PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Background Noise and Phonological Processing in Second Language Learners

Emil HOLMER[1]; Thaisy COSTA; Mary RUDNER [2]

Linnaeus Centre HEAD, Swedish Institute for Disability Research,

Department of Behavioural Sciences and Learning, Linköping University, Sweden

ABSTRACT

According to the Framework for Understanding Effortful Listening (FUEL), adverse listening conditions deplete the cognitive resources available for other tasks. For example, in a noisy classroom, students may not be able to devote their full cognitive capacity to learning. This may be a particular problem for second language learners. In an experiment, 20 international exchange students and 9 Swedish students performed a Swedish visual rhyme task in quiet and in noise. The rhyme task required the activation of phonological representations of Swedish but on average the exchange students had been learning Swedish as a second language in Sweden for only 3 months. T-testing showed that the exchange students had poorer Swedish vocabulary and lexical access skills than the Swedish group but similar cognitive skills and a repeated measures ANOVA based on rhyme task data showed a statistically significant effect of group with better performance for the Swedish group. Unexpectedly, there was no effect of noise on visual Swedish rhyme judgment and no significant interaction between noise condition and group. However, correlation patterns suggested different language based strategies in quiet and in noise. This may suggest that phonological processing strategies are influenced by background noise which may have implications for listening effort.

Keywords: Framework for Understanding Effortful Listening (FUEL), Background noise, Phonological processing, Second language learner, Cognition

1. INTRODUCTION

In today's global world, many students are acquiring knowledge through the medium of a language that is not their mother tongue. Thus, it is important to understand the effect of second language (L2) use on learning, and how this effect may interact with other known sources of classroom interference. Background noise reduces the audibility of speech and contributes to listening effort. Both of these effects are greater for foreign speech, even when the listener is proficient in the L2 (1). Listening effort can be understood in terms of the cognitive resources that are allocated to a listening task. The Framework for Understanding Effortful Listening (FUEL, 2) describes the factors that contribute to listening effort. These fall into two categories: individual factors and task demands. Listening effort increases as task demands increase as long as the individual is motivated to continue listening and has the necessary capacity to process the speech. However, if the listener is insufficiently motivated and the task is hard, listening effort may drop as the individual opts out of the task. Thus, when there is background noise in a learning situation, more cognitive resources need to be devoted to simply understanding what is being said, and learning suffers (3).

The Ease of Language Understanding Model (ELU, 4) describes the importance of phonological representations in language understanding. According to the ELU model, speech understanding is achieved by matching the incoming speech stream to the phonological representations associated with relevant lexical items stored in long-term memory. When background noise obscures parts of the speech signal, or distracts attention from them, then a mismatch may occur. In this situation, those parts of the speech signal that have been perceived must be maintained in working memory until they can be disambiguated using knowledge stored in long-term memory. Maintaining verbal information in working memory is harder if the equivalent phonological representations are not already stored in

[1] emil.holmer@liu.se
[2] mary.rudner@liu.se

long-term memory (5). The process by which appropriate phonological representations become established in long-term memory is described by the Developmental Ease of Language Understanding Model (D-ELU, 6). The D-ELU proposes that deliberate processing of novel exemplars of lexical items in working memory invokes updating of existing representations in long-term memory. If a novel exemplar significantly differs from pre-existing representations, a new phonological category is formed. Critically, exposure to and deliberate processing of linguistic input is the foundation of development in native languages and L2s.

Background noise, not only makes it challenging to understand speech, it also hinders the function of verbal working memory (7). Thus, it is likely that background noise not only generates listening effort by hindering speech perception but also by interfering with speech processing in working memory. Verbal working memory processing is more fragile for L2 (8). Thus, it is likely that L2 phonological processing is more susceptible to noise. Speech-based phonological processing can be disconnected from speech perception by using a visually based phonological processing task. The purpose of the present study was to determine whether acoustic noise interferes with phonological processing in L2 learners.

