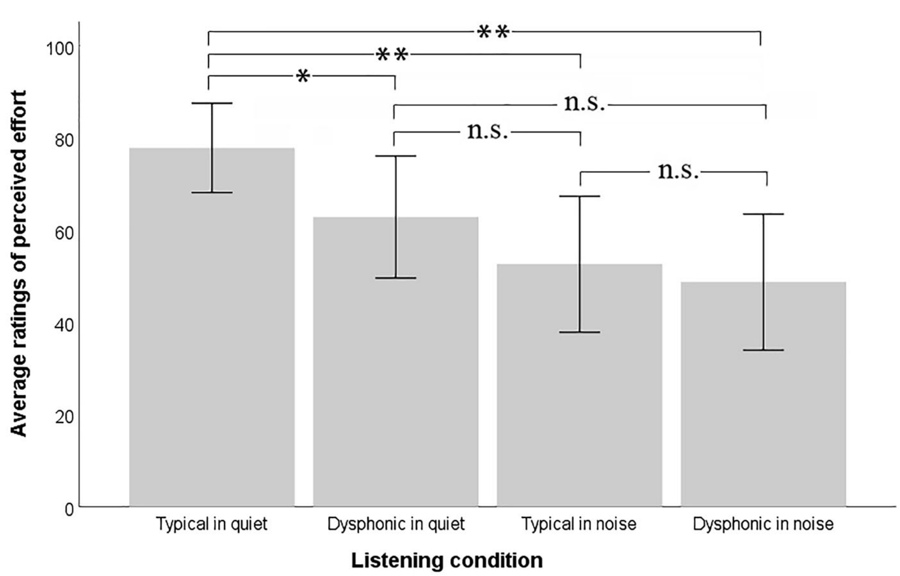

Figure 1. Average ratings of perceived effort on the auditory passage comprehension task (CELF-4) when listening to when listening to a typical voice in quiet, to a dysphonic voice in quiet, to a typical voice in background noise and to a dysphonic voice in background noise. A higher score indicates less perceived effort. Error bars represent 95% confidence intervals. Asterisks denote significant differences (*$p < .05$; **$p < .01$). Not significant differences (n.s.) are also shown.

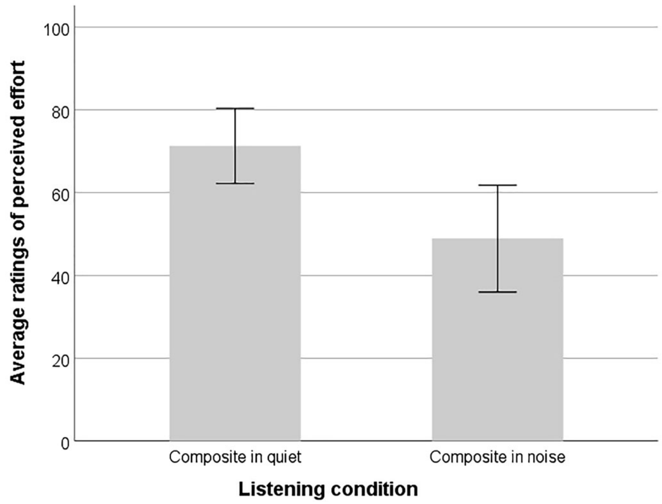

Figure 2. Average composite scores for perceived effort in quiet (average of ratings typical and dysphonic voice) and average composite scores for perceived effort in noise (average of ratings typical and dysphonic voice) on the auditory passage comprehension task (CELF-4). A higher score indicates less perceived effort. Error bars represent 95% confidence intervals.

