PITCH PERCEPTION AND PRODUCTION IN CHILDREN DIAGNOSED WITH CHILDHOOD APRAXIA OF SPEECH AND TYPICALLY DEVELOPING CONTROLS

By

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Abstract: Childhood Apraxia of Speech (CAS) is a pediatric neurodevelopmental speech sound disorder that presents with deficits in articulation and prosody. There have been multiple studies that have investigated aspects of prosody in children with CAS and have found that this population presents with a deficit in production. A major drawback of these studies is they have not considered investigating the mechanisms of perception of prosody in this population. If children with CAS present with perceptual deficits with regard to prosody, it is likely that they will have problems associated with production too. It is imperative to systematically investigate the perceptual deficit of prosody in this population. Considering this limitation, the current study aimed to investigate the perception of prosody in CAS. Participants in this group included 20 children (10 with CAS and 10 typically developing) ages 5-12. This study had two parts: perception and production. In the perception experiment, participants were asked to listen to CVC words and choose the emphatically stressed one. In the production experiment, participants were asked to listen to and produce emphatically stressed CVC words. Outcome measures included percent accuracy for the perception portion and vowel length for the production portion. We found that production as well as perception of prosody was impaired in children with CAS in comparison to their typically developing peers.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Overview

Childhood Apraxia of Speech (CAS) is a childhood speech production disorder that is primarily characterized by deficits in articulation and prosody (Morgan & Vogel, 2008). It resembles the Apraxia of Speech (AOS) that is seen in adults as they are both thought to interfere with the motor stages of speech production (Peter & Stoel-Gammon, 2005). Several different speech production models attempt to explain the pathological neurophysiological substrates of speech apraxia. The two most appropriate models are the ones proposed by Darley, Aronson, and Brown (1975) and more recently by van der Merwe (1997). Darley et al.'s (1975) model of speech programming model is a three stage model that discusses the role of central language processing (CLP), a motor speech programmer (MSP), and the motor speech cortex. Darley et al. postulated that speech apraxia occurs at the level of the MSP which receives neural codes of meaningful sequences of phonemes and activates the appropriate musculature (Darley et al., 1975). The model by van der Merwe expanded on the three-stage model by Darley and colleagues by including a fourth stage (1997). In the first step linguistic units are selected, next phonemes are organized into temporospatial codes for speech production in a motor planning phase, then muscle-specific motor programs are selected and sequenced in the motor programming phase and finally the sequences are carried out by musculature (van der Merwe, 1997). This model suggests that speech apraxia originates from a problem in the motor planning phase, which would fall between Darley et al.'s CLP and MSP phases (Peach, 2004). While these models are for AOS, it is possible they extend to explain pathological neurophysiological substrates of CAS as well. In both Darley's and van der Merwe's models, there is a disruption at the planning level of speech, which is true of both AOS and CAS.

Features

Childhood Apraxia of Speech (CAS) was reported over 50 years ago, but diagnostic features and etiologies have not been agreed upon (ASHA, 2007) because the co-occurrence of lexical, phonological and articulation deficits make it difficult to dissociate motor and linguistic features (Maassen, 2002). There has been controversy surrounding CAS including denial of the disorder, disagreement of etiology and localization, and disagreement on primary and secondary characteristics (Peter & Stoel-Gammon, 2005). A child with CAS may have impairments in: non-speech oral motor function, motor speech function, speech sounds and structures, prosody, language, phonemic awareness, and literacy (ASHA, 2007). The agreed upon features include disordered suprasegmental characteristics (prosody, voice quality, fluency), increased error on long utterances, limited phonemic inventory, omission errors, vowel errors, inconsistent articulation errors, difficulty imitating, primary use of simple syllable shapes, disordered volitional oral movements, receptive-expressive gap, and reduced diadochokinetic rates (DDK;

Davis, Jakielski & Marquardt, 1998). Other behavioral measures of CAS include inconsistent speech features (Iuzzini, 2012), errors in timing and co-articulation (Sussman, Marquardt, & Doyle, 2000), prosody (Munson, Bjorum, & Windsor, 1996), speech production and perception (Thoonen, Maassen, Gabreels, & Schreuder, 1999; Nijland, 2009), linguistic skills (Lewis, Freebairn, Hansen, Iyengar, & Taylor, 2004) and nonspeech oral motor skills (Murdoch, Attard, Ozanne, & Stokes, 1995).