We have previously developed the Cross-modal Phonological Awareness Test (C-PhAT, 11). The test is designated cross-modal because it is designed to test phonological awareness in speakers of Swedish and users of Swedish Sign Language (SSL), using the same set of materials. The materials are pairs of characters with phonological labels in both Swedish and SSL. However, the mapping between the written characters and phonology differs for the two languages. In the present study, we exploit the difference in mapping between written characters and phonology between different languages to test the efficiency of phonological processing in learners of Swedish as L2. In this context, the mapping between the characters and phonology in accordance with the Swedish manual systems is immaterial. Successful performance on the C-PhAT requires not only the ability to map written characters to phonology, but also the ability to maintain the resulting phonological representations in working memory until it has been determined whether or not those representations are phonologically similar. Our prediction is that not only will mapping between written characters and Swedish phonology be fragile in Swedish L2 speakers but also that the resulting Swedish phonological representations will be less robust and thus less durable in working memory than the representations of native speakers. This is in some sense similar to the fading of phonological representations in adults with post-lingual hearing loss (12). Importantly, for the purposes of this study, phonological representations are likely to be susceptible to noise, and the more fragile they are, the more susceptible to noise they are likely to be.

The FUEL (2) highlights the multiple causes of listening effort. Some of these are bottom-up signal related phenomena such as noise and others are top-down phenomena related to the individual such as motivation and knowledge, including language knowledge. If acoustic noise interferes with the phonological processing required to perform successfully on a visual rhyme task in L2 learners, then it is also likely to interfere with their ability to process spoken Swedish in a learning situation.

2. METHODS

2.1 Participants

Twenty foreign exchange students at Linköping University (6 males, mean age 24 years) took part in the study along with a comparison group of nine students at Linköping University (3 males, mean age 24 years) who were native Swedish speakers. The foreign exchange students included ten Europeans, five South Americans, four Asians and one African; all of them were studying Swedish as a second language and had been in Sweden for on average 3 months, ranging between two and six months. All participants gave written informed consent.

2.2 Experimental task

The Cross-modal Phonological Awareness Test (C-PhAT, 11) is a visual rhyme task that taps into phonological processing. Pairs of characters, either two letters or one letter and one digit, are presented on a computer screen and the participant makes a decision on the phonological characteristics of those characters as quickly as possible. There are two versions of C-PhAT, a Swedish version and a Swedish Sign Language version. The two versions are based on identical materials; only the instructions given to the participant differ. The Swedish version was used in the present study. In this version, the participants are asked to determine whether the Swedish labels of the two characters

rhyme with each other. For example, the Swedish labels of "U" (/ʉː/) and "7" (/ɧʉː/) but not "E" (/eː/) and "H" (/hoː/) rhyme with each other. "Yes" and "No" button-press responses are collected automatically and d' is calculated by adjusting hits for false alarms to adjust for response bias in accordance with signal-detection theory. The dependent variables from the experiment are d' and response time (RT) for correct responses.

There are two sets of C-PhAT material each including 24 trials and in the present study all participants performed the task with both sets of material in balanced order. One set of visual materials was presented in quiet and the other in background noise consisting of the International Speech Test Signal Noise (13). The materials were presented in black capital letters (Times New Roman, 115 points), on a white background using a laptop computer (Dell notebook, 2012). The noise was presented using the soundcard of the laptop computer at the same comfortable level (18%) for all participants over headphones, and headphones were worn for the duration of the experimental task to ensure that any effect of noise was not confounded by the effect of wearing headphones. Thus, mean d' and RT were calculated for quiet and noise conditions.

2.3 Behavioural test battery

Apart from the experimental task, six other behavioural tests were administered to all participants. These were Ravens Advanced matrices (9) which is a test of non-verbal cognition, a Swedish vocabulary test (10) and four tests reported in (11):

Motor speed. The participant pressed one key as fast as possible 30 times using the dominant hand. The dependent measure was mean response time in s for one keypress.

Cognitive speed. The Swedish words for ''yes'' and ''no'' were presented in unpredictable order on a computer screen for a maximum of five s and the participant's task was to press the corresponding key as fast as possible. The dependent variable was the mean response time for correct trials.

Letter decision. In the letter decision task letters were presented on a computer screen either in the correct orientation, or rotated 45, 90 or 180 degrees in the plane of the screen. The participant's task was to determine whether each item was correctly oriented or not during the five second presentation period and make the appropriate keypress response as fast as possible. The dependent variable was percent correct responses.

