

# Factors Affecting Articulation Skills in Children With Velocardiofacial Syndrome and Children With Cleft Palate or Velopharyngeal Dysfunction: A Preliminary Report

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**Objective:** To examine the influence of speech perception, cognition, and implicit phonological learning on articulation skills of children with velocardiofacial syndrome (VCFS) and children with cleft palate or velopharyngeal dysfunction (VPD).

**Design:** Cross-sectional group experimental design.

**Participants:** Eight children with VCFS and five children with nonsyndromic cleft palate or VPD.

**Methods and measures:** All children participated in a phonetic inventory task, speech perception task, implicit priming nonword repetition task, conversational sample, nonverbal intelligence test, and hearing screening. Speech tasks were scored for percentage of phonemes correctly produced. Group differences and relations among measures were examined using nonparametric statistics.

**Results:** Children in the VCFS group demonstrated significantly poorer articulation skills and lower standard scores of nonverbal intelligence compared with the children with cleft palate or VPD. There were no significant group differences in speech perception skills. For the implicit priming task, both groups of children were more accurate in producing primed nonwords than unprimed nonwords. Nonverbal intelligence and severity of velopharyngeal inadequacy for speech were correlated with articulation skills.

**Conclusions:** In this study, children with VCFS had poorer articulation skills compared with children with cleft palate or VPD. Articulation difficulties seen in the children with VCFS did not appear to be associated with speech perception skills or the ability to learn new phonological representations. Future research should continue to examine relationships between articulation, cognition, and velopharyngeal dysfunction in a larger sample of children with cleft palate and VCFS.

KEY WORDS: *22q11.2 deletion, articulation, cleft palate, velocardiofacial syndrome, velopharyngeal dysfunction*

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Velocardiofacial syndrome (VCFS) is a relatively common multianomaly syndrome characterized by cleft palate, velopharyngeal dysfunction, speech-language disorders, cardiac anomalies, cognitive-behavioral disorders, characteristic facial features, differences in brain morphology, and a variety of other health and psychosocial problems (Shprintzen et al., 1978, 1981; Golding-Kushner et al., 1985; Goldberg et al., 1993; McDonald-McGinn et al., 1997; Eliez et al., 2001; Golding-Kushner, 2005). VCFS is a genetic disorder associated with a microdeletion at chromosome 22q11.2, assessed by fluorescent *in situ* hybridization (FISH) testing (Driscoll et al., 1992; Scambler et al., 1992). Children with VCFS are often initially encountered and diagnosed through a cleft palate/craniofacial team, likely due to the high incidence of cleft palate, submucous cleft palate, and velopharyngeal dysfunction in this population (Shprintzen et al., 1978; Golding-Kushner et al., 1985; Golding-Kushner, 1991).

Speech disorders in children with VCFS have repeatedly been shown to be more severe and complex than those of children with similar histories of clefting and velopharyngeal dysfunction for speech (VPD) without VCFS (Scherer et al., 1999, 2001; D'Antonio et al., 2001; DeMarco et al., 2004, 2005). Children with VCFS often display persistent hypernasality and articulation skills that are significantly below those of their age peers. In addition, children with VCFS may demonstrate systematic phonological errors, dysarthria, developmental apraxia of speech, voice disorders, or a combination of these (Golding-Kushner, 1995, 2005; Carneol et al., 1999; Scherer et al., 1999; Persson et al., 2003; Kummer et al., 2007). Although children with VCFS may demonstrate speech that is in some ways similar to that of children with nonsyndromic cleft palate or VPD, children with VCFS, regardless of the presence of clefting, have consistently been shown to have more impaired articulation skills than these children (Golding-Kushner, 1991; Scherer et al., 1999, 2001; D'Antonio et al., 2001; DeMarco, 2004, 2005).

While most efforts have focused on describing the speech profile of children with VCFS, few have explored possible causal factors leading to the increased severity of speech disorders in children with VCFS. Researchers have not yet been able to demonstrate a direct link between velopharyngeal dysfunction and articulation skills in the VCFS population, although evidence of some relationship is supported (D'Antonio et al., 2001). In addition, there is very limited research on other factors that might contribute to the increased severity of articulation problems in children with VCFS.

### **Articulation Skills in Children With VCFS**

Previous research has shown that children with VCFS have reduced consonant inventories and a preference for voiceless consonants regardless of place or manner of articulation, compared with age-matched peers with phenotypic overlap (i.e., similar speech and learning characteristics) but who do not have VCFS or the 22q11.2 deletion (D'Antonio et al., 2001). Persson et al. (2003) and Golding-Kushner (2001, 2005) have reported systematic speech errors similar to the developmental phonological processes often observed in young children with typical speech development. In addition, studies also report a high percentage of glottal stops in the early speech productions of young children with VCFS (Golding-Kushner, 1991, 2005; Scherer et al., 1999; D'Antonio et al., 2001; Persson et al., 2003). Researchers have not yet found a direct relationship between velopharyngeal factors (e.g., extent of velopharyngeal inadequacy, age at time of palatal repair, type or timing of secondary speech surgery), and measures of articulation skills in children with VCFS (Scherer et al., 1999; D'Antonio et al., 2001). Differences in the ages of participants across studies, as well as variation in speech tasks utilized (e.g., word level versus spontaneous

speech sample) may play a role in explaining at least part of this discrepancy.

### **The Influence of Higher-Level Cognitive-Linguistic Deficits on Articulation Skills**

Learning disabilities or other language and cognitive impairments are among the most commonly identified characteristics associated with VCFS, with prevalence as high as 99% (Shprintzen et al., 1978; Golding-Kushner et al., 1985; Goldberg et al., 1993; Swillen et al., 1997; Moss et al., 1999; Glaser et al., 2002; Niklasson et al., 2002; Goorhuis-Brouwer et al., 2003; Campbell and Swillen, 2005; Golding-Kushner, 2005). Some previous studies have found a discrepancy between verbal and nonverbal IQ scores in the VCFS population, typically with higher verbal scores (Swillen et al., 1997; Gerdes et al., 1999; Moss et al., 1999; Woodin et al., 2001). Children with significantly decreased cognitive abilities have been found to have more difficulties and delays in processing and producing speech sounds (Eilers and Oller, 1980; Smith and Stoel-Gammon, 1983; Stoel-Gammon, 1997; Iacono, 1998; Kennedy and Flynn, 2002).

Scherer et al. (2001) compared the communication profiles of four children with VCFS to a group of four children with Down syndrome to examine the possible effect of cognitive impairments on speech-language skills. Children with Down syndrome share a common profile with children with VCFS, including histories of hypotonia, feeding difficulties, middle ear pathology, and developmental delays (Stoel-Gammon, 1997). Results revealed that the children with VCFS had less developed vocabulary skills and a smaller speech sound inventory compared with the Down syndrome group. So, while children with VCFS may exhibit speech delays or learn aberrant speech production patterns due to velopharyngeal and hearing-related deficits, they may also have more difficulty “unlearning” errors due to specific limitations in cognitive capacity.