Etiology

There is little known information on the etiology of CAS. It often presents as a comorbid condition with neurobehavioral and genetic disorders such as autism, epilepsy, and galactosemia (ASHA, 2007). According to Shriberg and colleagues, there is little agreement on complex behaviors that define CAS and on the natural history or explanatory framework (Shriberg et al., 2003b). The study series about the British family, KE, whose members have orofacial apraxia comorbid with a speech-language disorder, might lead to a neurobiological explanation for CAS (Lai et al., 2000; Lai, Fisher, Hurst, Vargha-Khadem and Monaco, 2001). In this family, the autosomal dominant trait FOXP2 that co-segregates with orofacial apraxia has been identified as a possible cause of their disorders (Lai et al., 2000; Lai et al., 2001). Speech processing loci for orofacial apraxia and, therefore, speech errors associated with CAS have been found through neuroimaging and psycholinguistic studies (Vargha-Khadem et al., 1998). These findings support that an impairment of praxis is the underlying deficit in CAS (Shriberg et al., 2003a). Praxis is defined as "the generation of volitional movement patterns for the performance of a particular action, especially the ability to select, plan, organize, and initiate the motor pattern" (Ayres 1985). There are additional studies that suggest CAS and speech delays have differing genotypes (Shriberg, et al., 2003b).

Diagnosis

Currently, there is no standardized test used to diagnose CAS because a lack of sensitive and specific markers that differentiate CAS from other disorders (Terband & Maassen, 2010). Due to this lack of standardized evaluation, the gold standard is expert opinion (Maas, Butalla, & Farinella, 2012). ASHA's technical report on CAS identified the three most agreed upon features for diagnosis which included "(a) inconsistent errors on consonants and vowels in repeated productions of syllables or words, (b) lengthened and disrupted co-articulatory transitions between sounds and syllables, and (c) inappropriate prosody, especially in the realization of lexical or phrasal stress" (2007). There is also a checklist, called the Strand's 10-point checklist, that provides 10 segmental and suprasegmental features that may or may not be present in CAS (Shriberg, Lohmeier, Strand & Jakielski, 2012; Shriberg, Potter, & Strand, 2009; Murray, McCabe, Heard, & Ballard, 2015). A combination of any four items from said checklist can imply a diagnosis of CAS (Murray, McCabe, Heard, & Ballard, 2015). Peter and Stoel-Gammon created four clusters to help in the diagnosis of CAS by rating 18 behaviors as present or absent in 100 children (Peter & Stoel-Gammon, 2008). The first cluster included primarily deviant inconsistent errors, the second cluster included deficits in oromotor and motor speech components, the third cluster included groping, consonant deletion, and gap in voluntary and involuntary speech performance, and the fourth included prosodic disturbances and a history of no babbling (Peter & Stoel-Gammon, 2008). Children who showed deficits in the first three clusters were diagnosed with CAS (Peter & Stoel-Gammon, 2008).

Treatment

Although there is little information about the long-term functioning of people with CAS, longitudinal studies suggest that CAS requires therapy as it is a persistent disorder (Hall, Jordan, & Robin, 1993; Jacks, Marquardt, & Davis, 2006; Stackhouse & Snowling, 1992). There have been a limited number of treatment investigations and proposed treatment types due to varying views on CAS (Morgan & Vogel, 2008). The two lines of treatment for CAS include perceptual-based therapy approaches and instrumental-based biofeedback treatments. Perceptually-based therapy approaches include traditional articulation and phonological therapy, PROMPT system, melodic intonation therapy, oral form recognition training, dynamic temporal and tactile cueing, orofacial myofunctional therapy, adapted cueing technique, rate control therapy and AAC (Morgan & Vogel, 2008). In addition, biofeedback treatments including delayed auditory feedback and electropalatography have been used with clients with CAS (Morgan & Vogel, 2008). Among the myriad of communication deficits in children diagnosed with CAS, the prosodic deficit is one of the most common deficits seen in this population. The following section reviews literature on prosody deficits in children with CAS.

CHAPTER II

LITERATURE REVIEW

As stated previously, children with CAS can present with deficits in suprasegmental features, specifically prosody (ASHA, 2007; Davis, Jakielski & Marquardt, 1998; Munson, Bjorum, & Windsor, 1996). The development of coordinated, rapid control of articulatory muscles that are necessary to produce lexical stress appear to be impaired in CAS (Shriberg, Aram, & Kwiatkowski, 1997; Skinder, Strand, & Mignerey, 1999). Lexical stress involves the manipulation of vowel duration, vocal intensity, and fundamental frequency (Kager, 2007). Several studies that have looked at the production of prosody in children with CAS are discussed below.

