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THE INFLUENCE OF A SPEAKER'S VISIBLE CRANIOFACIAL SYNDROME ON THE INTELLIGIBILITY OF SIMULATED HYPERNASAL SPEECH IN NOISE

Original research paper
https://doi.org/10.17234/9789533791821.04

The study investigated whether the visible presence of a repaired cleft of the lip and/or palate (CLP) had an influence on the intelligibility of hypernasal speech in noise ("intelligibility cost"). Thirty-two adults, who were self-identified native Canadian English speakers, with no history of speech or hearing disorders transcribed a series of sentences with simulated hypernasal or normal speech in noise, which was matched with faces of individuals with visible signs of a repaired CLP or with typical faces. The participants were also asked to rate intelligibility for each sentence. The presence of a CLP or non-CLP face did not have a significant impact on speech intelligibility based on the percentage of words incorrect or the intelligibility ratings. The simulated hypernasal speech with audible nasal air emission was significantly more difficult to understand for the listeners, and female speakers were more unintelligible than male speakers. In the present study, the presence of a visible repaired CLP did not have an intelligibility cost for the listeners.

Keywords: Craniofacial syndrome, cleft lip and palate, hypernasality, speech intelligibility, intelligibility cost

INTRODUCTION

Spoken language is the primary way through which humans communicate thoughts, emotions, and intentions (Babel & Russell, 2015). In her research, Prof. Dr. Vesna Mildner has investigated the process from both the production and reception sides (e.g., Mildner et. al., 2006; Liker et. al., 2007; Mildner & Liker, 2008). Importantly, individuals with communication disorders may be subject to negative stereotyping. Judgements may be made about personal attributes such as social status (Zacharias et. al., 2013), education (Allard & Williams, 2008), intelligence (Ma & Yu, 2013), attractiveness (Amir & Levine-Yundof, 2013) and personality (Eadie et al., 2017). This generalization from difference in one domain to inadequacy in another has been called a "spread effect" (Wright, 1960). Overby and colleagues (2017) found that teachers expected children with typical speech to have more positive literacy outcomes and be better learners, compared to children with speech disorders. Thus, negative attitudes about individuals with speech disorders may result in psychological, educational and employment disadvantages in society (Lee et. al., 2017).

The most common type of congenital craniofacial malformation in newborns is cleft of the lip and/ or palate (CLP) (Peterson-Falzone et. al., 2001). A CLP occurs early in fetal development when there is improper fusing of the lateral and central segments of the lip, alveolus and hard and soft palate. The cause of the disorder is thought to be a multi-factorial combination of possible genetic and environmental factors. After surgical treatment of the CLP, the individual may still have visible facial scarring and other facial features such as orthognathic imbalance (class III underbite) and nasal septum deviation (Berkowitz, 2013). The speech of individuals with CLP may be characterized by hypernasality, nasal air emissions and articulation errors (Whitehill & Chau, 2004; Peterson-Falzone et al., 2001). Even after the surgigal repair, these characteristic visual and audible features may result in social stigma (Lee et al., 2017).

When hearing and processing speech, we apply the results of learning from past experiences (Babel & Russell, 2015). However, such learning may also result in linguistic profiling (Baugh, 2000). Not all speech is deemed socially equivalent (Williams et. al., 1999). This may then result in social biases (Babel & Russell, 2015), and listeners may link their preconceived social notions to specific acoustic cues (Sumner, 2014). For example, when examining race bias, mismatching of visual and acoustic information (i.e., showing a photo of a Caucasian face paired with Chinese-accented speech) resulted in lower transcription accuracy (McGowan, 2015). An elegant way to investigate the cognitive load of social factors in speech perception is to use speech in noise. For example, Babel and Russell (2015) found that when unaccented Canadian English speech in noise was primed with Chinese Canadian faces, there was a speech "intelligibility cost," compared to when it was primed with Caucasian Canadian faces.