### **The Influence of Hearing Factors and Speech Perception on Articulation Skills**

Children with VCFS, as well as those with cleft palate or velopharyngeal dysfunction, are at high risk for otitis media with effusion (OME) and subsequent hearing loss (Moller and Starr, 1993; Broen et al., 1996; McDonald-McGinn et al., 1997; Digilio et al., 1999). OME may cause the child to receive an incomplete or distorted auditory signal, due to fluctuating conductive hearing loss. This may then interfere with the development of speech sound perception or discrimination skills (Stool and Randall, 1967; Philips and Harrison, 1969; Heller et al., 1978; Broen et al., 1996) and subsequently, speech production (Finnegan, 1974). Indeed, this relationship is true even in children without craniofacial anomalies. Paden et al. (1987) found that three factors, low articulation scores, elevated hearing

thresholds at 500 Hz, and a history of early onset and late remission from otitis media with effusion, were the most important variables predicting phonological development in children with otherwise typical development. It is possible that increased persistence and severity of hearing impairment in children with VCFS (Digilio et al., 1999) play a larger role in the phonological development of children with VCFS than other children with isolated cleft palate and VPD.

### The Influence of Implicit Phonological Learning Ability on Articulation Skills

Another possible explanation for the increased severity of articulation disorders in children with VCFS is a decreased ability to learn phonological representations for newly encountered words. Many contemporary theories of speech production (such as the DIVA model, Perkell et al., 2000), posit that auditory-perceptual representations are the targets of speech production. That is, children must accrue information about the acoustic-perceptual characteristics of words so that they have well-defined targets in speech production. Hence, a deficit in learning perceptual representations might lead to deficits in expressive phonology. Previous demographic research (i.e., Paden et al., 1987) and experimental research (Munson et al., in press; Munson et al., 2005) has converged on the notion that an inability to learn phonological representations for novel words underlies the speech production problems of children with phonological disorders (i.e., highly inaccurate speech production in the absence of a clear predisposing condition). It is possible that the articulation errors seen in children with VCFS could be related to a similar perceptual-learning deficit. In addition, if the relationship between phonological learning and speech production learning were seen as reciprocal, then the deficits in articulation in VCFS could also be related to their vocabulary deficits (Scherer et al., 2001).

Phonological learning can be studied experimentally. Fisher et al. (2001) used a long-term auditory priming experiment with preschoolers to investigate this ability. These investigators presented children with spoken nonwords in a *prime phase*, which was followed by a *test phase* in which children repeated nonwords. They found that 2.5-year-old children more accurately identified and repeated nonwords that had been presented twice in the prime phase than nonwords that had not been presented. This result shows that typically, developing children can form perceptual representations for words based on minimal exposures. Munson et al. (in press) found that children with phonological disorder show a reduced benefit of priming (brief auditory-perceptual exposure to novel words) in an implicit word-learning task compared with children with typical phonological development. Across the two groups, a statistically significant proportion of variance in the degree of priming (defined operationally as the difference in

repetition accuracy between primed and unprimed nonwords) was predicted by a measure of phonetic accuracy in single-word naming, even when chronologic age and speech discrimination were controlled statistically. This suggests that speech production abilities are supported by the ability to learn new phonological representations in the implicit priming task.

Overall, there are many complex and interrelated variables which may contribute to the articulation and phonological difficulties in children with VCFS. Studies must take into account factors related to hearing, VPD, cognitive-linguistic abilities, and treatment history. The purpose of this study was to examine the influence of speech sound perception skills, cognitive skills, and implicit phonological learning ability on the articulation skills of children with VCFS and those with cleft palate or VPD. To investigate these factors, we proposed the following hypotheses:

- (1) children with VCFS have poorer speech sound perception skills, as measured by accuracy on a minimal pairs discrimination task, compared with children with isolated cleft palate or VPD;
- (2) children with VCFS have a disproportionately poorer ability to learn new words, as measured by their articulation skills in an implicit word-learning paradigm, compared with children with isolated cleft palate or VPD; and,
- (3) speech perception skills, nonverbal intelligence, and implicit word-learning ability are correlated with articulation skills for both groups of children.

We also attempted to replicate previous research confirming that children with VCFS do have more severe articulation difficulties compared with children with non-syndromic cleft palate, and also expanded our investigation of articulation to include both single word and conversational level phonetic accuracy.

## METHOD

### Subjects

This study was approved by the University of Minnesota Institutional Review Board, and all subjects underwent informed consent procedures and were paid for their participation in the study. Participant demographics are presented in Table 1. Children were recruited through the University of Minnesota Cleft Palate and Craniofacial Clinics by personal or telephone contact, and through a Velocardiofacial Syndrome Family Support Group in the Minneapolis/St. Paul metropolitan area. Parents of all participants completed a Speech Study Parent Questionnaire (Appendix A). This questionnaire was designed for the parent to provide relevant background information on oral-facial structural features, speech therapy history,

**TABLE 1** Information for the 13 Participants Obtained From the Parent Questionnaire, Medical Records Review, and Hearing Screening\*

Subject	Sex	Age (Y;Mos)	VP Dx	VP Surgical Hx	Resonance	VPI Severity	Speech Tx (Y)	OME Hx	Hearing	Tubes	Tymps
VCFS1	F	4;11	SMCP	none	hyper	1.5	4	no	20 dB	no	WNL
VCFS2	M	7;6	VPD	none	hyper	5.5	5	yes	20 dB	no	NPP
VCFS3	F	6;11	VPD	ph flap	hyper	2	6	yes	20 dB	no	WNL
VCFS4	F	7;6	SMCP	ph flap	hyper	3	7	no	25 dB	no	NPP
VCFS5	M	5;11	VPD	none	hyper	7	3	no	20 dB	no	WNL
VCFS6	F	6;2	SMCP	ph flap	hypo	0	2	yes	25 dB	yes	FPP
VCFS7	F	7;5	SMCP	sphincter	hyper	6	7	yes	20 dB	no	WNL
VCFS8	M	4;9	CP	sphincter	hyper	3.5	3	yes	20 dB	no	WNL
CPO/VPD1	F	5;9	SMCP	none	hyper	1	3	no	20 dB	no	NPP
CPO/VPD2	M	6;5	CP	none	hypo	0	1	yes	20 dB	no	NPP
CPO/VPD3	M	6;6	VPD	none	hyper	2	3	yes	20 dB	no	WNL
CPO/VPD4	F	4;8	CP	none	hyper	1.5	0	yes	25 dB	yes	WNL
CPO/VPD5	M	3;10	VPD	none	hyper	1	1	yes	20 dB	yes	WNL

\* VP Dx = initial velopharyngeal diagnosis: CP = cleft palate, SMCP = submucous cleft palate, VPD = other velopharyngeal dysfunction (noncleft, e.g., postadenoidectomy). VP surgical hx = velopharyngeal speech surgical history: ph flap = pharyngeal flap, sphincter = sphincter pharyngoplasty. Resonance = current type of resonance distortion, hyper = hypernasality, hypo = hyponasality. VPI severity = global rating of severity of velopharyngeal inadequacy for speech (based on conversational sample using 8 point equal-appearing interval scale rating, 0 = no current symptoms of VPI, 7 = severe velopharyngeal inadequacy for speech). Speech tx = years of speech therapy. OME hx = history of chronic otitis media with effusion. Hearing = hearing screening pass level. Tubes = current presence of ventilation tubes. Tymps = tympanometry results: WNL = within normal limits, NPP = negative pressure peaks, FPP = flattened pressure peaks.

medical and surgical history, hearing history, and known cognitive-learning factors. The questionnaire was adapted from the University of Minnesota Neuropsychology Clinic Intake Questionnaire to include more speech-specific items and to include elements of the VCFS Specialist Fact Sheet (Velocardiofacial Syndrome Educational Foundation). Selected information from this questionnaire is presented in Table 1.

