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Obligatory Nasal Turbulence as a Trigger for the Development of Posterior Nasal Fricatives in a Child with Repaired Cleft Palate

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Abstract

Posterior nasal fricatives (PNFs) are unusual articulations that occur in some children with and without cleft palate. The etiology of PNFs is unclear. A young girl with repaired cleft palate is described who exhibited inconsistent obligatory nasal turbulence during production of stops at two years of age. At three years of age, she exhibited various phonological processes and used PNFs to replace sibilants and affricates. Pressure-flow testing showed a relatively small velopharyngeal area during production of stops. These observations are consistent with obligatory nasal turbulence triggering the development of PNFs as an unusual phonological process, perhaps facilitated by reduced hearing.

Introduction

Posterior nasal fricatives (PNFs) are unusual articulation errors exhibited by some children with and without palatal anomalies. PNFs are produced by actively stopping oral airflow while directing all airflow through a partially closed velopharyngeal (VP) port. Although the place of oral stopping can be variable – bilabial, alveolar, or velar – lingual-velar contact is most common (Peterson, 1975; Trost, 1981). The combination of relatively high driving air pressure and a relatively small VP port opening results in various degrees of turbulent airflow and tissue vibration or flutter (Trost, 1981; Zajac, 2015). PNFs are typically used to replace sibilant and affricate sounds although any of the fricatives may be affected (Peterson-Falzone and Graham, 1990).

Trost (1981) used radiographic imaging to describe the articulatory components of PNFs. She noted that a) the velum approximated but did not contact the pharyngeal wall, and b) the tongue articulated with the velum in some patients. Peterson (1975) and Peterson-Falzone and Graham (1990) also noted a retracted tongue with velar contact. Trost (1981) further described “a blurring of movement or a velar flutter” (p. 197). Zajac (2015) used oral-nasal audio recordings obtained with the Nasometer (Kay Pentax) to acoustically describe PNFs. He noted a silent interval in the oral waveform consistent with stop production. A spectrogram of the nasal signal showed quasi-periodic energy consistent with tissue flutter

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(see Figure 4, p. 22). Because Zajac (2015) did not use imaging procedures, the source of the spectral flutter as velar could not be confirmed.

Audible nasal turbulence is usually an obligatory symptom of incomplete VP closure that occurs on obstruent consonants – stops, fricatives, and affricates. It is considered a more perceptually severe form of nasal air emission due to extra noises that occur when intranasal or VP resistance is high (Peterson-Falzone et al., 2010). Peterson-Falzone et al. (2010) suggest that the extra noises are due to soft tissue vibration (as occurs with a PNF) or displacement of mucous that pools in the constriction. It should be noted that Kummer and colleagues refer to nasal turbulence as nasal rustle and have shown that it is associated with a relatively small VP port opening (e.g., Kummer et al., 1992). Kummer (2014) further suggests that the fricative noise of the nasal rustle results from bubbling of secretions in the VP port. Recently, Zajac and Preisser (2016) used oral-nasal audio recordings to show that nasal turbulence, in most cases, was associated with a quasi-periodic component that was consistent with tissue flutter. Zajac and Preisser, however, like Zajac (2015), did not use imaging procedures to identify the source of the quasi-periodic noise.

Obligatory nasal turbulence may sound similar to a PNF. Differential diagnosis, therefore, is important relative to treatment recommendations. In some children, the oral stopping component is quite salient to the extent that a stop consonant is heard along with the nasal turbulence (see Figure 1 in the Case Study section). To facilitate identification of a PNF, many clinicians will occlude the nose of the child during fricative production. If a PNF is produced, all expiratory airflow will abruptly stop as both the oral and nasal cavities are occluded. Conversely, oral airflow will continue in the presence of obligatory nasal turbulence. Alternatively, clinicians can audio record the child using the oral-nasal microphones of the Nasometer (Baylis et al., 2011; Zajac, 2015). As reported by Zajac (2015), an active PNF will show a silent interval on the oral signal consistent with a stop production and acoustic energy on the nasal signal consistent with friction (see Figure 4, p. 22). Obligatory nasal turbulence, however, will show acoustic energy on both the oral and nasal signals.