The social perception of speakers with a repaired CLP has been investigated in several studies. Podol and Salvia (1976) found that a visible repaired cleft prompted students of speech-language pathology to rate speech samples as more hypernasal. When attempting to replicate and further investigate this finding, Glass and Starr (1979) found the opposite effect that lower severity of hypernasality resulted in higher facial attractiveness ratings for individuals with CLP. Bressmann et al. (2019) investigated whether a speaker's visible repaired cleft lip and nasal asymmetry results in an "intelligibility cost" for the listener. Speech samples of eight typical speakers were combined with noise and presented together with faces of individuals with repaired cleft lip and nasal asymmetry or typical faces. Twenty-eight listeners transcribed the sentences, rated speaker intelligibility and answered a questionnaire about their previous knowledge about cleft lip and palate. The results showed no statistically significant differences between speech stimuli that were presented with the faces with repaired cleft lip and nasal asymmetry or the typical faces. The percentage of words transcribed correctly and the speech intelligibility ratings were lower for female speakers.

The study by Bressmann et al. (2019) used speech recordings that were difficult to listen to because they were embedded in noise. However, while the photos showed visual features typical of repaired CLP, the speech samples did not have any of the acoustic characteristics of speech of individuals with CLP. The present study therefore aimed to repeat the research by Bressmann et al. (2019) but added perceptual features of hypernasality and audible nasal air emission to the speech samples. Since individual speaker characteristics may influence intelligibility in noise (Barker & Cooke, 2007), the hypernasality and audible nasal air emission in the present experiment were added by signal manipulation to minimize speaker effects.

The present study investigated whether naive listeners had more difficulty understanding hypenasal speech in noise when the auditory stimulus was paired with the face of an individual with a visible repaired cleft lip and a nasal asymmetry, compared to the same sound sample with the face of an individual without cleft. Based on Babel and Russell (2015), the hypothesis was that the intelligibility of hypernasal speech in noise would be lower when the listeners were presented with the photo of an individual with a repaired cleft lip and nasal asymmetry. Similar to Bressmann et al. (2019), the outcome measures used were the percentage of words transcribed correctly as well as listeners' subjective ratings of perceived speech intelligibility.

METHODOLOGY

Speech stimuli

The speech stimuli were re-used from a previous experiment by Bressmann, Eick and Pardo (2019). Based on the research methods by Babel and Russell (2015), the first 6 sentences from lists 1 to 8 had been selected from the Bamford, Kowal, and Bench (BKB) sentence lists (Bench & Bamford, 1979), resulting in a total of 48 stimuli. The BKB sentences vary in the number of words and syllables. The phonetic content is varied, and the semantic content of the sentences cannot be predicted from one sentence to the next. The sentences were then recorded by 4 female and 4 male model speakers who were typical speakers of Southern Ontario English, aged between 19 and 32 years.

Acoustic simulation of hypernasal speech and audible nasal air emission

The sound files with the original recordings 48 BKB Sentences were duplicated, and the duplicated files were manipulated in GoldWave (GoldWave Inc., 2015), using the spectrum filter function. In a first step, a spectrum filter with antiresonances centered at 500 Hz and 1 kHz was used to create a signal that emphasized low frequency nasal murmur. The resulting file approximated a perceptual impression of increased nasality but preserved most of the phonetic content of the message. In the next step, the original signals were filtered with a bandpass-filter between 200 Hz and 2 kHz, with anti-resonances centered around 500 Hz. This left only low frequencies including the range of the nasal murmur, creating an impression of severe hypernasality with weak consonants. In a final step, the original files were high pass-filtered at 5 kHz to isolate the high-frequency components of the consonant sounds to simulate audible nasal emission. Using Audacity (Audacity Team, 2014), the three filtered files were mixed to approximate the perceptual impression of severe hypernasality with weak oral consonants and audible nasal air emissions. Similar to the approach by Babel & Russell (2015), the amplitudes of the original recordings and the manipulated files were standardized to a root mean square (RMS) of -18 dB and mixed with pink noise with an RMS of -17 dB in Audacity (Audacity Team, 2014). Because GoldWave and Audacity were used, the technical aspects of the procedure differed from Bressmann et al. (2019), who had created their stimuli in Praat (Boersma, 2001).