A total of 13 children (7 female and 6 male) participated in this study and were between the ages of 3;10 and 8;6 (years;months). The VCFS group consisted of five girls and three boys (ages 4;9 to 7;0, *mean* = 6;4). The comparison group consisted of children with a history of nonsyndromic repaired cleft palate, submucous cleft palate, or velopharyngeal dysfunction (referred to as the “CPO/VPD group”). This comparison group consisted of three boys and two girls (ages 3;10 to 6;6, *mean* = 5;6). The VCFS subjects were, on average, almost 1 year older than the CPO/VPD group, although this difference did not achieve statistical significance in a Mann-Whitney *U* test ( $p = .171$ ). All participants were native English speakers in order to rule out confounding effects of second language learning on speech production characteristics and language skills. The CPO/VPD group was selected as an appropriate comparison group for this study because of their phenotypic overlap with children with VCFS. Children in this comparison group would have the following factors in common with the children with VCFS: (1) presence or history of velopharyngeal dysfunction, (2) increased risk of otitis media and fluctuating hearing loss, and (3) increased risk for the development of articulation disorders.

All eight participants in the VCFS group had a 22q11.2 deletion confirmed by fluorescent *in situ* hybridization testing and clinical diagnosis of VCFS by a geneticist. According to parent report and medical records review, the five children in the CPO/VPD group had (1) no known learning disabilities or mental retardation, (2) no other

congenital anomalies or syndromes, (3) no known behavioral or psychiatric conditions, (4) no known language impairments, and (5) no oronasal fistulae at the time of their participation in the study (also confirmed by oral examination). Children with a history of clefting of the primary palate (i.e., involving the lip and alveolus) were excluded from the study to limit interference from dental-occlusal hazards as contributing to articulation errors. Additional information about velopharyngeal and cleft diagnoses and surgical history is presented in Table 1.

Participants were not excluded from the study on the basis of speech therapy or surgical history. While it would have been desirable to control for variables associated with these treatments, it would have been difficult to determine the amount, focus, or therapeutic approach for speech therapy and surgeon or surgery-specific factors for each child. A brief oral examination was also conducted. All speech and hearing testing for this study was conducted in a sound-treated room at the University of Minnesota Department of Speech-Language-Hearing Sciences. All testing was conducted by the first author, a certified and licensed speech-language pathologist.

Global ratings of severity of velopharyngeal inadequacy for speech (VPI) were made from a 2-minute audiorecorded portion of each participant’s conversational speech sample. Two listeners (the first author and a second rater who works as a speech-language pathologist in a cleft palate clinic) independently rated these samples for type of resonance distortion and overall severity of VPI using an 8-point equal-appearing interval scale. On this scale, 0 indicated no symptoms of VPI and 7 indicated severe symptoms of VPI. Samples were presented in a randomized order. The second listener was not informed of the diagnosis of the participants in the study. The two listeners’ severity ratings were averaged and are presented in Table 1. Interlistener reliability for ratings within  $\pm$  one scale point was 85%.



All children participated in a brief hearing screening and underwent tympanometry, administered by the first author. Children responded to pure tones at 20 dB HL for 500, 1000, 2000, 4000 Hz bilaterally, using a Maico Audiometer (Model MA-20) according to the procedures recommended by the American Speech-Language-Hearing Association (ASHA Panel on Audiologic Assessment, 1996). Tympanometry was also performed according to these ASHA standards. Any participants who did not pass the first hearing screening at 20 dB HL were re-screened again at 25 dB HL. Hearing screening and tympanometry results, as well as information regarding history of otitis media and ventilation tube placement, as obtained from the parent questionnaire, are presented in Table 1. All participants passed the hearing screening at 25 dB HL or better. For the VCFS group, two subjects did not pass the screening at 20 dB HL at two frequencies. However, both of these children did pass a second screening at 25 dB HL. Moreover, both had abnormal tympanometry findings. Neither of these participants had a diagnosed permanent hearing loss, according to the parent report. One VCFS participant had negative pressure peaks bilaterally, and it was reported in the questionnaire that this was consistent with this participant's history of chronic middle ear dysfunction. The second VCFS participant, who had a reported history of chronic otitis media, had a flattened pressure peak in the right ear, likely due to the presence of fluid in the middle ear space and an extruded ventilation tube present in the ear canal. One child in the CPO/VPD group with no known history of hearing loss also did not pass the hearing screening at 20 dB HL for two frequencies, but did pass at 25 dB HL, and tympanometry revealed patent ventilation tubes. Two children in the CPO/VPD group, both with reported histories of chronic OME, had abnormal tympanometry results indicating slightly negative pressure peaks.

## Tasks

### *Measures of Articulation Skills*

*Phonetic Inventory (Single-Word Phonetic Accuracy).* All children were administered a novel phonetic inventory task in which they named basic items on black-and-white picture cards (see Appendix B for a full list of stimulus words). These single word responses provided a sample of all English phonemes in initial, medial, and final word position. The 39 items for this test (including 59 scored consonants and 13 vowels) were selected from existing picture-stimuli based on their phonemic make-up and children's familiarity with the items, as gauged by normative studies by Cywicz et al. (1997).

Pictures were presented in semantically uniform sets to facilitate word retrieval and speed of test administration. For example, the stimulus "banana" was followed by "pear," and "pig" was followed by "goat." In the event that a child did not know the name of the pictured item, the

examiner had the child produce the correct response after delayed imitation. The responses of this single word articulation inventory were audiorecorded using a Marantz Professional CD Recorder (Model CDR300, Marantz America Inc., Mahwah, NJ) and AKG condenser microphone (Model C419IIPP, AKG Acoustics, Vienna, Austria).

*Conversational Speech Sample.* Children were given a standard set of toys and parents/caregivers were instructed to play and speak with their child for 15 minutes while a conversational sample was collected. Parents were instructed to limit use of yes/no questions, imitation, and item naming with their child during this time. Speech samples were audiorecorded and later transcribed phonetically by the first author and one independent listener.