A study by Shriberg, Aram, and Kwiatkowski (1997) looked at stress in connected speech in children diagnosed with CAS in comparison to children with delayed speech. There were nineteen participants aged 4;7 to 14;4. Connected speech samples were collected and were transcribed and prosody-voice coded by a transcriber. Results indicated that children with CAS had lower scores for rate and stress in comparison to the children with speech delays. The children with CAS were described as having slower articulation and increased pause time in terms of rate and excess, equal, or misplaced stress in terms of stress. Excess, equal, or misplaced stress in connected speech was perceived in 52% of children with CAS and in 10% of children with a speech delay.

Another study by, Shriberg, Green, Campbell, McSweeny, and Scheer (2003) researched temporal regularity of speech in children with CAS in comparison to children with speech delays and typical development. Their study compared variation and pause events in connected speech of children with CAS, typical developing speech, and delayed speech of unknown origin. The authors gathered 75 speech samples of children aged three to six years-old from audio archives include 30 samples of typical speech, 30 samples of delayed speech, and 15 samples of CAS. A coefficient of variation (CV) was calculated separately for all speech and pause events in an utterance. The coefficient of variation is described as the standard deviation of event (speech or pause) divided by the mean of the event. The CV of all utterances were averaged for each participant. A lower CV indicates lower pause events and variation in the sample. After the CV was calculated, a coefficient of variation ratio (CVR) was found by dividing the pause event CV by the speech events CV. A low CVR indicates low variation in pause events and a high CVR indicates a low variation in duration of speech events. The results of this study indicated that children with CAS had higher CVRs. This means that the children with CAS had less variability in duration of speech events and more variability in the duration of pause events in comparison to the typically developing group and the speech delay group.

Shriberg, Campbell, Karlsson, Brown, McSweeny, and Nadler (2003) also researched prosody production by looking specifically at lexical stress in children with CAS and children with speech delays. There were 35 participants aged three to twelve years old. Of the 35 participants, 24 were identified with speech delay and 11 were identified with CAS. The participants were asked to imitate 24 words in isolation, eight for each bisyllabic stress patterns: trochaic, iambic, and spondee. A lexical stress ratio included components of duration, frequency and intensity. It was calculated from recordings of the imitation using frequency area, amplitude area, duration and the averaged ratio score of each word for each acoustic measure. Results indicated a variability in production of stress as some participants with CAS were in the typical range while others had excess or reduced lexical stress.

Nijland, Maassen, and van der Meulen (2003) researched articulatory compensation in children with CAS in order to study motor programming involvement. Participants, aged 5;0 to 6;10, included five children with typically developing speech and five children with CAS. Participants were asked to imitate nonsense utterances in two conditions: normal and bite-block. The nonsense utterances were bisyllabic with simple CV syllables and presented in a carrier phrase in both conditions. In the bite block condition, participants were asked to clench a bite block between their teeth while producing the utterances. The results showed that the bite block did not affect coarticulatory patterns in children with typically developing speech. Interestingly, when the children with CAS produced utterances using the bite-block, vowel quality and coarticulation showed improvement. Coarticulation in the typically developing group was not improved in the bite-block condition, indicative of varying compensatory abilities between the two groups. If acoustic measures of coarticulation in the bite-block condition were similar across the groups, it would rule out a deficit in motor programming. Therefore, a deficit of motor programming is a possible explanation for the varying production abilities in the two conditions in the CAS group.

Peter and Stoel-Gammon (2005) hypothesized that the control of movement timing, instead of vocal characteristics, has the most impact on lexical stress in CAS. They also hypothesized that this temporal inaccuracy could be pervasive enough to be seen in musical tasks (Peter & Stoel-Gammon, 2005). If this theory, known as the Internal Metronome Hypothesis, is true then a slow functioning central time keeper (internal metronome) explains the difference in speech prosody that is observed in children with CAS (Peter & Stoel-Gammon, 2005). To test their hypothesis, 2 children with CAS aged 4;3 and 9;5 and 2 children aged 4;3 and 8;9 participated in the following tasks by imitating a pre-recorded adult voice: sentence imitation, non-word imitation, monosyllabic word generation, singing happy birthday, clapped rhythm imitation, and paced repetitive tapping. Recordings of each task were addressed for accuracy through the measured units of vowel duration, note duration, interval duration, number of element and the metrics correlation coefficient, relative error, effect size, ratio, and relative standard deviation. Temporal accuracy was shown as a function of mean unit duration by averaging child to adult correlation coefficients. Results indicated that the metrics were less accurate for children with CAS compared to peers. The authors also found that nucleus and coda durations were longer in children with CAS compared to the typically developing peers. Peter and Stoel-Gammon suggested slow speaking rate, decreased resources for programming of coda consonant, and decreased acquisition of vowel duration could explain the long duration of the nuclei.