Traditionally, PNFs are considered to be compensatory misarticulations that develop in response to VP inadequacy (Trost, 1981; Peterson-Falzone et al., 2006). Peterson-Falzone et al. (2006) define compensatory misarticulations as errors in placement that are learned early in speech development to achieve *pressure-valving* requirements due to structural impediments (italics by author). Classification of PNFs as compensatory according to this conceptual framework, however, is problematic for several reasons. First, PNFs are the hallmark of phoneme-specific nasal emission in children without palatal anomalies and/or VP inadequacy. In such cases, the cause of PNFs is considered to be phonologic in nature (i.e., VP mislearning) (Trost-Cardomone, 1989; Peterson-Falzone et al., 2006). Second, children with palatal anomalies who produce PNFs typically do not have gross VP inadequacy with reduced pressure-valving. Zajac and Vallino (2015), for example, reported that approximately 90% of children with repaired cleft palate who used PNFs demonstrated adequate VP closure during pressure-flow testing. Adequate was defined as estimated orifice areas that were less than 5 mm² during production of /p/ in syllables and the word *hamper* (Warren, 1979; Warren et al., 1989). Zajac and Weissler (2004) has shown that an orifice

area of 5 mm² has minimal effect on oral air pressure levels. It must be noted that although a small orifice may not significantly reduce oral air pressure, obligatory symptoms such as audible nasal turbulence may occur (e.g., Kummer et al., 1992).

Zajac (2015) hypothesized that a combination of early conductive hearing loss and obligatory nasal turbulence during production of stop consonants may lead to the development of PNFs. Both conditions are likely to occur in children with repaired cleft palate and may occur in some children without cleft palate. Relative to the latter, large and/or irregular adenoids may prevent complete VP closure in some children. Such children are also likely to have Eustachian tube dysfunction and conductive hearing loss. Indeed, Peterson-Falzone and Graham (1990) reported that a majority of children who produced phoneme-specific nasal emission had “highly suspicious” early histories of otitis media (p. 138).

The purpose of this case report is to describe the development of PNFs in a girl born with a complete cleft of the secondary palate. The child was followed longitudinally from 12 to 36 months of age as part of a larger study. At 24 months of age, the child exhibited inconsistent obligatory nasal turbulence during production of stops and had reduced hearing at 4 kHz. At 36 months of age, the child exhibited various phonological processes and used PNFs to replace sibilant and affricate targets. Pressure-flow testing showed inconsistent and relatively small VP orifice areas with normal, even high, oral air pressure. As described below, these observations suggest that the child developed PNFs as an unusual phonological process in response to obligatory nasal turbulence, perhaps facilitated by reduced hearing at frequencies critical to fricative production.

Case Report

Patient

This case report presents observations of a Caucasian girl born with a complete cleft of the secondary palate. She was born full term, passed a newborn hearing screening, and had no known syndromes, sensorineural hearing loss, or developmental delays. The mother reported at least one ear infection prior to 11 months of age. At 11 months of age, an ENT noted the presence of bilateral serous effusions. The palate was repaired at 11 months of age via a 2-flap palatoplasty. The child also underwent bilateral myringotomies and insertion of ventilation tubes at the time of palate repair.

Observations

As part of a prospective, longitudinal study investigating the development of stop consonants, the child was seen for speech, language, and hearing assessments at 12, 24, and 36 months of age. The larger study was approved by an IRB and the parents received monetary compensation for participating.

Specific observations and assessments consisted of the following: 1) Oral examinations were done at each visit to rule out surgical dehiscence of the palate and/or the presence of oronasal fistulae. 2) Audiometric evaluations and tympanometry were performed at each visit. Audiometry consisted of either sound-field or individual ear testing. 3) Speech and

language were assessed at 12 and 24 months of age via the Communication and Symbolic Behavior Scales Developmental Profile (CSBS DP) (Wetherby and Prizant, 2002). The CSBS DP takes approximately 30 minutes and consists of six semi-structured communication opportunities that involve the child, parent, and examiner. It assesses social communication, use of gestures, sounds, and words, receptive understanding, and object use of children up to 24 months of age. The CSBS DP was video recorded. 4) Articulation was assessed at 36 months of age via the Goldman-Fristoe Test of Articulation 3 (GFTA-3), Sounds-in-Words subtest (Goldman and Fristoe, 2015). 5) VP closure was assessed at 24 months of age using nasal ram pressure (NRP) monitoring. NRP assesses VP function by detecting the presence of air pressure at the exit of the nares during speech and breathing (Thom et al., 2006). It provides a binary index of the VP port as either open or closed. A pediatric-sized nasal cannula was looped over the child's ears and inserted into the nostrils. The end of the cannula was connected to a bidirectional air pressure transducer. A small lapel microphone was used to record speech. Utterances produced without significant positive NRP were considered to have VP closure (see Eshghi et al., 2017, for details). 6) Standard pressure-flow testing was done at 36 months of age to assess VP function. Nasal airflow was obtained using a small mask coupled to a calibrated and heated pneumotachograph. Oral air pressure was obtained with a catheter connected to a calibrated differential pressure transducer. VP orifice area was estimated using pressure-flow data and PERCI-SARS software (Microtronics, Inc., Chapel Hill, NC) (see Zajac, 2008, for details).