Experimental design

The experiment was created using an OpenSeasame script (Mathôt et. al., 2012) from the earlier study by Bressmann et al. (2019). Eight facial photographs of individuals (4 with CLP, 4 typical) were matched in pairs with similar facial appearances, skin tones and hair textures. Four photographs were from individuals (2 females) with visible repaired CLP and nasal asymmetry (Branemark et. al., 1999; Bennun et al., 2016). Of the four individuals with CLP, two (1 female) had unilateral, and two (1 female) had bilateral CLP. Matching typical faces were selected from an open-source database (Fundação Educacional Inaciana Face Database, 2010).

The sound files with the typical speech in noise or the simulated hypernasality and nasal emission in noise were then paired with the different faces of the same sex. An example for a mismatch was a non-CLP individual paired with simulated hypernasal speech, and a match was a non-CLP individual paired with typical speech. To allow for all combinations of faces and recordings, there were four configurations of the study, which may be reviewed on the left sides of the four results columns for the different experimental configurations in Table 1.

After the participants had transcribed and rated all sentences in their respective experimental conditions, they listened to the sound files with the simulated hypernasality and audible nasal air emissions for a second time. During this second round, the sound files were presented without accompanying photos and without the masking noise. The purpose of this part of the experiment was to assess the intelligibility and perceived auditory-perceptual difficulty of the simulated hypernasal speech.

Listeners

32 listeners (16 females), between the ages of 18 and 40 (mean age 23 years) were recruited. They were self-identified native Canadian-English speakers with no history of speech or hearing disorders. Eight participants, equally divided between males and females, were placed in each of the 4 experimental configurations.

At the beginning of the experiment, consent was obtained from the participants without informing them that the study was about visual appearance and speech in CLP. Instead, they were told that the topic of study was speech intelligibility in noise. Once consent was given, the participants were asked to listen to the sentences and to transcribe what they heard into a box that appeared after the auditory presentation of each sentence. Following this, participants were asked to rank the intelligibility of each sentence on a scale of one (very clear) to nine (very unclear).

After the first round in which the sound files were presented with accompanying speaker photos and masking noise, the listeners then again transcribed and rated only the speech stimuli with simulated hypernasality and audible nasal air emission from the four speakers in their experimental condition, this time without the photos and without the masking noise.

When the experiment was complete, participants filled out a brief questionnaire about their previous knowledge on CLP (Vallino & Brown, 1996). Finally, they were debriefed on the true nature of the study and re-consent was obtained.

Statistical Analysis

For each transcribed sentence, the number of words incorrect was determined based on the number of incorrect words. Since the number of words per sentence varied, the results were transformed into percentages. The percentages of words incorrect and the rating data were analyzed in the Number Cruncher Statistical System 8 software (NCSS Inc, Kaysville, UT). Two repeated measures analyses of variance (ANOVAs) were calculated. The percentages of words transcribed incorrectly and the intelligibility ratings were the dependent variables. Photo with cleft versus no cleft, simulated hypernasal vs. typical speech in noise and speaker sex were entered as the independent variables.

RESULTS

Table 1 provides an overview of the results for the mean percentage of words transcribed incorrectly. A repeated-measures ANOVA with the percentage of words transcribed incorrectly as the dependent variable showed no significant main effect for the photos of faces with cleft vs. no clefts. There was a significant main effect ($F = 4058.5$, $df = 1$, $p < 0.01$) for the typical sentences (mean 17.9) versus the sentences with simulated hypernasality and audible nasal emission (mean 90.0). There was also a significant main effect ($F = 10.6$, $df = 1$, $p < 0.05$) for speaker sex, with higher mean values for female (mean 55.8) versus male speakers (mean 52.1).