The transcribed responses were used to calculate the percent phonemes correct (PPC), using the criteria of Shriberg et al. (1997). The PPC metric expresses the percentage of intended consonant sounds in a speech sample that was articulated correctly. Clinical distortions, deletions, or substitutions of any consonant or vowel are scored as incorrect. Articulation errors were also coded by type and frequency (e.g., substitutions, omissions, distortions, compensatory errors). For both the single-word picture naming and conversational sample tasks, a separate PPC score was calculated based on these transcriptions, referred to as PCC-WORD and PCC-CONV, respectively.

### *Independent Measures*

*Nonverbal Intelligence.* Children were administered the *Kaufman-Brief Intelligence Test* (K-BIT) matrices and vocabulary sections (Kaufman, 1990). The K-BIT is a brief, individually administered measure of verbal and nonverbal intelligence skills. The vocabulary subtest measures language development and level of verbal conceptualization as children name black-and-white picture drawings. The matrices subtest was included in this study as a nonverbal measure of analogical knowledge using visual stimuli, both meaningful (people and objects) and abstract (designs and symbols). From these test sections, vocabulary raw scores, matrices raw scores, and matrices standard scores and percentile ranks were calculated.

*Speech-Sound Perception Skills.* To investigate whether children with VCFS have more difficulty detecting the subtle differences between speech sounds, all children participated in a novel minimal-pair identification task. Forty-one sets of minimal pairs of pictures were selected. Stimuli were selected primarily from the same source as the phonetic inventory stimuli, based on their phonetic features and their familiarity to children. These word pairs featured initial and final position phoneme contrasts, selected with the speech characteristics of children with VCFS or cleft palate in mind. For example, the pair "man-pan" was selected because it demonstrates the error of nasal sub-

stitution, “boat-goat” was selected for its backing process, and “tie-eye” was selected to resemble a possible glottal stop substitution. Stimuli were produced by a male adult with native Minnesotan dialect (the third author), audio-recorded, and later screened for intelligibility before use with the subjects (see Appendix C for a full list of stimulus words).

The child was seated at a table as single auditory stimulus items were presented at 65 dB HL using a laptop computer, E-Prime software (Psychology Software Tools Inc., Pittsburgh, PA), and two Audix speakers (Model PH5, Audix Inc., Wilsonville, OR). As each auditory item was presented, a pair of black-and-white picture cards was shown to the child, who was asked to point to the correct response. Responses were scored as correct or incorrect. Overall percentage correct was calculated for each child.

*Phonological Learning Ability: The Implicit Priming Task.* The implicit priming task explored possible differences in ability to learn new “words” and build phonological representations based on minimal exposure. This was an implicit priming task, modeled on that presented by Fisher et al. (2001). A set of 79 nonwords was created using the phonemes /h, w, p, b, m, n, g, k, t, d, f/, since these are typically the earliest phonemes present in children’s speech repertoire (Smit et al., 1990). These phonemes were combined with vowels to create sequences of CVC and CVCVC nonwords. All of the sequences of sounds in the nonwords were attested in real English words. For the creation of these stimuli, six adult speakers (three male, three female, all Minnesota natives) were first selected to read aloud this list of nonwords (three times each), and these productions were audiorecorded. These six speakers’ productions were then randomized and presented to a set of five independent adult listeners with normal speech and hearing using E-Prime software, a laptop computer, and two Audix speakers. Listeners were seated in a soundproof room, presented with the auditory stimulus (the nonword), and then asked to repeat the nonword aloud. The first author then scored the item as intelligible, if the listener produced the word according to the phonetic model, or unintelligible, if the listener’s production varied from the phonetically correct model. A percentage of intelligible nonwords was calculated for each of the six speakers, and the most intelligible speaker’s nonword productions (a female adult) were selected for use in the implicit priming task. Average intelligibility for adults judging the implicit priming stimuli chosen was 99% (see Appendix D for a complete list of implicit priming stimuli).

The procedures for the implicit priming task used with the children were similar to those used by Fisher et al. (2001). In the *prime phase*, children listened to an audiorecording of 52 nonwords which lasted approximately 5 minutes. Each nonword was presented three times in a randomized order for each subject at approximately 65 dB HL. While listening to the string of nonwords, children were instructed to refrain from talking and color

a picture in a coloring book until this recording finished. All participants were compliant with these instructions with the exception of the youngest participant in the CPO/VPD group, who required multiple cues to redirect his attention to the task. After the prime phase, children participated in a 2-minute distractor task, which included a brief oral examination and short conversation.

During the *test phase*, children were redirected to listen to a set of 52 nonwords, one at a time. The test phase took most children, on average, about 5 minutes to complete. Twenty-six of these nonwords had been presented to the child during the prime phase (“primed nonwords”) and 26 were novel nonwords (“unprimed nonwords”). After each nonword was presented, the child was asked to repeat each nonword back to the examiner. Children’s productions were audiorecorded onto CD-R. Nonword responses were later transcribed to calculate PPC-PRIMED and PPC-UNPRIMED scores for each participant.

A quasi-random representative subset of the Phonetic Inventory and implicit priming responses was transcribed and scored by a second independent listener (blind to the diagnosis of the speakers) to assess interjudge reliability. Reliability for the Phonetic Inventory was calculated at 81.8% overall, with 79.9% agreement for VCFS group responses and 87.0% agreement for the CPO/VPD group’s responses. Reliability for the implicit priming task was calculated at 83.3%, with 81.5% agreement for VCFS group responses and 90.0% agreement for the CPO/VPD group. Generally, these percentages of agreement are similar to those encountered in other studies utilizing transcription of articulation errors including those associated uniquely with the speech of children with cleft palate (e.g., Estrem and Broen, 1989; Shriberg et al., 1997; D’Antonio et al., 2001). It is likely that there was better reliability for the CPO/VPD group due to decreased frequency of errors and decreased severity of articulation impairment. Two Pearson chi-square tests were conducted to determine if these differences in reliability differed significantly between the CPO/VPD and VCFS groups. Neither test was significant ( $\chi^2_{[df=1]} = 1.36, p > .05$  for the PPC-WORD score;  $\chi^2_{[df=1]} = 3.27, p > .05$  for the combined implicit priming PPC scores).

### Data Analysis

Statistical tests used to examine group differences included the Mann-Whitney *U* test and a series of univariate analyses of variance (ANOVAs). Spearman rank correlation ( $\rho$ ) coefficients were calculated to examine relations among measures. An  $\alpha$  level of 0.05 was used to determine statistical significance. Scores for the children in each group were summed and averaged for a comparison of group means. In general, nonparametric statistical tests were employed where possible due to the small sample size and exploratory nature of this study.