Lexical decision. Items consisting of three letters (two consonants and one vowel) were presented on a computer screen for a maximum of five s and the participant's task was to determine whether each item was a Swedish word or not and give a key-press response as quickly as possible. There were 40 trials and half the items were targets. The other 20 items were equal numbers of pseudowords (orthographically legal but non-lexicalized items) and non-words (orthographically illegal items). The dependent measures was d'.

2.4 Data analysis

The data (d' and RT) from the experimental task were analysed using repeated measures analysis of variance (ANOVA) for the foreign exchange students alone and then for both groups together. T-tests were performed to determine between-group differences in test battery performance. Pearson's correlations between the experimental task and test battery performance were also calculated for all 29 participants.

3. RESULTS

3.1 Experiment

Experimental data were normally distributed and performance is shown in Figure 1. Two repeated measures ANOVAs were performed with d' as the dependent variable, first one for the L2 group alone and another across groups. Both ANOVAs included noise as a within-group factor. Neither of the ANOVAs showed a main effect of noise, L2: $F_{(1, 19)} = 0.04$, $MSE = 0.03$, $p = .85$; across-group: $F_{(1, 27)} = .97$, $MSE = 1.07$, $p = .35$. The effect of group was significant, $F_{(1, 27)} = 12.18$, $MSE = 0.94$, $p = .001$, but there was no significant interaction between group and noise, $F_{(1, 27)} = 1.28$, $MSE = 1.07$, $p = .27$. Due to the lack of the expected effect of noise, we performed the same set of ANOVAs with RT as the dependent variable. However, there was no significant effect of noise in either of the RT ANOVAs, L2: $F_{(1, 19)} = .59$, $p = .45$; across-group: $F_{(1, 27)} = .004$, $p = .95$. The effect of group was small and did not reach significance, $F_{(1, 27)} = 4.02$, $p = .055$, $\eta^2 = .13$ and there was no significant interaction between group and noise, $F_{(1, 27)} = .55$, $p = .55$.

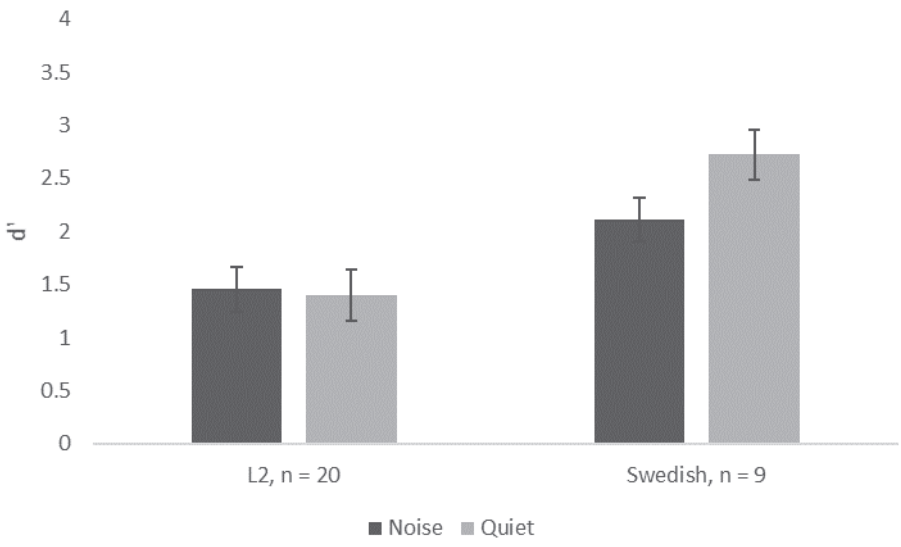

Figure 1. C-PhAT performance. Error bars show standard error.

3.2 Behavioural test battery

Non-normal distributions were detected for Button pressing, Physical matching, Lexical decision, Letter identification, and Vocabulary but not Ravens matrices. The results of the test battery are shown in Table 1. Importantly, the two groups did not differ on Ravens Advanced Matrices, the measure of non-verbal cognition. Three of the L2 participants did not complete this test due to fatigue. Unexpectedly, the L2 group showed slower motor speed. However, there was no difference between groups on Physical Matching, our measure of cognitive speed. As expected, the L2 group had poorer Swedish vocabulary and poorer Swedish lexical decision ability. Two of the L2 participants did not complete the vocabulary test due to fatigue. It should also be noted that the L2 group had poorer letter identification than the Swedish comparison group. This may have been due to varying degree of familiarity with the Latin alphabet in the L2 group.