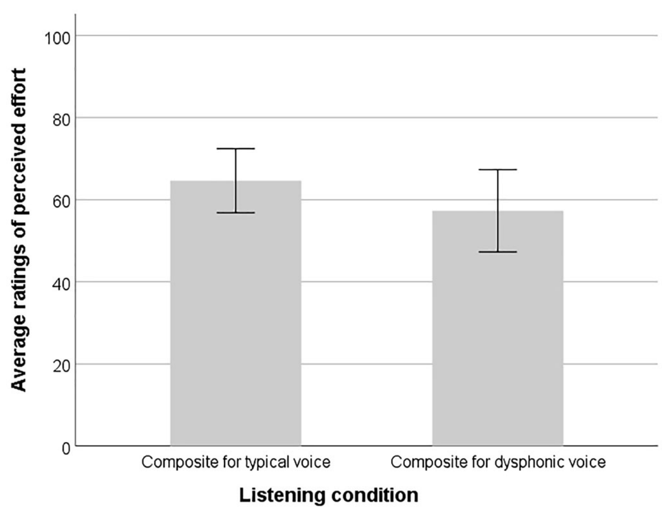

Figure 3. Average composite scores for perceived effort in quiet with typical voice (average of ratings in quiet and in noise) and average composite scores for perceived effort with dysphonic voice (average of ratings in quiet and in noise) on the auditory passage comprehension task (CELF-4). A higher score indicates less perceived effort. Error bars represent 95% confidence intervals.

increased when listening in noise compared to listening in quiet. More cognitive resources seem to be required to perform explicit processing in the degraded listening condition which in turn results in that less resources are available for the listener to encode information into and retrieve information from long-term memory representations. The increased use of cognitive resources to explicitly process speech signal presents itself as an increased perceived effort [7]. The present findings lend support to this reasoning. We found that children with CI and/or HA experienced significantly higher perceived effort when listening to passages presented in noise compared to listening in quiet. It is a similar finding as seen in children with normal hearing. von Lochow et al. [1] found that perceived effort increased in background listening conditions consisting of one or four competing speakers compared to listening in quiet when listening to a typical and a dysphonic voice. In one condition, they used the same four speaker multi-talker babble noise as in the present study but used a 5 dB SNR compared to a 10 dB SNR in the present study. They also assessed perceived effort using a slightly different response scale compared to the present study. However, using the same voice samples they reported ratings of perceived listening effort in quiet and in noise for both the typical and the dysphonic voice that were similar to those seen in the present study despite their more challenging SNR.

The present findings also showed that ratings of perceived effort increased significantly when listening to a dysphonic voice compared to a typical voice. This finding is also in line with the assumptions of explicit processing [3,4]. It is a finding similar to those reporting that children with normal hearing have more negative attitudes towards listening to a dysphonic voice compared to listening to a typical voice [14]. However, previous studies have not reported on the effect of a dysphonic voice on ratings of perceived listening effort in children with hearing loss. In children with normal hearing, previous studies suggest the opposite: von Lochow et al. [1] found no effect of a dysphonic voice on ratings of perceived listening effort in children with normal hearing. A possible explanation for the discrepancies in findings between the present study and the previous, could be that the amount of signal degradation that the dysphonic voice represented was only sufficient to force the children with CI and/or HA to exert explicit processing. It was not sufficient for children with normal hearing, perhaps indicating too low task demands. In addition, we found no interaction for ratings of perceived listening effort between background noise and voice quality indicating that the effect of background noise was not influenced by the effect of voice quality and vice versa. The effects of noise and voice quality on ratings of perceived effort may thus be considered to be additive.

In the present study, no association was seen between ratings of perceived effort and executive function despite that previous studies suggest that more cognitive resources are used for explicit processing [3–6]. The present finding seems contrary to this assumption. However, there may be several reasons why we failed to see a relationship. Executive function was assessed offline. It may be more accurate to assess executive function directly during exposure to background listening condition and voice quality. Brännström et al. [33] found an effect of a dysphonic voice on sentence processing in an online working memory task in children with normal hearing. In children with CI and/or HA, Brännström et al. [34] found an effect of noise on performance in a working memory task but not voice quality. It may thus be more relevant to use an online task to assess the influence of voice quality and noise on executive function. Furthermore, the executive function task measures general executive functions (e.g. planning and organisation skills, inhibition, and processing). A more fine-grained examination of the components of executive function [35] could possibly provide more information on the relationship between executive control and perceived listening effort.