Peter and Stoel-Gammon (2008) conducted a second study similar to the one described above to replicate and expand on previous findings. Participants included eleven children with speech disorders of unknown origin and an aged-matched control group. The eleven children with speech disorders were screened for CAS characteristics and six were noted to have altered suprasegmental features. The participants completed three tasks (non-word imitation, clapped rhythm imitation, and paced repetitive tapping) that produced seven measures of temporal accuracy (percent accuracy of imitated syllables, adult: child correlation coefficient of vowel duration, Cohen's d of unstressed vs stressed vowel duration, percent accuracy of imitated claps, child: adult correlation coefficient of clap intervals, average speed match, and steadiness). The authors concluded that lower timing accuracy was found in participants with CAS characteristics and their results support a "deficit-driven view of timing accuracy". A deficit in timing accuracy could account for the prosodic deficits seen in children with CAS including stress and rhythm.

Based on the previously cited studies, we know that prosody is often affected in CAS. However, the perception of prosody remains to be investigated. The ability to produce acoustic details and suprasegmental aspects of speech is preceded by the ability to perceive such details (Preston, Irwin, & Turcios, 2015). At present, we do not know if the production deficit in prosody seen in children with CAS is due to a prosody perception deficit. To address this limitation, the current study intended to systematically investigate perception as well as production of prosody in children with CAS. Based on the theoretical underpinnings of CAS, we hypothesized that children with CAS have production deficits as well as perceptual deficits.

CHAPTER III

METHODOLOGY

Participants

Clinical group. Ten children with a diagnosis of CAS (clinical group), ages 5-10, were recruited based on a non-probability convenience sampling procedure. The participants were recruited from the speech and language clinics as well as from the community in the state of Oklahoma. Of the 10 participants with CAS, 8 were male and 2 were female. Inclusion criteria required participants be monolingual English speaking, have normal hearing, cognition, and motor skills, and have a diagnosis of CAS. Participants with delayed expressive language that impaired the ability to repeat the stimulus words were excluded from the experiment as well as participants who had comorbid conditions. All participants were diagnosed with CAS as defined by ASHA's (2007) criteria of: "a) inconsistent errors on consonants and vowels in repeated productions of syllables or words, b) lengthened and disrupted co-articulatory transitions between sounds and syllables and c) inappropriate prosody, especially in the realization of lexical or phrasal stress". Diagnosis was made by a licensed speech language pathologist prior to study and was obtained from the participants' case history. All participants were receiving speech services. The *Clinical Evaluation of Language Fundamentals Fifth Edition* (*CELF-5*) was administered by the researcher prior to participating in the study to determine age appropriate receptive vocabulary in each participant (Wiig, Semel, & Secord, 2013).

Control group. Ten typically developing children (control group), ages 5-12, served as participants for the typically developing group. The control group participants were recruited from the community in the state of Oklahoma based on non-probability convenience sampling. Of the 10 participants in the control group, 8 were male and 2 were female. Inclusion criteria for the control group was the same as the criteria for the clinical group with exception of a CAS diagnosis. Participants with a history of sensory, cognitive and/or motor disorder were excluded from participation.

Table 1 CAS Participant Characteristics

Participant	**Age**	**Gender**	**Time in Therapy**
CAS 1	7	M	3 years
CAS 2	9	M	6 years
CAS 3	5	M	3 years
CAS 4	6	M	3 years
CAS 5	6	M	3 years
CAS 6	10	M	8 years
CAS 7	5	F	2 years
CAS 8	8	F	5 years
CAS 9	6	M	3 years
CAS 10	5	M	3 years
Average	7;1		
Range	5-10		

Table 2 TD Participant Characteristics

Participant	**Age**	**Gender**
TD 1	9	M
TD 2	11	M
TD 3	12	M
TD 4	7	M
TD 5	5	M
TD 6	7	M
TD 7	8	F
TD 8	7	M
TD 9	5	M
TD 10	6	F
Average	7;10	
Range	5-12	

Additionally, all participants' parents completed a case history prior to the experiment. The case history included speech and language history, birth and medical history and developmental history. The children's parents provided written informed consent and the children provided written assent prior to participating in the study. This study was approved by the Institutional Review Board of Oklahoma State University.