Table 1. Mean percentages and standard deviations of words wrong in the 4 configurations of the experiment. SD = standard deviation; BCLP = bilateral cleft lipa and palate; UCLP = unilateral cleft lip and palate; TF = typical face; TS = typical speech; HN = simulated hypernasal speech with audible nasal emissions.

Speaker	Mean Percentage and SD of Words Incorrect in Configuration 1		Mean Percentage and SD of Words Incorrect in Configuration 2		Mean Percentage and SD of Words Incorrect in Configuration 3		Mean Percentage and SD of Words Incorrect in Configuration 4	
Female 1	BCLP; TS	13.5 SD 19.5	TF; TS	27.0 SD 30.9	BCLP; HN	93.7 SD 11.2	TF; HN	95.0 SD 11.3
Male 2	BCLP; TS	29.3 SD 31.4	TF 1; TS	37.6 SD 31.3	BCLP; HN	90.8 SD 13.6	TF; HN	93.0 SD 16.2
Female 3	TF; TS	17.1 SD 23.2	BCLP; TS	26.3 SD 25.5	TF; HN	93.8 SD 11.1	BCLP; HN	95.6 SD 9.3
Female 4	TF; HN	91.3 SD 15.4	UCLP; HN	92.5 SD 13.7	TF; TS	5.3 SD 10.7	UCLP; TS	3.8 SD 8.2
Male 5	TF; TS	8.5 SD 15.3	BCLP; TS	12.3 SD 24.3	TF; HN	73.6 SD 33.8	BCLP; HN	30.8 SD 4.4
Male 6	TF; HN	88.5 SD 19.9	UCLP; HN	94.0 SD 16.5	TF; TS	15.6 SD 24.5	UCLP; TS	11.4 SD 19.2
Female 7	UCLP; HN	93.9 SD 13.7	TF; HN	90.9 SD 16.6	UCLP; TS	26.6 SD 30.2	TF; TS	25.6 SD 31.6
Male 8	UCLP; HN	86.1 SD 22.9	TF; HN	87.3 SD 18.7	UCLP; TS	14.0 SD 20.8	TF; TS	11.8 SD 20.2

Table 2 shows the listeners' intelligibility ratings for each individual speaker. A repeated-measures ANOVA with the intelligibility ratings as the dependent variable showed no significant main effect for the photos of faces with cleft vs. no clefts. There was a significant main effect ($F = 2951.4$, $df = 1$, $p < 0.01$) for the typical sentences (mean 3.7) versus the sentences with simulated hypernasality and audible nasal emission (mean 8.0). There was also a significant main effect ($F = 26.7$, $df = 1$, $p < 0.01$) for speaker sex, with higher mean scores for female (mean 6.1) versus male speakers (mean 5.7).

Table 2. Mean scores and standard deviations of intelligibility ratings in the 4 configurations of the experiment. SD = standard deviation; BCLP = bilateral cleft lipa and palate; UCLP = unilateral cleft lip and palate; TF = typical face; TS = typical speech; HN = simulated hypernasal speech with audible nasal emissions.

Speaker	Mean Scores and SD of Intelligibility Ratings in Configuration 1		Mean Scores and SD of Intelligibility Ratings in Configuration 2		Mean Scores and SD of Intelligibility Ratings in Configuration 3		Mean Scores and SD of Intelligibility Ratings in Configuration 4	
Female 1	BCLP; TS	4.1 SD 1.7	TF; TS	4.4 SD 2.5	BCLP; HN	8.6 SD 0.7	TF; HN	8.5 SD 0.8
Male 2	BCLP; TS	4.9 SD 2.2	TF 1; TS	4.9 SD 2.6	BCLP; HN	8.4 SD 0.8	TF; HN	8.5 SD 0.6
Female 3	TF; TS	3.8 SD 1.6	BCLP; TS	4.2 SD 2.3	TF; HN	8.3 SD 1.2	BCLP; HN	8.5 SD 0.7
Female 4	TF; HN	8.1 SD 1.1	UCLP; HN	8.3 SD 1.1	TF; TS	2.5 SD 1.5	UCLP; TS	2.8 SD 2.0
Male 5	TF; TS	2.9 SD 1.6	BCLP; TS	2.9 SD 2.3	TF; HN	7.5 SD 1.3	BCLP; HN	7.6 SD 1.3
Male 6	TF; HN	7.9 SD 1.2	UCLP; HN	7.4 2.0	TF; TS	3.2 SD 2.2	UCLP; TS	3.4 SD 2.2
Female 7	UCLP; HN	8.0 SD 1.3	TF; HN	8.1 SD 1.3	UCLP; TS	4.5 SD 2.0	TF; TS	4.2 SD 2.1
Male 8	UCLP; HN	7.4 SD 1.3	TF; HN	7.4 SD 1.5	UCLP; TS	3.0 SD 1.7	TF; TS	3.3 SD 2.0