**TABLE 2 Participant Scores for All Tasks\***

<i>Subject</i>	<i>Age (Y;Mos)</i>	<i>K-BIT VRAW</i>	<i>K-BIT MRAW</i>	<i>K-BIT MSS</i>	<i>SPEECH PERCEP</i>	<i>PPC- WORD</i>	<i>PPC- PRIMED</i>	<i>PPC- UNPRIMED</i>	<i>PPC- CONV</i>
VCFS1	4;11	11	7	73	84	83	66	58	86
VCFS2	7;6	32	16	84	98	92	92	84	94
VCFS3	6;11	26	16	92	95	90	88	87	94
VCFS4	7;6	26	20	97	95	99	92	87	95
VCFS5	5;11	16	14	92	88	25	39	34	49
VCFS6	6;2	26	18	102	100	94	85	91	94
VCFS7	7;5	32	19	96	98	64	88	82	78
VCFS8	4;9	15	6	68	70	75	68	73	87
Mean		23	15	88	91	78	77	75	85
SD		8	5	12	10	24	19	19	16
CPO/VPD1	5;9	23	14	94	98	92	91	84	88
CPO/VPD2	6;5	36	33	156	98	97	98	90	95
CPO/VPD3	6;6	33	23	112	100	96	96	90	89
CPO/VPD4	4;8	27	14	105	98	100	92	90	99
CPO/VPD5	3;10	15	12	103	75	97	74	84	96
Mean		27	19	114	94	96	90	88	93
SD		8	9	24	11	3	9	3	5

\* K-BIT VRAW = K-BIT vocabulary section raw score; K-BIT MRAW = K-BIT matrices section raw score; K-BIT MSS = K-BIT matrices standard score (mean = 100, 50th percentile); SPEECH PERCEP = percentage correct on minimal pairs perception task; PPC-WORD = single-word picture naming phonetic accuracy (percent phonemes correct); PPC-PRIMED = implicit priming task primed words phonetic accuracy; PPC-UNPRIMED = implicit priming task unprimed words phonetic accuracy; PPC-CONV = conversational speech sample phonetic accuracy.

## RESULTS

### Articulation Skills

Results for the phonetic inventory and conversational speech sample PPC scores are presented in Table 2. As expected, group differences were statistically significant for the PPC-WORD score, with the children with VCFS demonstrating poorer speech production skills (VCFS: 77.8%, CPO/VPD: 96.4%;  $z = -2.13$ ,  $p = .03$ ). Frequency counts and the types of errors produced by the participants are shown in Table 3. Inspection of these data suggest that children with VCFS had a higher frequency of sound substitutions, omissions, compensatory articulation errors, and voicing errors compared to the children with CPO/VPD. Children with VCFS also had lower PPC-CONV scores; however, group differences did not achieve statistical significance at the  $\alpha$  level of 0.05 (VCFS: 84.6%, CPO/VPD: 93.4%;  $z = -1.69$ ,  $p = .09$ ). There was no correlation

between age and PPC-WORD score (Spearman  $\rho = -.070$ ,  $p = .819$ ).

### Nonverbal Intelligence

For the K-BIT matrices standard score, group differences in nonverbal intelligence were statistically significant, with the children with VCFS scoring lower than the children with CPO/VPD (VCFS mean = 88, CPO/VPD mean = 114;  $z = -2.49$ ,  $p = .011$ ). Another important finding is that although the children with VCFS, on average, had lower nonverbal intelligence, a mean score of 88 does not classify this group as clinically mentally impaired using conventional criteria, as this score falls within one standard deviation of the normative-sample mean score.

For the K-BIT vocabulary raw score, group differences were not statistically significant (VCFS: 23, CPO/VPD: 26.8;  $z = -.96$ ,  $p = .35$ ) indicating that both groups of

**TABLE 3 Frequency and Types of Articulation Errors From the Phonetic Inventory Task\***

<i>Subject</i>	<i>Substit</i>	<i>Omiss</i>	<i>Glottal</i>	<i>N Fric</i>	<i>Distort</i>	<i>Voicing</i>	<i>Weak PR</i>	<i>ANE</i>
VCFS1	9	3	0	0	1	3	2	0
VCFS2	1	5	0	0	1	1	9	0
VCFS3	6	1	0	0	0	3	0	1
VCFS4	1	0	0	0	0	0	3	0
VCFS5	34	11	16	6	0	0	2	5
VCFS6	3	1	0	0	4	2	0	0
VCFS7	25	1	2	0	1	0	9	3
VCFS8	15	0	0	0	0	0	0	0
CPO/VPD1	5	1	0	2	6	0	2	2
CPO/VPD2	2	0	0	0	0	0	0	0
CPO/VPD3	2	1	0	0	2	0	2	10
CPO/VPD4	0	0	0	0	0	0	0	0
CPO/VPD5	2	1	0	0	0	0	0	0

\* Frequency counts above reflect raw number of errors for each error type based on words produced during phonetic inventory task. Substit = substitutions (including compensatory errors); Omiss = omissions; Glottal = glottal stop substitutions; N Fric = nasal fricative substitutions; Distort = distortions (placement-related distortions only); Voicing = voicing errors (i.e., devoicing); Weak PR = weak pressure consonants; ANE = audible nasal air emission (does not include nasal fricatives).

children in this study had similar expressive vocabulary skills (see Table 2).

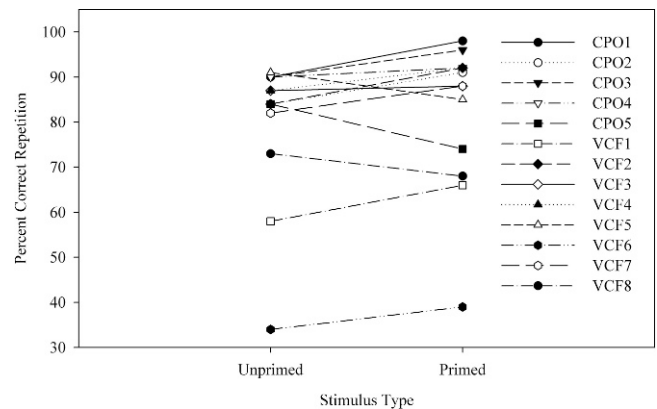
### Speech-Sound Perception Skills

Group means for performance on the minimal-pair speech-perception task were very similar (VCFS: 91%, CPO/VPD: 93.8%), suggesting that the groups had comparable speech sound discrimination skills. Rationalized arcsine transformed scores did not significantly differ ( $z = -.98, p = .33$ ), indicating similar abilities to detect differences among minimal pairs. Qualitative analysis of Tables 1 and 2 suggests the hearing screening status of participants did not appear to affect speech-sound discrimination or articulation performance in this study.

For example, subjects VCFS4, VCFS6, and CPO/VPD4 all passed the screening at 25 dB HL but outperformed several other subjects who passed at 20 dB HL (e.g., VCFS1, VCFS5, VCFS8, and CPO/VPD3) on the speech sound perception task. In addition, visual inspection also shows that these subjects who passed at 25 dB HL had very high PPC-WORD scores (i.e., VCFS4: 95%, VCFS6: 94%, CPO/VPD4: 100%) which were not lower than the rest of the subjects. Unequal group sizes prevented further statistical analysis of these hearing screening data.