Procedure

Stimuli. Both the clinical group and the control group participated in a production and perception experiment. The stimuli for the two experiments were the same and consisted of 20 pairs of monosyllabic, CVC words (Appendix A). Each word was represented by a picture card printed in color and was pre-recorded by an English-speaking monolingual female. In each pair, there was one emphatically stressed word (increased vowel duration and intonation contours) and one neutral word. Of the 20 pairs, 15 pairs were used for data collection and 5 pairs were used for practice trials with the participants (Appendix A). The experiment occurred in a location that was free of auditory and visual distractions. The details of the experiments are outlined below.

Field Testing. The two tasks were field tested with 7 children, ages 5-12, with typically developing language to ensure that they could be completed by a child with typical language skills. The participants of field testing were not included in the control group. During the field testing, all stimuli (20 pairs of words including picture cards and recordings) was used to determine appropriateness of materials. All participants from field testing were able to complete the tasks with high accuracy.

Practice Trial. Prior to both experiments, each participant participated in a trial in which the instructions were explained as often as necessary to ensure the participant understood what was required. The practice trial contained up to 5 pairs of words (Appendix A) that were not used in data collection.

Perception experiment. Both groups of participants were presented with 15 pairs of words. The same pairs were presented to every participant in a random order. For every pair, the experimenter placed two picture cards in front of the participant and presented the recording of the words through headphones. The specific instructions provided to participants were "*We are going to play a game. You are going to hear two words and I want you to touch which one sounds silly*." There were three trials for each pair, and the participant had to correctly identify the emphatically stressed word all three times to receive credit. If the participant did not touch a card after the first presentation, the recording was played one more time. If the participant failed to select a word after the second presentation, the response was counted incorrect.

Production experiment. Following the third presentation of each pair in the perception experiment, the participant was asked to repeat the emphatically stressed word after attempting to identify it. The experimenter played only the emphatically stressed word, even if it was not identified correctly, and asked the participant to imitate it. Specific instructions to the participant were, *"You're going to hear a word and I want you to say it exactly like you hear it."* If the participant did not imitate the first time, the researcher played the recording again.

Data analysis

Perception. Data analysis for the perception experiment included a percent (%) accuracy score. This score was determined based on the number of words that were accurately identified by each participant. The percentage accuracy scores were subjected to an independent *t*-test.

Production. For the production experiment, the participants' productions were recorded using a digital voice recorder with a microphone-mouth distance of 10 cm. The productions were transferred to a laptop computer that had PRAAT acoustic analysis software (version 6.0.32) with a sampling rate of 44100 Hz and generalization level rate of 10 bits. Using two vertical cursors, one at the onset of the vowel and one at the offset of the vowel, vowel length was measured. The time (s) between the two cursors was recorded as the vowel duration for each word. The participants' productions were compared to the adult model as the stress in a word is primarily determined by the vowel duration.

CHAPTER IV

FINDINGS

Statistical Analysis

Separate analyses were carried out perception and production experiments. For the perception experiment, accuracy scores were calculated in percentage (%) for each participant. The percent accuracy scores from the perception experiment were subjected to an independent *t*-test using R project for Statistical Computing (R Development Core Team, 2010). An alpha value of .05 was considered statistically significant.

For the production experiment, the vowel duration values from both the groups were compared with the adult model using Pearson's product moment correlation using R project for Statistical Computing (R Development Core Team, 2010). This was done to minimize the differences in vowel duration as a result of differences in speech rate between the child and adult productions. Additionally, the vowel duration values between the two groups were subjected to an independent *t*-test using R project for Statistical Computing (R Development Core Team, 2010). An alpha value of .05 was considered statistically significant.

Results

Perception. The results of the perception experiment are shown in Table 3. For the perception experiment, independent sample *t* test revealed that the accuracy of control group participants' (*M*=94.63, *SD*=.08) varied significantly from that of those in the CAS group (*M*=12.28, *SD*=.10); $t(17)= -19.76$, $p < .001$.