We found no associations between ratings of perceived listening effort and passage comprehension performance. This finding is contrary to the assumption that less use of explicit processing results in lower use of cognitive resources which in turn manifests as lower perceived listening effort [7].

According to the prediction in the motivational intensity theory regarding the relationship between task difficulty and perceived listening effort for tasks with fixed difficulty [21,22], we initially expected that as speech signal deterioration increases, i.e. task difficulty increases, perceived listening effort will increase proportionally from listening to a typical voice in quiet to listening to a dysphonic voice in background noise. The present findings are in line with the theory: as signal degradation (interpreted as task difficulty) increased (typical voice in quiet < dysphonic voice in quiet < typical voice in noise < dysphonic voice in noise), ratings of perceived effort increased as well. Also, the findings suggest that demands were not perceived as too excessive.

Twenty-four children with CI/HA participated in the study. The sample was heterogeneous, which resulted in increased potential variance. Therefore, in future studies a larger and more homogenous sample would be beneficial and provide more conclusive findings. One shortcoming is the lack of audiological baseline data of the children, such as age at fitting or implant and information on CI/HA fitting accuracy but also the influence of different listening device signal processing algorithms. These factors may influence the present findings. In future studies this information should be collected. In all listening tasks there is a risk that performance is influenced by reduced audibility, i.e. that not all target speech signals are possible to detect. Non word discrimination could be used to collect information on potentially reduced audibility in future studies [36]. The impact of these shortcomings were reduced by the fact that a within-subject design was used.

Future studies on children should consider to use a combination of behavioral and physiological measures along with self-ratings to better understand the concept of listening effort. There are behavioral measures such as dual-task paradigms (the limited cognitive resources need to be distributed between a primary and a secondary task) and there are physiological measures such as pupil dilatation [26]. A third way is through self-reports as used in the present study. Previous studies have shown poor if any associations between both behavioral and physiological measures and perceived listening effort [37–42]. Using a similar complex passage comprehension task in adults, Brännström et al. [43] demonstrated a clear effect of background noise on ratings of perceived listening effort but found no influence on several behavioral measures such as dual-task cost. Furthermore, we relied on provoked dysphonia in the present study which may have an impact on the general applicability of the present findings.

In the introduction we argued that ecological validity of a study is important when assessing the effect of signal degradation on perception and comprehension in children. We used a spoken narrative task presented in quiet and in multi-talker babble noise that consisted of children as competing speakers. In addition, we used a vocal loading procedure to achieve the dysphonic voice quality. Despite these steps, the design of the experiment was experimental and much of the classroom context and distractions were eliminated. In future studies, testing in the actual classroom setting would improve the ecological validity furthermore.

The present findings suggest some clinical implications. Perceived listening effort increased both for background noise and voice quality for a narrative task that is very similar to everyday classroom tasks. The ordinary classroom is often not a quiet but noisy environment. Such an environment has an impact on both teachers and children. In a teacher perspective, increased vocal load due to background noise may result in a dysphonic voice, which in turn may influence well-being for the individual but also have a negative influence on classroom communication. From the perspective of the mainstreamed child with CI/HA, the present findings seem to suggest that less resources will be available to benefit from teaching and to store information. In a study by Brännström et al. [44] on children with normal hearing, it was found that less information could be recalled after approximately one week if that information was encoded when listening to passages in noise compared to listening in quiet. It is therefore important to inform teachers, schools and policy makers about the potential impact degraded speech signals on all children in learning environments but especially in those where children with hearing loss are placed.

Conclusions

Both poor voice quality and background noise increase perceived listening effort in children with CI/HA. Since increased listening effort seems to be a consequence of increased cognitive resource spending, it is likely that less resources will be available for these children not only to comprehend but also to learn in challenging listening environments such as classrooms.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article. Viveka Lyberg-Åhlander is an associate editor with the journal.

Funding

The Hearing Foundation (Hörselfonden–Hörselskadades Riksförbund) and the Linneaus' environment Cognition, Communication and Learning at Lund University provided partial financial support for the study.

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