### Ability to Learn New Words: The Implicit Priming Task

For the PPC-PRIMED score, children with VCFS scored lower than the children with CPO/VPD (VCFS 77.3%, CPO/VPD 90.2%,  $z = -1.77, p = .093$ ), but this difference did not achieve statistical significance at the  $\alpha$  level of 0.05. For the PPC-UNPRIMED score, children with VCFS again had lower scores, but the difference was not statistically significant (VCFS 74.5%, CPO/VPD 87.6%;  $z = -1.42, p = .171$ ). Average PPC scores were higher for primed nonwords than for unprimed nonwords; however, this effect was not statistically significant ( $z = -1.508, p = .132$ ) for the combined group of 13 participants. Individual participants' performance on the implicit priming task is shown in Figure 1. As this figure shows, one child (CPO/VPD5), showed the largest difference between primed and unprimed words in the opposite-than-predicted direction.



**FIGURE 1** Percent phonemes correctly repeated for unprimed and primed words in the implicit priming task, separated by individual subject.

This child was the youngest to participate in the study and showed high levels of distraction during the prime phase of this task. When results were reanalyzed without this subject's data, a significant effect of priming was detected ( $z = -2.207, p = .027$ ). This indicates that the primed nonwords were produced more accurately than the unprimed nonwords. The degree of priming was similar for both groups as reflected by a small gain (approximately 3%) in phonetic accuracy PPC scores for the primed nonwords.

### Relations Among Measures

Nonparametric Spearman  $\rho$  correlation coefficients were utilized in this study to explore relations among measures. The results are presented in Table 4 and show strong correlations ( $**p < .01$  and  $*p < .05$ ) among several measures. In this study, we were most interested in the relationships between measures that might be associated with articulation skills in these groups of children. The correlations between the PPC-CONV and both the PPC-WORD scores ( $\rho = .920, p = .01$ ) and PPC-UNPRIMED scores ( $\rho = .704, p = .01$ ) suggest some relationship between phonetic accuracy at the single word level and the connected speech level. Similar relations were observed between other articulation skill measures, such as between the PPC-WORD scores and both implicit priming PPC

**TABLE 4** Correlations (Spearman  $\rho$ ) Among Measures†

	K-BIT VRAW	K-BIT MSS	SPEECH PERCEP	PPC-WORD	PPC-PRIMED	PPC-UNPRIMED	PPC-CONV
PPC-CONV							1.000
K-BIT VRAW	1.000						0.285
K-BIT MSS	0.599*	1.000					0.604*
SPEECH PERCEP	0.777**	0.563*	1.000				0.156
PPC-WORD	0.350	0.739**	0.315	1.000			0.920**
PPC-PRIMED	0.855**	0.639*	0.655*	0.666*	1.000		0.549
PPC-UNPRIMED	0.620*	0.756**	0.709**	0.759**	0.702**	1.000	0.704**

† K-BIT VRAW = K-BIT vocabulary section raw score; K-BIT MRAW = K-BIT matrices section raw score; K-BIT MSS = K-BIT matrices standard score (mean = 100, 50th percentile); SPEECH PERCEP = percentage correct on minimal pairs perception task; PPC-WORD = single-word picture naming phonetic accuracy (percent phonemes correct); PPC-PRIMED = implicit priming task primed words phonetic accuracy; PPC-UNPRIMED = implicit priming task unprimed words phonetic accuracy; PPC-CONV = conversational speech sample phonetic accuracy.



scores (PPC-PRIMED:  $\rho = .666$ ,  $p = .013$ ; PPC-UNPRIMED:  $\rho = .759$ ,  $p = .003$ ). Speech sound perception skills were also related to phonetic accuracy but only for the implicit priming task (PPC-PRIMED:  $\rho = .655$ ,  $p = .015$ ; PPC-UNPRIMED:  $\rho = .709$ ,  $p = .007$ ) and not for the single-word phonetic inventory ( $\rho = .315$ ,  $p = .294$ ).

Age was not correlated with phonetic accuracy (i.e., PPC-WORD,  $\rho = -.070$ ,  $p = .819$ ), likely due to the heterogeneity of articulation skills in the groups of participants. This obviated the need to control for age in our nonparametric correlational analyses. Two factors were found to be significantly correlated with speech production accuracy. First, our measure of nonverbal intelligence (K-BIT matrices standard score) was highly correlated with phonetic accuracy at the single word and conversational level (PPC-WORD scores: Spearman's  $\rho = .739$ ,  $p = .004$ ; PPC-CONV scores:  $\rho = .604$ ,  $p = .05$ ). Nonverbal intelligence was also correlated with performance on the implicit priming task (PPC-PRIMED scores:  $\rho = .639$ ,  $p = .019$ ; PPC-UNPRIMED scores:  $\rho = .756$ ,  $p = .003$ ). Second, the severity of VPI was also significantly correlated with speech production accuracy (PPC-WORD scores:  $\rho = -.580$ ,  $p = .038$ ), reflecting that the children with more severe symptoms of VPI were more likely to have poorer articulation skills.

## DISCUSSION

Results from this study provide further evidence that the speech phenotype of children with VCFS does demonstrate some overlap with that of children with nonsyndromic cleft palate or velopharyngeal dysfunction; however, we have also identified group differences which may provide insight into the possible nature of each group's speech disorders. As seen in previous studies (Scherer et al., 1999; D'Antonio et al., 2001), we found that children with VCFS have poorer articulation skills than children with isolated cleft palate or velopharyngeal dysfunction and, on average, more severe ratings of VPI. Severity of VPI was negatively correlated with the articulation performance of the children in this study, suggesting that the more severe the rating of VPI, the lower the phonetic accuracy score.

In addition to severity of VPI, other treatment factors may have been influencing articulation skills in the VCFS group. Specifically, the two subjects in this study who produced glottal stops (VCFS5 and VCFS7) also had the most severe ratings of VPI. Subject VCFS5 was almost 6 years of age and had severe articulation difficulties, severe symptoms of VPI, and had not yet received any physical management. In some cases, this could be due to the multiple medical needs that may receive priority over surgical intervention for speech in the more severely affected children with this syndrome. On the other hand, it is also possible that some children with VCFS may have such severe articulation disorders that they interfere with clinicians' ability to diagnose underlying VPI; consequent-

ly, appropriate treatment is delayed. Later age of diagnosis and intervention for VPI may account for the more severe articulation difficulties of children with VCFS. Multiple studies of children with cleft palate have found evidence of better velopharyngeal closure and more typical phonological development in children with early palate repair (Dorf and Curtin, 1982; Grobbelaar et al., 1995). In addition, it is probable that later diagnosis of VPI is more likely in children with VCFS relative to children with cleft palate, given the large proportion of those children with VCFS without overt clefting. With later treatment, maladaptive articulation behaviors may have already been learned, and these new sound production patterns will have become integrated into the child's developing phonological system. Hence, treatment could be considered "delayed" in many children with VCFS compared to cleft populations. An additional factor worthy of future investigation is the behavioral speech therapy history of children with VCFS, including an examination of duration of therapy, frequency, treatment strategies utilized, and age at which therapy was initiated to determine to what degree earlier and more intensive speech services play a role in the development of articulation skills.