12 Months of Age.—An oral exam revealed an intact hard and soft palate. The parents reported no nasal regurgitation of foods or liquids. A certified audiologist performed sound-field testing using narrow band noise and visual reinforcement techniques. Results showed normal to borderline-normal hearing in the better ear as evidenced by thresholds of 25, 20, 20, and 25 dB at 500, 1000, 2000, and 4000 Hz, respectively. Tympanometry indicated a large volume Type B (flat) response in the left ear and a small volume type B (flat) response in the right ear. The former was consistent with a patent ventilation tube; the latter was considered an abnormal response.

During administration of the CSBS DP, the child produced the consonants /m/, /b/, /d/, /g/, and /k/ and obtained a standard score of 102 that placed her in the 55th percentile for age. The CSBS DP was scored by a trained speech-language pathologist (SLP) who maintained at least 85% intra- and inter-scorer reliability as part of the larger study. There was no perceived audible nasal air escape or weak pressure consonants during administration of the CSBS DP as judged by the author, an experienced craniofacial SLP. Resonance of the child was also judged to be normal. It should be noted, however, that resonance is difficult to judge in single-word utterances that was typical of the child at this age.

24 Months of Age.—An oral exam revealed an intact hard and soft palate. The parents reported no nasal regurgitation of foods or liquids. A certified audiologist evaluated hearing using ER-3A inserts and tonal stimuli. Based on limited responses from the child, the audiologist reported normal to borderline-normal hearing. That is, the child responded at 20 dB to 500 Hz in the right ear and at 25 dB to 4000 Hz in both ears. Tympanometry indicated bilateral large volume type B (flat) responses consistent with patent ventilation tubes.

The child obtained a standard score of 97 on the CSBS DP that placed her at the 42nd percentile for age. Her consonant inventory consisted of /m/, /n/, /b/, /p/, /d/, /t/, /g/, /k/, /w/, and /j/. No fricatives were observed. The child was also audio recorded using a head-mounted condenser microphone during a picture naming/imitation task that targeted stop consonants. Although she produced only a few of the target stimuli (e.g., *duck*, *dog*, *pig*), she exhibited two instances of obligatory audible nasal turbulence with flutter. As shown in Figure 2, she produced the word *pig* with clear quasi-periodic spectral components during the /p/ and /g/ segments, especially the /p/. This pattern is consistent with flutter as a component of obligatory nasal turbulence (Zajac and Preisser, 2016). The child's resonance was judged to be within normal limits by the author.

During NRP monitoring, the child produced nine /p/ segments, all in the word *please* (produced as /pi/). Six of the /p/ segments (67%) were determined to be produced with VP closure. It should be emphasized that NRP does not provide information on the size of the VP gap. Based on the occurrence of audible nasal turbulence with flutter during the picture naming task, it is likely that the child had a relatively small VP gap during the three productions of /p/ that registered positive NRP. As reported later, this was confirmed via standard pressure-flow testing at 36 months of age.

36 Months of Age.—An oral exam revealed an intact hard and soft palate. The parents reported no nasal regurgitation of foods or liquids. Sound-field audiometry showed normal hearing in the better ear as evidenced by thresholds of 20 dB at the frequencies of 500, 1000, 2000, and 4000 Hz. Tympanometry indicated a type A (normal) response in the right ear and a small volume type B (flat) response in the left ear. The audiologist noted wax impacted in the left ear canal.