Table 3 Perception Data

	CAS 1	**CAS 2**	**CAS 3**	**CAS 4**	**CAS 5**	**CAS 6**	**CAS 7**	**CAS 8**	**CAS 9**	**CAS 10**	**TD 1**	**TD 2**	**TD 3**	**TD 4**	**TD 5**	**TD 6**	**TD 7**	**TD 8**	**TD 9**	**TD 10**
Bat		X									X	X	X	X	X	X	X	X	X	X
Bus										X		X	X	X	X	X	X	X	X	X
Cub		X	X			X				X	X	X	X	X	X	X	X	X	X	X
Cup	X										X	X	X	X	X	X	X	X	X	X
Dog									X		X	X	X	X	X		X	X	X	X
Fan											X	X	X	X	X	X	X	X	X	X
Hat											X	X	X	X		X	X	X	X	X
Lip		X		X						X		X	X	X	X	X	X	X		X
Log									X			X	X	X	X	X	X	X	X	X
Mop											X	X	X	X		X	X	X	X	X
Net					X				X	X	X	X	X	X		X	X	X	X	X
Pig	X										X	X	X	X	X	X	X	X	X	X
Pop											X	X	X	X	X	X	X	X	X	X
Ten					X						X	X	X	X	X	X	X	X	X	X
Web		X									X	X	X	X	X	X	X	X	X	X
Percent Accuracy	13	27	7	7	13	7	0	0	20	27	80	100	100	100	80	93	100	100	93	100

Production. The vowel duration values of the adult, clinical group, and control group are shown in Tables 6, 7, and 8. The independent sample *t* test revealed that the vowel duration of the control group participants differed significantly from that of participants with CAS $t\ (17) = -4.76$, $p < .001$.

The vowel duration of the TD group (M=.33, SD=.04) was higher than that of those in the CAS group (M=.25, SD=.06). Results of comparison of the CAS group and adult model revealed that there was a moderate positive correlation that was significant, r=.57, p<.05. The vowel duration of children in the control group and the adult model had a strong positive correlation that was significant, r=.91, p<.01.

Table 4 TD Production Data

	TD 1	TD 2	TD 3	TD 4	TD 5	TD 6	TD 7	TD 8	TD 9	TD 10	Word Average
Bat	0.28	0.18	0.30	0.34	0.35	0.34	0.32	0.40	0.25	0.30	0.31
Bus	0.20	0.23	0.26	0.26	0.42	0.27	0.27	0.35	0.30	0.26	0.29
Cub	0.34	0.21	0.27	0.25	0.36	0.32	0.35	0.40	0.31	0.30	0.31
Cup	0.25	0.24	0.19	0.22	0.27	0.22	0.25	0.33	0.30	0.23	0.25
Dog	0.38	0.25	0.35	0.45	0.39	0.39	0.38	0.45	0.40	0.38	0.38
Fan	0.41	0.38	0.36	0.38	0.39	0.40	0.31	0.51	0.45	0.39	0.40
Hat	0.38	0.33	0.35	0.27	0.46	0.33	0.37	0.43	0.30	0.38	0.36
Lip	0.20	0.25	0.16	0.28	0.20	0.20	0.28	0.28	0.18	0.24	0.23
Log	0.41	0.34	0.30	0.35	0.37	0.36	0.40	0.52	0.50	0.37	0.39
Mop	0.36	0.33	0.26	0.41	0.41	0.39	0.37	0.45	0.41	0.38	0.38
Net	0.23	0.20	0.33	0.34	0.36	0.37	0.30	0.27	0.25	0.29	0.30
Pig	0.41	0.23	0.38	0.29	0.31	0.41	0.35	0.43	0.42	0.36	0.35
Pop	0.23	0.39	0.33	0.25	0.36	0.37	0.35	0.47	0.50	0.44	0.38
Ten	0.22	0.19	0.21	0.31	0.38	0.37	0.26	0.38	0.47	0.34	0.32
Web	0.28	0.18	0.24	0.21	0.35	0.31	0.28	0.37	0.20	0.25	0.26
Participant Average	0.31	0.26	0.29	0.31	0.36	0.34	0.32	0.40	0.35	0.33	