Table 3 shows the mean scores and standard deviations of percent words wrong and intelligibility ratings for the simulated hypernasal speech with audible nasal air emissions when they were presented for a second time without masking noise and without speaker photographs. Data were aggregated across the four experimental conditions. A one-way ANOVA for the mean percent number of words incorrect showed a significant main effect, $F = 1480.0$, $df = 2$, $p < 0.01$. Tukey-Kramer post hoc tests showed that the typical speech in noise (mean 17.9), the simulated hypernasality and audible nasal air emission without masking noise (mean 34.5) and the simulated hypernasality and audible nasal air emission with masking noise (mean 89.7) all differed significantly from each other (all contrasts $p < 0.5$). An additional t-test showed that the percentages of words incorrect were significantly higher for female (mean 38.0) than male (mean 33.0) speakers ($t = -2.0$, $p < 0.5$).

Table 3. Mean percentage scores and standard deviations of percent words wrong and intelligibility ratings for the simulated hypernasal speech with audible nasal air emissions, presented for a second time without masking noise and without speaker photographs. Data were aggregated across the four experimental conditions. SD = standard deviation.

Speaker	Mean Percentage and SD of Words Incorrect	Mean Scores and SD of Intelligibility Ratings
Female 1	36.2 SD 34.7	4.7 SD 2.1
Male 2	40.0 SD 33.3	5.3 SD 2.1
Female 3	43.2 SD 30.7	5.6 SD 1.8
Female 4	35.0 SD 34.9	4.8 SD 2.2
Male 5	34.5 SD 35.2	5.0 SD 2.2
Male 6	32.4 SD 35.0	4.5 SD 2.5
Female 7	37.5 SD 37.3	5.1 SD 2.2
Male 8	26.1 SD 31.8	4 SD 2.2

A second one-way ANOVA for the mean intelligibility ratings for the simulated hypernasal speech with audible nasal air emissions without masking noise and photographs showed another significant main effect, $F(2) = 1024.5$, $p < 0.01$. Tukey-Kramer post hoc tests showed that the intelligibility ratings of typical speech in noise (mean 3.7), the simulated hypernasality and audible nasal air emission without masking noise (mean 4.9) and the simulated hypernasality and audible nasal air emission with masking noise (mean 8.0) all differed significantly from each other (all contrasts $p < 0.5$). An additional t-test showed that the intelligibility ratings were significantly worse for female (mean 5.1) than male (mean 4.7) speakers ($t = -2.2$, $p < 0.5$).

On the questionnaire regarding the participants' previous knowledge about cleft lip and palate, the first question about ever seeing an individual with cleft lip and/or palate was answered with “yes” by 23 of the 32 participants (72%). Only 4 (12.5%) participants had personally met an individual with cleft lip and/ or palate (question 2) and nobody had a family member with the condition (question 3). Thirteen participants (41%) had learned about cleft lip and/or palate in various courses in biology, pharmacology, nutrition science and English literature. Of these, 4 (12.5%) participants reported that they had done additional readings of books, web sites, or journal articles on the topic.