Table 1. Performance in the behavioural test battery for the L2 group (n=20) and the Swedish comparison group (n=9). Missing data from L2 participants in Ravens Advanced Matrices (n=17) and Vocabulary (n=18).

	Swedish		L2		t-test	
	Mean	SD	Mean	SD	*p*	sign.
Button pressing	76.21	24.89	130.52	94.18	0.03	*
Physical Matching, d'	2.61	0.31	2.72	0.51	0.47	
Lexical decision, d'	3.22	0.68	1.00	0.41	< .001	***
Letter identification, d'	3.60	0.17	3.37	0.31	0.02	*
Vocabulary	71.67	0.50	53.94	7.92	< .001	***
Ravens Advanced Matrices	12.78	3.96	14.00	3.12	0.44	

3.3 Correlations

We report results from parametric tests, with a comment when non-parametric test showed a different result. C-PhAT performance correlated significantly with lexical decision, $N = 29$, $r = .50$, $p = .006$, and vocabulary, $N = 27$, $r = .44$, $p = .02$, but only in the quiet condition. There was also a significant correlation between lexical decision and vocabulary, $N = 27$, $r = .72$, $p < .001$. The pattern was the same for non-parametric correlations, except for the association between C-PhAT performance in the quite condition and Button pressing which was significant for the non-parametric test, N = 29, $r_s = -.44$, $p = .017$. There were no other significant correlations between C-PhAT and the behavioural test battery. Surprisingly, there was no significant correlation between C-PhAT performance under the two conditions (quiet and noise).

4. DISCUSSION

The purpose of the present study was to determine whether acoustic background noise interferes with phonological processing in L2 learners. To this end, 20 adult exchange students who had been in Sweden between two and six months and who were learning Swedish performed a visual rhyme task (C-PhAT, 11) in quiet and in noise. ANOVA provided no evidence of an effect of acoustic noise on visual rhyme judgment in the L2 group. Thus, we found no evidence to support the notion that background noise contributes to effort in L2 listeners by interfering with phonological processing. There was no floor effect at group level that could have been driving the lack of an effect of noise. The noise used in the present study was ISTS noise that is created from short segments of speech in six different languages (13) and is thus speech-like but unintelligible. Previous work has shown that competing speech interferes more with both recognition and cognitive processing of speech than other kinds of fluctuating noise (14). Thus, there is no reason to suppose that our results are unreliable due to the sensitivity of the test or the type of noise used. However, although the same comfortable noise level was used for all participants, the absolute level of the noise was not measured in the present study. It is possible that the noise level was too low to interfere with phonological processing. In future work, the noise level should be well controlled.

Although there was no effect of noise on C-PhAT performance, there was no correlation between the two conditions and further, the pattern of associations between C-PhAT performance and the behavioural test battery differed between conditions. This suggests that C-PhAT scores were differently distributed in quiet and noise conditions. Specifically, vocabulary and lexical decision performance predicted C-PhAT performance in quiet but not in noise. Non-parametric tests suggested a similar predictive value for Button Pressing. This suggests that the size of the Swedish lexicon and efficiency in searching it, as well as motor speed, were important for making phonological decisions in quiet but not in noise. According to the ELU model (4), access to the mental lexicon and the phonological representations stored there is vital for language understanding and that it is this process that is disturbed under challenging listening conditions when background noise is present. The pattern of correlations in the present study support this notion.

As predicted, there was a significant difference between the two groups in rhyme judgment performance demonstrating poorer ability in the L2 group to process Swedish phonology. The L2 group also had poorer vocabulary and slower lexical access than the Swedish group. Although we cannot separate the effects of phonological representation and processing, it is likely that the discrepancy is due to poorer phonological representations in the L2 group due to their short exposure of on average 3 months to Swedish. Because there was no difference between groups in non-verbal cognition, it is unlikely that the effect of group is due to differences in the ability to process representations.