An interesting finding in this study included the observation of higher articulation accuracy at the conversational speech level compared with the single-word level for the VCFS group. This result might suggest that the children with VCFS in this study either (1) employed phonetic avoidances or preferences to maximize intelligibility during conversational speech (e.g., chose to use words with a higher probability of being intelligible to their caregiver), or (2) had restricted expressive vocabularies based on a limited phonetic inventory, thus resulting in obligatory use of a more restricted set of words during the conversational sample. The second hypothesis is not supported by our results, given that we found similar expressive vocabulary levels between the VCFS and CPO/VPD groups in our study. Instead, the phenomenon of phonetic avoidances or preferences has previously been observed in the Down syndrome population (Iacono, 1998). While the phonetic inventory task in our study ensured that all phonemes were produced in multiple word positions, it is possible that in the conversational speech samples, not all phonemes were represented in all positions, resulting in a lack of opportunity for certain target phoneme production. Iacono (1998) hypothesized that children with speech production deficits may demonstrate this discrepancy between conversational and word-level speech samples due to avoidance of certain sounds that they have not mastered, which is also supported by the research of Morrison and Shriberg (1992). It is unclear whether this finding suggests an "active" strategy of phonetic sophistication being utilized by some of the children with VCFS in this study. Given the common finding of relatively stronger verbal than nonverbal intelligence in children with VCFS, this hypothesis appears

plausible and is deserving of further investigation in future research (Swillen et al., 1997; Gerdes et al., 1999; Moss et al., 1999; Woodin et al., 2001).

The children with VCFS in this study did have significantly lower nonverbal intelligence scores than the children with cleft palate or VPD, but their scores were not low enough to be considered clinically mentally impaired. The K-BIT matrices subtest score depends heavily on visual skills and children with VCFS have previously been shown to have difficulties in this area (Wang et al. 1998, 2000; Simon et al., 2005). Our exploratory analysis of relations among measures revealed a high correlation between nonverbal intelligence and articulation skill measures. There may be a relationship between articulation difficulties in children with VCFS and broader cognitive-linguistic deficits; however, since we did not match our groups for nonverbal intelligence levels, we are unable to determine if this finding is an artifact of having unmatched groups. Future studies should attempt to include a larger group of children with VCFS that represent a wider distribution of cognitive skills, as well as comparison groups matched for cognitive ability, to further examine the influence of nonverbal intelligence on speech performance. This would help provide further insight into whether or how cognitive deficits might be a limiting factor as to why children with VCFS have such significant articulation delays and difficulties.

Regarding the nature of articulation difficulties, this study is the first to provide preliminary information suggesting that children with VCFS may have similar speech sound perception skills compared with children with isolated cleft palate or VPD. The children with VCFS in this study did not demonstrate specific difficulties with a speech sound discrimination task, and performance on this task was not associated with phonetic accuracy. This finding is also important given the history or presence of mild fluctuating hearing loss present in some of the participants. It shows that even in the presence of reduced auditory input, both groups of children were still able to perceive subtle speech sound differences among stimuli.

In addition, no particular deficits were shown by the children with VCFS in the implicit priming task. This suggests that there may be no difference between these two groups of children in terms of their ability to learn new phonological representations. Thus, based on the tasks employed in this study, there were no indications to suggest that the articulation difficulties seen in this group of children with VCFS are necessarily related to deficient phonological processing skills or perceptual-learning deficits. Perceptual-learning deficits have recently been suggested to be an endophenotypic marker of phonological impairment in children (Munson et al., in press) and were not found to be characteristic of the group of children with VCFS who participated in this study.

Limitations of this study include the small sample size and an unbalanced group design, which may have reduced the statistical power of our data analysis. This limits our

ability to generalize results beyond the groups of children who participated in this study. However, our results lead to some preliminary conclusions and suggest avenues for future research. That is, results from this study suggest that the articulation difficulties seen in children with VCFS may not be related to a specific deficit in speech sound perception or a reduced ability to learn new phonological representations. On the other hand, other types of perceptual-learning processes have not yet been explored in the VCFS population. Neuromotor differences have recently been suggested as a factor influencing articulation difficulties in VCFS (Kummer et al., 2007), but further research is needed to examine how and to what extent VPI affects the articulation profile of children with VCFS. Results of this study lead to additional questions as to how the severity of VPI might interact with the development of articulation skills in VCFS, as well as which speech treatment approaches are most effective for children with this syndrome.

With a better understanding of the underlying factors which contribute to the severe articulation difficulties in VCFS, speech treatment paradigms might be devised to specifically target or compensate for those areas of deficits. Our finding of the lack of group differences in vocabulary, speech sound discrimination, and ability to learn new words supports the idea that auditory-verbal aspects of learning may be a relative strength for some children with VCFS, since more consistent deficits have been found in areas of nonverbal and visual-spatial skills. For some children with VCFS, behavioral speech treatment incorporating a combination of traditional visual placement cues and enhanced auditory-perceptual feedback may be effective in facilitating progress with articulation skills. Future research should examine whether there are perceptual-learning strategies and strengths that could be better utilized in behavioral treatment approaches to improve speech outcomes in children with VCFS.

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# APPENDIX A. PARENT QUESTIONNAIRE

## VELOCARDIOFACIAL SYNDROME RESEARCH STUDY QUESTIONNAIRE\*

Date of birth: \_\_\_\_\_ Gender: Male Female

Today's date: \_\_\_\_\_

Person filling out this form: Mother Father Other: \_\_\_\_\_

Primary language spoken by this child: \_\_\_\_\_

Which of the following conditions, if any, has your child been formally diagnosed with?

- ☐ Velocardiofacial syndrome
- ☐ DiGeorge syndrome
- ☐ None of these

Result of FISH test: ☐ positive for 22q11.2 deletion (confirmed by medical records)

☐ negative (no deletion)

### Facial/Oral Findings

Has this child been diagnosed as having any of the following conditions?