DISCUSSION

The current study expanded on previous work by Bressmann et al. (2019) and investigated the hypothesis that the presentation of a face of an individual with a visible repaired CLP would affect naive listeners’ ability to understand speech in noise. This hypothesis was investigated with the percentage of words incorrectly transcribed and the intelligibility ratings as the outcome measures. The present study also contrasted speech with simulated hypernasality and audible nasal air emissions with typical speech in noise.

Based on the results of the repeated-measures ANOVAs, the presentation of photos of individuals with repaired CLP did not significantly affect the accuracy of the participants’ transcriptions or their speech intelligibility ratings. The “intelligibility cost” proposed by Babel and Russell (2015) was not confirmed in this study. The original study on this topic by Podol and Salvia (1976) described an adverse effect on listeners’ ratings of hypernasality when the sound recording was presented together with a photo of an individual with CLP. However, this effect has so far proven elusive in subsequent studies (Glass & Starr, 1979; Bressmann et al., 2019).

There are several explanations that could explain the absence of an intelligibility cost. Since the photos were static, it is possible that listeners did not pay particular attention to them and instead focused their attention on the listening task. Alternatively, listeners may not have found the facial differences of the individuals with repaired cleft lip particularly obvious or remarkable. While cleft lip and palate is the most frequent congenital craniofacial malformation, it is still rare in the general population. The listeners may not have had sufficient exposure to develop expectations or preconceived notions. This may differ from ethnic biases, which are believed to consolidate with repeated exposure to a more numerous group (Rubin, 1992; Kang & Rubin, 2009; Babel & Russell, 2015).

The simulated hypernasal speech with audible nasal air emissions was significantly more difficult to understand in noise compared to the typical speech. The descriptive results in Tables 1 and 2 show that there may have been a ceiling effect for simulated hypernasal speech with audible nasal air emissions and a floor effect for typical speech. Compared to Bressmann et al. (2019), the noise levels in the present study had to be lower because the simulated hypernasal speech with audible nasal air emissions would have become impossible to understand with the original noise levels. As in the previous study, female speakers were more difficult to understand than males. This finding was not surprising because the same speaker recordings from Bressmann et al. (2019) had been used in the present study. Research has found that it is difficult to pinpoint specific predictors for speech intelligibility and that inter-speaker variability plays a key role (Barker & Cooke, 2007).

When the speech stimuli with simulated hypernasality and audible nasal air emissions were transcribed and assessed without the masking noise, Table 3 shows that the ceiling and floor effects, which had been observed for the experimental speech stimuli in noise, were now absent. In hindsight, this may have been a more appropriate level of auditory-perceptual challenge for the listeners. The finding that female speakers were found to be more difficult to understand than the males was consistent with the findings of the main experiment.

The questionnaire data showed that most participants had only limited knowledge of cleft lip and palate, and most had learned what they knew through coursework rather than personal acquaintance with affected individuals. Research is inconclusive whether previous knowledge or professional training may make listeners more (Dagenais et al., 1999; Damrose et al., 2004; Brunnegård et al., 2009) or less critical in their auditory-perceptual assessments (van As et al., 2003; Laczi et al., 2005). The finding that there was no clear intelligibility cost for listeners when the speech samples were paired with images of individuals with cleft palate may indicate that the listeners were not affected by negative prejudices, which would be a positive finding. On the other hand, several possible limitations in the experiment's design must be considered when interpreting the results. The participants' eye movement on the speaker photos was not tracked, so there is no measure how intently they engaged with the photos. The speech stimuli with the simulated hypernasality and audible nasal air emission appeared to capture these specific features of cleft palate speech well. Nevertheless, the speech stimuli were not natural representations of cleft palate speech, and the addition of masking noise resulted in ceiling effects for the percentage of words perceived incorrectly.

DECLARATION OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

We thank Gillian DeBoer and Monique Tardif for their support. Myles Drayton helped create the signal filters. Wei Deng, Vlad Vamanu, Alan Yang and Kelly Zhao, students in the Department of Statistics at the University of Toronto worked on a first version of the statistical analyses for this study.

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