Table 5 CAS Production Data

	CAS1	CAS2	CAS3	CAS4	CAS5	CAS6	CAS7	CAS8	CAS9	CAS10	Word Average
Bat	0.23	0.28	0.29	0.26	0.13	0.30	0.25	0.26	0.17	0.25	0.24
Bus	0.28	0.13	0.24	0.22	0.14	0.27	0.20	0.17	0.12	0.16	0.19
Cub	0.24	0.21	0.51	0.18	0.23	0.22	0.28	0.17	0.20	0.24	0.25
Cup	0.24	0.25	0.13	0.28	0.20	0.24	0.34	0.18	0.10	0.15	0.21
Dog	0.21	0.26	0.38	0.20	0.17	0.36	0.24	0.36	0.32	0.24	0.27
Fan	0.23	0.29	0.33	0.24	0.28	0.34	0.46	0.22	0.16	0.34	0.29
Hat	0.30	0.17	0.30	0.34	0.12	0.17	0.38	0.32	0.19	0.22	0.25
Lip	0.16	0.35	0.20	0.25	0.28	0.16	0.27	0.21	0.10	0.18	0.22
Log	0.28	0.46	0.27	0.26	0.22	0.34	0.25	0.21	0.27	0.27	0.28
Mop	0.22	0.13	0.39	0.12	0.34	0.17	0.33	0.23	0.27	0.20	0.24
Net	0.13	0.33	0.20	0.42	0.25	0.17	0.24	0.20	0.19	0.19	0.23
Pig	0.15	0.20	0.66	0.22	0.42	0.26	0.24	0.22	0.20	0.20	0.28
Pop	0.30	0.22	0.22	0.28	0.30	0.15	0.32	0.24	0.23	0.20	0.25
Ten	0.24	0.24	0.41	0.19	0.27	0.27	0.18	0.16	0.20	0.22	0.24
Web	0.25	0.30	0.31	0.29	0.44	0.34	0.27	0.23	0.13	0.30	0.29
Participant Average	0.23	0.26	0.32	0.25	0.25	0.25	0.28	0.23	0.19	0.22	

Table 6 Adult Production Data

Bat	Bus	Cub	Cup	Dog	Fan	Hat	Lip	Mop	Net	Pig	Pop	Ten	Web		Average
0.29	0.31	0.30	0.25	0.44	0.42	0.35	0.25	0.38	0.39	0.36	0.36	0.30	0.29		0.34

Discussion

The purpose of this study was to investigate the perception versus the production of prosody in children diagnosed with childhood apraxia of speech (CAS) in comparison to their typically developing peers. Specifically, this study looked at perception and production in terms of vowel duration. The main research question was to determine if children with CAS had deficits in perception as well as production when examining prosody.

The finding that children with CAS have prosody production deficits support previous studies that had similar findings. Shriberg et al. (2003a) found children with sAOS had variable lexical stress (excess or reduced) when repeating words in isolation. The current study shows that the experimental group had a significantly shorter vowel duration when compared to the vowel duration of the control group. Results from this study also support findings in both Peter and Stoel-Gammon (2005, 2008) studies that found that children with CAS had decreased temporal accuracy when imitating words. In the current study, the children with CAS had a weaker correlation to the adult model of vowel production than their typically developing peers. Peter and Stoel-Gammon (2005) also found that children with typically developing speech had a higher correlation to the adult model than the CAS group had when imitating nonwords.

The production deficits seen in children with CAS can be explained by a timing model described by Wing and Kristofferson (1973). According to this model, there are two levels of timing: (1) a central time keeper level and, (2) a motor implementation level. The centrally-generated ‘internal clock’ brings about the movement of desired goal duration by sending pulses via the central nervous system. Wing and Kristofferson proposed that motor movement is initiated by a central time keeper, but there is a motor implementation delay before a response occurs (Doumas & Wing, 2007). A study by Doumas and Wing (2007) looked at timing in rhythm production using the Wing-Kristofferson two-step model to determine if increased interresponse interval variability is caused by the central time keeper level or the motor implementation level of timing. The authors of this study concluded that the central time keeper level, not the motor implementation level, is responsible for the variability of timing in rhythm (Doumas & Wing, 2007). If the Wing-Kristofferson two-step model is accurate, prosody production deficits in children with CAS could be explained by a disrupted central time keeper. Since the central time keeper initiates motor movement, motor movement would be delayed or interrupted when the central time keeper is interrupted. This could cause a disruption in production of prosodic elements of speech including stress and rhythm.

As this is one of the first studies to evaluate perception of prosody in children with CAS, the current findings cannot be compared to previous studies of similar nature. However, the findings from the current studies indicate that children with CAS have a deficit in perception as noticeable with the group differences. When presented with the recordings of two words, the control group had an average of 94% accuracy in choosing the emphatically stressed word. When asked to complete the same task, the children with CAS had an average of 12% accuracy.

Perception of stress is influenced by the acoustic factors: rise time, frequency, duration and intensity. Perception deficits could be attributed to decreased sensitivity to the auditory envelope which provides prosodic information such as rhythm and stress across words, phrases and utterances (Richards & Goswami, 2015). The auditory envelope conveys information by inflectional changes in intensity level where peak temporal rate is at 3 to 5 Hz (Richards & Goswami,2015). This rate is consistent with syllable production rate (Greenberg, Carvey, Hitchcock, & Chang, 2003). Listeners are able to segment speech into syllables by perceiving the variation in rate of rise time (time between onset and nucleus) provided by the auditory envelope (Richards & Goswami, 2015). The rise time gives the listener information about the amount of lexical stress assigned to a syllable (Richards & Goswami, 2015). Children with CAS could have a deficit in their auditory envelope which leads to decreased ability to process incoming prosodic information (stress and rhythm). This would lead to the inability to create accurate lexical stress representations and therefore inaccurate productions of stress.