A head-mounted condenser microphone was used to record the child during administration of the GFTA-3. The child obtained a standard score of 96 that placed her at the 39th percentile for age. She exhibited various phonological processes including cluster reduction, stopping, gliding, deaffrication, and inconsistent initial and final consonant deletion. The child also produced PNFs with a flutter component for /s/, /z/, /ʃ/, /tʃ/, and /dʒ/. PNFs were fairly consistent for /s/ and /z/, especially in word final position. She omitted /s/ in most consonant clusters (e.g., *spider*, *slide*). The child's use of PNFs for /ʃ/, /tʃ/, and /dʒ/ was somewhat inconsistent. Although she produced a PNF in *shoe*, she produced a correct /ʃ/ in *shovel*. It should be noted that the latter was not a spontaneous production as the examiner needed to prompt the girl with a model. Regarding the affricate /tʃ/, she produced a PNF for the final /tʃ/ in *watch* but a correct /tʃ/ in *chair* and *cheese* (the /z/ was produced as a PNF in *cheese*). She produced a PNF in *vegetable* (after a model) but a correct /dʒ/ in *pajamas* (produced as *jam* also after a model). Other fricatives such as /f/ were produced correctly. As described below, the child also exhibited one instance of obligatory nasal turbulence during stop production (see Figure 3). All other stops were produced without audible nasal turbulence as judged by the author. Resonance was judged to be within normal limits.

Figure 1 shows the audio signal and spectrogram of the child saying *princess* with a PNF produced for the first /s/ target, the second /s/ was omitted. As seen in the figure, the PNF is rather prolonged and has a quasi-periodic component that is evident in both the waveform

and spectrogram. As noted previously, a PNF and obligatory nasal turbulence may sound similar. Unfortunately, the girl was not cooperative for either nose occlusion or wearing the headset of the Nasometer to confirm active oral stopping. Nonetheless, Figure 1 shows evidence of oral stopping. As seen in the figure, there is a clear silent interval with a release burst in both the waveform and spectrogram that occurs at the end of the PNF. Perceptually, this segment sounded like an intrusive /d/, confirming an active PNF.

Figure 3 shows the audio signal and spectrogram of the child saying *a glasses* with a PNF produced for the final /z/ target. Again, both the waveform and spectrogram show a clear quasi-periodic component. It should be noted that the periodic (flutter) component extends to the low frequencies, well below 1 kHz, similar to the PNF in Figure 1. It should also be noted that there is no clear stop release as part of the PNF in Figure 3. This does not discount the production of a stop, however, as stops in syllable final position are often unreleased (Kent and Read, 2002). As also seen in the figure, the child exhibited some audible nasal turbulence during production of the /gl/ target that was produced as a single /k/. The production of the /s/ target was difficult to transcribe with certainty but appeared to be either a fricationalized /k/ or a velar fricative with some nasal turbulence.

During standard pressure-flow testing, the child produced 24 syllables as part of the larger study's protocol – six /pi/, eight /pa/, four /bi/, and six /ba/ syllables. These syllables were produced on single breath groups, simulating connected oral-only speech. The child demonstrated VP closure during 20 of the syllables (83%), defined as nasal airflow that was less than or equal to 30 mL/s during the stop segment. This airflow value is typically associated with estimated VP orifice areas that are 1 mm² or less (Zajac, 2000). Overall, the girl's oral air pressure was adequate (actually high) at 10.4 and 8.8 cm H₂O for /p/ and /b/ segments, respectively (Searl and Knollhoff, 2013). The estimated VP area during the four syllables that were not closed was approximately 2 to 3 mm². Unfortunately, pressure-flow data were not obtained during sibilants or affricates as this was not part of the larger project's protocol.

Discussion

The purpose of this case report was to describe the development of PNFs in a young girl with repaired cleft palate. PNFs are unusual articulations that are produced by actively stopping oral airflow and directing all airflow through a partially closed velopharyngeal port. Perceptually, the nasal turbulence associated with a PNF is similar to obligatory nasal turbulence that can occur on all obstruent consonants. Traditionally, the occurrence of PNFs in a child with repaired cleft palate is considered to be a compensatory misarticulation that is learned to circumvent inadequate pressure-valving for speech. As described in this case report, however, although the girl exhibited inconsistent and a relatively small VP gap, she was more than capable relative to the generation of oral air pressures for speech purposes.

Rather, the observations in this case report are consistent with the development of PNFs as an unusual phonological process that was triggered by the early occurrence of obligatory nasal turbulence during production of stop consonants. Harding and Grunwell (1998) hypothesized that nasal fricatives develop within a phonological framework to establish

phonemic contrasts, consistent with this case report. Harding-Bell and Howard (2011) make the case that both articulatory and perceptual constraints associated with cleft palate operate to influence phonological development. In the present case, articulatory constraints were operating in the sense that normal production of stops were distorted by sporadic obligatory nasal turbulence during early learning. In addition, the child had slightly reduced hearing sensitivity at one frequency (at least) critical to the perception of normal fricatives.