- ☐ Cleft palate
- ☐ Submucous cleft palate (age at diagnosis: \_\_\_\_\_)
- ☐ Cleft lip only
- ☐ Cleft lip and cleft palate
- ☐ No cleft diagnosed but "velopharyngeal dysfunction," "velopharyngeal inadequacy for speech," "VPI," or "hypernasal speech"

At what age was this diagnosed? \_\_\_\_\_

### Ear/Hearing Findings:

Has this individual had ear or hearing-related problems? Yes / No

Which type? (please check all that apply)

☐ Frequent ear infections or fluid in ears

Did this child require placement of tubes in the ears? Yes / No

At what age were tubes placed? \_\_\_\_\_

☐ Hearing loss (Please specify: \_\_\_\_\_)

☐ Other: \_\_\_\_\_

### Surgical History

Please check which of following procedures this child has had performed:

- ☐ Palate repair: age \_\_\_\_\_
- ☐ Pharyngeal flap: age \_\_\_\_\_
- ☐ Sphincter pharyngoplasty: age \_\_\_\_\_
- ☐ Tonsils removed: age \_\_\_\_\_
- ☐ Adenoids removed: age \_\_\_\_\_
- ☐ Heart surgery: age \_\_\_\_\_
- ☐ Other hospitalizations, illnesses, and surgeries: \_\_\_\_\_

### Speech/Language History

Has your child been diagnosed with a communication disorder? Yes / No

At what age was this problem identified? \_\_\_\_\_

Please check which of the following your child has been diagnosed with:

- ☐ Delay in speech sound development
- ☐ Delay in expressive language development
- ☐ Delay in receptive language development
- ☐ Articulation disorder
- ☐ Phonological disorder
- ☐ Apraxia of speech (difficulty with coordination or sequencing of speech sounds)
- ☐ Language disorder (difficulty with forming sentences, concepts, grammar, syntax, word finding)
- ☐ Voice disorder (hoarseness, breathy, strained voice, vocal nodules, etc.)
- ☐ Hypernasal speech (too much nasality in speech, associated with VPI)
- ☐ Stuttering
- ☐ Social interaction difficulties
- ☐ Other: \_\_\_\_\_

Has this child received speech therapy? Yes / No

At what age did he/she start speech therapy? \_\_\_\_\_

How many years has he/she received speech services? \_\_\_\_\_

### Cognitive/Learning/Behavioral

Has this individual received a formal diagnosis of any of the following:

- ☐ Learning disabilities
  - In which areas (e.g., math, reading, spelling)? \_\_\_\_\_
- ☐ Cognitive impairment or mental retardation
- ☐ ADHD (Attention deficit hyperactivity disorder) or ADD
- ☐ Nonverbal learning disability
- ☐ Auditory processing disorder (APD or CAPD)
- ☐ Autistic spectrum disorder:
  - ☐ Asperger's ☐ PDD (pervasive developmental disorder) ☐ Autism
- ☐ Obsessive-compulsive disorder
- ☐ Depression
- ☐ Anxiety Disorder

\* This is an abbreviated version of the original questionnaire provided to parents. This version includes those questions most relevant to the data reported in this study, seen in Table 1.

**APPENDIX B. STIMULI FOR THE PHONETIC INVENTORY, WITH BROAD PHONETIC TRANSCRIPTIONS**

Word	Transcription	Word	Transcription
banana	[bəˈnænə]	thumb	[θʌm]
lemon	[ˈlemən]	teeth	[tiθ]
carrot	[ˈkærɪt]	whistle	[ˈwɪsəl]
potato	[pəˈteɪtoʊ]	watch	[wɒtʃ]
cookie	[ˈkʊki]	glove	[glʌv]
gum	[gʌm]	zipper	[ˈzipə]
cat	[kæt]	matches	[ˈmætʃɪz]
elephant	[ˈɛlɪfənt]	scissors	[ˈsɪzəz]
giraffe	[dʒəˈɹæf]	shovel	[ˈʃʌvəl]
pig	[pɪɡ]	ladder	[ˈlædə]
sheep	[ʃip]	table	[ˈteɪbəl]
chicken	[ˈtʃɪkən]	vase	[veɪs]
duck	[dʌk]	house	[haʊs]
feather	[feð]	bridge	[brɪdʒ]
cages	[ˈkeɪdʒɪz]	wagon	[ˈwæɡən]
fish	[fɪʃ]	moon	[mun]
fishing	[ˈfɪʃɪŋ]	web	[web]
boy	[bɔɪ]	red	[ɹɛd]
nose	[noʊz]	those	[ðoʊz]

**APPENDIX C. STIMULUS PAIRS FOR THE MINIMAL-PAIRS SPEECH PERCEPTION TASK\***

Pair		Contrast	Pair		Contrast
pan	man	/p/-/m/	kite	knight	/k/-/n/
pear	hair	/p/-/h/	goat	coat	/g/-/k/
pants	ants	/p/-/θ/	mail	whale	/m/-/w/
purse	nurse	/p/-/n/	nose	hose	/n/-/h/
peel	wheel	/p/-/w/	knot	hot	/n/-/h/
bat	hat	/b/-/h/	farm	arm	/f/-/θ/
bee	key	/b/-/k/	fan	can	/f/-/k/
bone	phone	/b/-/f/	fire	tire	/f/-/t/
book	cook	/b/-/k/	fox	socks	/f/-/s/
bear	pear	/b/-/p/	sail	nail	/s/-/n/
boat	goat	/b/-/g/	sew	toe	/s/-/t/
bite	kite	/b/-/k/	sand	hand	/s/-/h/
tie	eye	/t/-/θ/	shoe	zoo	/ʃ/-/z/
tail	nail	/t/-/n/	wig	pig	/w/-/p/
top	mop	/t/-/m/	spit	sit	/sp/-/s/
dog	hog	/d/-/h/	ski	see	/sk/-/s/
deer	ear	/d/-/θ/	swing	sing	/sw/-/s/
cat	hat	/k/-/h/	snail	nail	/sn/-/s/
cap	map	/k/-/m/	scale	mail	/sk/-/m/
comb	home	/k/-/h/	stool	tool	/st/-/t/
cook	hook	/k/-/h/	chair	hair	/tʃ/-/h/
jacks	ax	/dʒ/-/θ/	cup	cut	/p/-/t/
bat	bag	/t/-/g/	rope	road	/p/-/d/
lock	log	/k/-/g/	mouth	mouse	/θ/-/s/
leaf	leak	/f/-/k/	wash	watch	/ʃ/-/tʃ/
gun	gum	/n/-/m/	soap	sew	/p/-/w/
pipe	pie	/p/-/θ/	ice	eye	/s/-/θ/
beach	bee	/tʃ/-/θ/	time	tie	/m/-/θ/

\*“Ø” indicates the omission of a consonant.

## APPENDIX D. STIMULI FOR THE IMPLICIT PRIMING EXPERIMENT, TRANSCRIBED PHONETICALLY

PRIMED STIMULI		UNPRIMED STIMULI	
[bug]	[kʌtəm]	[bən]	[kænid]
[bukɛf]	[kɪdəm]	[bʊkæm]	[keɪnid]
[fæfeɪb]	[nædəm]	[dɪt]	[mudub]
[fub]	[nek]	[dɪnəp]	[næf]
[gæɡʊt]	[pɛd]	[fudʊp]	[pæb]
[ɡɪb]	[pɛnɪn]	[ɡɪf]	[pætɪk]
[hʌɡæb]	[tem]	[ɡɪɡeɪm]	[pɛk]
[jæbeɪɡ]	[tʊɡ]	[hɪmʊt]	[tɪmæk]
[jæg]	[tʌmud]	[jæf]	[tɪp]
[jeɪf]	[wɛdɪt]	[jɛb]	[wæfug]
[jun]	[wɛk]	[jʌɡɪf]	[wʌb]
[judɪk]	[wuk]	[jum]	[wʊdɪk]
[kʌn]	[wupɛɪd]	[kæk]	[wʊk]