5. CONCLUSIONS

The FUEL (2) highlights multiple causes of listening effort, some of which are related to perception and some to cognition and yet others to individual factors such as motivation. We found no significant effect of background noise on L2 phonological processing in young adults and thus no hard evidence that background noise specifically causes listening effort at the cognitive level in early L2 learners. However, differences in correlation patterns suggested different phonological processing strategies in quiet and in noise, in line with the ELU model (4) and this in turn suggests a redistribution of cognitive resources. This phenomenon deserves further investigation.

ACKNOWLEDGEMENTS

This work was supported by the Swedish Research Council Grant 2017-06092 and through funding of the Linnaeus Centre HEAD Grant 349-2007-8654.

REFERENCES

1. Borghini G, Hazan V. Listening Effort During Sentence Processing Is Increased for Non-native Listeners: A Pupillometry Study. Front Neurosci. 2018 Mar 13;12:152. doi: 10.3389/fnins.2018.00152.
2. Pichora-Fuller MK, Kramer SE, Eckert MA, Edwards B, Hornsby BW, Humes LE, Lemke U, Lunner T, Matthen M, Mackersie CL, Naylor G, Phillips NA, Richter M, Rudner M, Sommers MS, Tremblay KL, Wingfield A. Hearing Impairment and Cognitive Energy: The Framework for Understanding Effortful

Listening (FUEL). Ear Hear. 2016 Jul-Aug;37 Suppl 1:5S-27S. doi: 10.1097/AUD.0000000000000312.
3. Rudner M, Lyberg-Åhlander V, Brännström J, Nirme J, Pichora-Fuller MK, Sahlén B. Listening Comprehension and Listening Effort in the Primary School Classroom. Front Psychol. 2018 Jul 12;9:1193. doi: 10.3389/fpsyg.2018.01193.
4. Rönnberg J, Holmer E, Rudner M. Cognitive hearing science and ease of language understanding. Int J Audiol. 2019 May;58(5):247-261. doi: 10.1080/14992027.2018.1551631.
5. Hulme, C., Maughan, S., & Brown, G. D. (1991). Memory for familiar and unfamiliar words: Evidence for a long-term memory contribution to short-term memory span. Journal of Memory and Language, 30(6), 685-701. Doi: 10.1016/0749-596X(91)90032-F
6. Holmer E, Heimann M, Rudner M. Imitation, Sign Language Skill and the Developmental Ease of Language Understanding (D-ELU) Model. Front Psychol. 2016 Feb 16;7:107. doi: 10.3389/fpsyg.2016.00107.
7. Obleser J, Wöstmann M, Hellbernd N, Wilsch A, Maess B. (2012). Adverse listening conditions and memory load drive a common alpha oscillatory network. J.Neurosci. 32, 12376–12383. doi: 10.1523/JNEUROSCI.4908-11.2012.
8. Kilman L, Zekveld A, Hällgren M, Rönnberg J. The influence of non-native language proficiency on speech perception performance. Front Psychol. 2014 Jul 2;5:651. doi: 10.3389/fpsyg.2014.00651.
9. Raven, J. C. (1976). Advanced Progressive Matrices. Oxford: Information Press.
10. Nauclér, K., & Magnusson, E. (2010). OS64. Studentlitteratur: Lund.
11. Holmer E, Heimann M, Rudner M. Evidence of an association between sign language phonological awareness and word reading in deaf and hard-of-hearing children. Res Dev Disabil. 2016 Jan;48:145-59. doi: 10.1016/j.ridd.2015.10.008.
12. Rudner M, Danielsson H, Lyxell B, Lunner T, Rönnberg J. Visual rhyme judgment in adults with mild-to-severe heaering loss. Under review.
13. Holube I, Fredelake S, Vlaming M, Kollmeier B. Development and analysis of an International Speech Test Signal (ISTS). Int J Audiol. 2010 Dec;49(12):891-903. doi: 10.3109/14992027.2010.506889.
14. Zekveld AA, Rudner M, Johnsrude IS, Rönnberg J. The effects of working memory capacity and semantic cues on the intelligibility of speech in noise. J Acoust Soc Am. 2013 Sep;134(3):2225-34. doi: 10.1121/1.4817926.