Peterson-Falzone and Graham (1990) acknowledged that the occurrence of nasal fricatives “does signal the presence of a clearly aberrant phonologic rule or set of rules” that could be conceptualized as “fricative preference” or “nasal preference” (p. 137). Ingram (1976) identified “nasal preference” as an unusual phonological process in the speech of some children with deviant processes (p. 116). Peterson-Falzone and Graham (1990) speculated that such a rule would require one of two presumptions. First, that nasal frication “contains more of the feature of frication than the normal fricative” (p. 137). In essence, the child believes that a nasal fricative is a better exemplar of frication than an oral fricative. Second, the child finds nasal fricatives easier to produce than oral fricatives during early speech learning. The observations presented in this case report support both of these assumptions to various degrees.

Relative to the first assumption, the child produced PNFs with a clear quasi-periodic (flutter) component that was very evident in the lower frequencies as illustrated in Figures 1 and 3. Normal oral production of fricatives by children and adults is characterized by the relative lack of energy in the low frequencies with a concentration of aperiodic energy well above 3 kHz (e.g., Daniloff et al., 1980; Kent and Read, 2002; Hixon et al., 2008). In addition, the flutter component of the PNF provided the child with vibrotactile feedback that would be absent during production of an oral fricative. The child in the present study, therefore, clearly experienced more of the spectral and tactile features of frication, albeit different from normal, when producing a PNF.

Relative to the second assumption, the child experienced obligatory nasal turbulence due to VP dysfunction during early production of some stops. As indicated by NRP monitoring at 24 months of age, the child exhibited incomplete velopharyngeal closure on 33% of stops. Essentially, it may have been easier for the child to actively produce nasal turbulence in the form of a PNF as she was already experiencing obligatory nasal turbulence during production of stops.

It is also possible that perceptual constraints as proposed by Harding-Bell and Howard (2011) may have facilitated the development of PNFs. At 12, and especially, 24 months of age, the child’s hearing thresholds were slightly elevated (25 dB) at 4 kHz. Because hearing was not evaluated at frequencies above 4 kHz, it is not known if hearing was also reduced at higher frequencies. The slight reduction at a frequency critical to hearing and producing oral fricatives, especially /s/, may have caused the child to rely more on salient spectral and vibrotactile feedback at lower frequencies provided by a PNF. It should be noted that DeBonis and Donohue (2008) emphasize that even a slight hearing loss may have significant effects on communication. In support of this, Shriberg et al. (2000) reported that children with average hearing thresholds greater than 20 dB at 12 to 18 months had a significantly

higher risk of clinical or subclinical speech delay at 36 months compared to children with less than 20 dB average thresholds at 12 to 18 months. It must be acknowledged, however, that there is controversy regarding the impact of otitis media and conductive hearing loss on speech development (see Lim, 2007, for a review).

The present case study suggests that clinicians should not automatically assume that the presence of PNFs in a young child with repaired cleft palate signals grossly inadequate VP function and the need for secondary surgery. Indeed, the girl's obligatory symptoms of VP dysfunction were infrequent and perceptually mild. If, indeed, PNFs develop as a phonological process in some children with repaired cleft palate, then behavioral speech therapy is indicated, as for the child without cleft palate. Although the girl's overall articulation was considered age appropriate by a standardized test score, speech therapy was nevertheless recommended due to the relatively frequent and perceptually salient nature of her PNFs.

Conclusions

PNFs are unusual articulations characterized by oral stopping with all airflow directed through a partially closed velopharyngeal port. This case report suggests that obligatory nasal turbulence due to a relatively small VP gap and, perhaps, reduced hearing in the higher frequencies may trigger the occurrence of PNFs in some children with repaired cleft palate.

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Figure 1. Audio signal and spectrogram of the word *princess* produced by the child at 36 months of age. A posterior nasal fricative with flutter occurs during the first /s/ target.

Figure 2. Audio signal and spectrogram of the word *pig* produced by the child at 24 months of age. Obligatory nasal turbulence with flutter is most salient during the /p/ segment.

Figure 3. Audio signal and spectrogram of the words *a glasses* produced by the child at 36 months of age. A posterior nasal fricative with flutter occurs during the final /z/ target.