An alternative thought that can account for pitch perception deficits in CAS is auditory processing deficit. Intact pitch perception requires accurate representation of stimulus properties in the ascending auditory pathway as well as in the primary auditory cortex. Emerging research indicates that there may be a “pitch center” in secondary auditory cortex where brain activity is involved with the actual perception of pitch instead of the physical properties of the acoustic stimulus (Griffiths, 2004). An abnormality in the representation of stimulus properties in the ascending auditory pathway and primary auditory cortex, or in the secondary auditory cortex, could lead to pitch perception deficits.

Our research suggests that children with CAS have a deficit in both the perception and production of prosody, specifically increased vowel duration. However, there are constraints in this study that reduce the ability to generalize this finding. First, due to non-probability convenience sampling, the diversity of our participants were minimal and our sample size was relatively small. Additionally, length of time in therapy (Table 1) and therapy goals were not controlled. Another constraint is that production and perception were measured only in isolated words not in phrases or connected speech.

CHAPTER V

CONCLUSION

Despite the preliminary nature of this study, the current findings interestingly suggest that children with CAS present with prosody perception deficits along with prosody production deficits. Although this study was unable to conclude that the deficit in perception precedes the deficit in production of prosody in children with CAS, it is important to emphasize that perceptual deficits should be treated prior to prosody production deficits. Future studies should consider large scale studies that are similar in nature to this study as well as manipulating perception and measuring production outcomes.

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APPENDICES

Appendix A

Word pairs used for training

1. Cat, Hip
2. Pan, Pup
3. Sub, Top
4. Rug, Hen
5. Dad, Jet

Word pairs used for data collection

1. Web, Van
2. Jam, Ten
3. Vet, Lip
4. Bat, Bed
5. Mop, Gum
6. Dot, Bus
7. Pig, Pen
8. Bug, Fan
9. Pin, Cup
10. Hat, Pot
11. Pop, Wig
12. Net, Lid
13. Fin, Log
14. Kid, Dog
15. Mom, Cub

Appendix B

Oklahoma State University Institutional Review Board

Date:	Tuesday, April 25, 2017
IRB Application No	GC173
Proposal Title:	Pitch Perception and Production in Children Diagnosed with Childhood Apraxia of Speech and Typically Developing Controls
Reviewed and Processed as:	Expedited

Status Recommended by Reviewer(s): Approved Protocol Expires: 4/24/2018

Principal Investigator(s):

Klairissa Tolf	Ramesh Kaipa
	042 Murray Hall
Stillwater, OK 74078	Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☐ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1.Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval. Protocol modifications requiring approval may include changes to the title, PI advisor, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms.
2.Submit a request for continuation if the study extends beyond the approval period. This continuation must receive IRB review and approval before the research can continue.
3.Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of the research; and
4.Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Dawnett Watkins 219 Scott Hall (phone: 405-744-5700, dawnett.watkins@okstate.edu).

Sincerely,

Hugh Crethar, Chair
Institutional Review Board

Oklahoma State University Institutional Review Board

Date:	Thursday, August 31, 2017	**Protocol Expires: 4/24/2018**
IRB Application No:	GC173	
Proposal Title:	Pitch Perception and Production in Children Diagnosed with Childhood Apraxia of Speech and Typically Developing Controls	
Reviewed and Processed as:	Expedited **Modification**	

Status Recommended by Reviewer(s) **Approved**

Principal Investigator(s):

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The requested modification to this IRB protocol has been approved. Please note that the original expiration date of the protocol has not changed. The IRB office MUST be notified in writing when a project is complete. All approved projects are subject to monitoring by the IRB.

☐ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

The reviewer(s) had these comments:

Mod to 1) add Appendix A and 2) recruit via social media

Signature :

Hugh Crethar, Chair, Institutional Review Board

Thursday, August 31, 2017
Date

VITA

Klairissa Adrian Tolf

Candidate for the Degree of

Master of Science

Thesis: PITCH PERCEPTION AND PRODUCTION IN CHILDREN DIAGNOSED WITH CHILDHOOD APRAXIA OF SPEECH AND TYPICALLY DEVELOPING CONTROLS

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