A Diagnostic Marker to Discriminate Childhood Apraxia of Speech (CAS) from Speech Delay (SD): The Pause Marker

Technical Report No. 22

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OVERVIEW

Research Background for the Pause Marker

Phonology Project Technical Reports provide technical and substantive information on methods developed for a program of research in speech sound disorders of known and unknown origins. Primary goals of the Phonology Project are to identify etiologic origins, risk and protective factors, and diagnostic markers for eight subtypes of speech sound disorders of currently unknown origin (Shriberg et al., 2010). These goals are studied within a research framework termed the Speech Disorders Classification System (SDCS). All measures described in the present and other Phonology Project Technical Reports are included in a software package termed PEPPER: Programs to Examine Phonetic and Phonologic Evaluation Records). PEPPER is scheduled to be freely available in 2018. Computational information on all measure is provided in research publications, technical reports, and in PEPPER help screens. All research findings have been completed using the computerized measures and a suite of output options in PEPPER.

The present technical report provides additional information on the Pause Marker (PM) – a behavioral marker of Childhood Apraxia of Speech described in a supplement to the *Journal of Speech, Language, and Hearing Research* titled *A diagnostic marker to discriminate Childhood Apraxia of Speech from Speech Delay*. The Supplement includes an Introduction that includes a key to abbreviations, and four articles, for efficiency referenced as “PM I,” “PM II,” “PM III,” and “PM IV.” PM I (Shriberg et al., 2017a) describes the development of and methods for the PM; PM II (Shriberg et al., 2017b), provides findings from validity and reliability studies; PM III (Shriberg et al., 2017c) reviews research supporting the theoretical coherence of the PM with processes proposed to underlie apraxia of speech; and PM IV (Shriberg et al., 2017d) includes

rationale for and development of an ordinal severity metric of the PM termed the Pause Marker Index (PMI).

Part I of the present technical report on the Pause Marker includes brief descriptions of terms defined in the four Supplement papers cited above and in the present technical report. Part II provides audio-visual exemplars of the eight types of inappropriate pauses that comprise the Pause Marker, with focus on Type 1, *Abrupt* pauses. Part III includes Pause Marker findings that space constraints prohibited including in Pause Marker Supplement papers. These findings include tabular information that may stimulate additional research with the PM or suggest clinical approaches using individual differences in PM scores and inappropriate pause types (see PM III; Shriberg et al., 2017c).

As is customary in Phonology Project Technical reports, the information in the present report is presented without comment. The authors invite email questions or comments on any aspect of the information in this technical report that readers might find helpful.

Definition, Procedures, and Computation of the Pause Marker

The PM defines a between-words pause as any between-words period of at least 150 ms in which there is no speech. An inappropriate pause is "a between-words pause that occurs either at an inappropriate linguistic place in continuous speech and/or has one or more inappropriate articulatory, prosodic, or vocalic features within the pause or in a sound segment preceding or following the pause." As described in PM I (Shriberg et al., 2017a), the following five steps summarize the procedures used to compute a Pause Marker classification (CAS+, CAS-) for a speaker.

1. Obtain a conversational speech sample.

2. Complete transcription and prosody-voice coding to yield 24 useable utterances.

3. Complete acoustic analyses to identify occurrences of Type I (abrupt, alone, change, grope) and Type II (addition, repetition/revision, long, breath) between-words pauses in each utterance.

4. Calculate the Pause Marker (PM)

$$PM = 100 - \left[\frac{\text{No. Type I pauses}}{\text{No. pause opportunities (No. words – No. utterances)}} \right] \text{ x } 100$$

5. Classify CAS status: [a]

PM > 96% = CAS- (does not meet criterion for CAS)

PM < 94% = CAS+ (meets criterion for CAS)

[a] Classify marginal PM scores (94.0-95.9%) using the Supplemental Pause Marker Signs criterion, which requires positive findings on at least two of three standardized signs of CAS (Slow Articulatory Rate, Inappropriate Sentential Stress, Transcoding Errors).

PART I. REVIEW OF TERMS FOR THE PAUSE MARKER (PM), THE SUPPLEMENTAL PAUSE MARKER SIGNS (SPMS), AND THE PAUSE MARKER INDEX (PMI)

Following are brief descriptions of terms used in Parts II-III of this technical report.

Pause Marker (PM)

The Pause Marker (PM) is a diagnostic marker to discriminate a type of Speech Sound Disorder (SSD) termed Motor Speech Disorder-Childhood Apraxia of Speech (MSD-CAS) from Speech Delay (SD) and from two other subtypes of Motor Speech Disorder described in Shriberg, Strand, and Mabie (2017).

Type I and Type II Inappropriate Between-Words Pauses

The PM Score (previewed in the Overview and see following definition) is based on the occurrence of four types of inappropriate between-words pauses collectively termed Type I pauses. Shriberg et al. (2017a) includes descriptions of each of the four Type I pauses included in the tabular information in Part II of this report. Shriberg et al. (2017a) also includes descriptions of the four inappropriate between-words pauses termed Type II pauses that provide additional information on speech processes in clinical and research applications in MSD-CAS.

Pause Marker Score

The PM score is the percentage (subtracted from 100%) of Type I pauses that occur in 24 utterances of a continuous speech sample that meet eligibility criteria for the Prosody-Voice Screening Profile (PVSP: Shriberg, Kwiatkowski, & Rasmussen, 1990). A minimum of 40 between-words pause opportunities must occur in the speech sample in order to obtain a valid PM score. PM classification (i.e., whether a speaker is classified as positive [PM+] or negative

[PM-] for CAS) from a continuous speech sample with fewer than 40 between-words pause opportunities is classified Indeterminate.

Negative Pause Marker Score (PM-)

A PM score above 96%, is termed a Negative Pause Marker score (PM-). Speakers with PM- scores are classified as negative for CAS (i.e., CAS-).

Positive Pause Marker Score (PM+)

A PM score below 94% is termed a Positive Pause Marker score (PM+). Speakers with PM+ scores are classified as positive for CAS (i.e., CAS+).

Marginal Pause Marker Score

A PM score from 94%-95.9% (i.e., within one percentage point of the 95% cutoff for PM+ scores) is termed a Marginal PM score. To resolve the CAS classification of a speaker with a marginal PM score, findings from three signs termed the Supplemental Pause Marker Signs (SPMS; see Part II) are used. As defined and described in Shriberg et al. (2017a), CAS+ classification of a marginal PM score requires that at least two of the three SPMS (Slow Rate, Inappropriate Stress, Transcoding Errors) are positive. Marginal PM scores that cannot be resolved by SPMS findings (due to missing data and other reasons) are also classified as Indeterminate PM scores.

The Pause Marker Index (PMI)

To scale the severity of CAS for clinical and research needs, the Pause Marker Index (PMI) divides PM positive scores into four ordinal levels: “Mild” CAS severity scores include PM percentages from 90.0% to 93.9%; “Mild-Moderate” severity scores include PM percentages between 85.0% and 89.9%; “Moderate-Severe” severity scores include PM percentages between 80.0%-84.9%; and “Severe” severity scores include PM percentages below 80.0%.

PART II. SPECTROGRAPHIC EXEMPLARS FOR THE FOUR TYPE I AND FOUR TYPE II INAPPROPRIATE PAUSE TYPES

See accompanying PowerPoint for Phonology Project Technical Report No. 22:

A Diagnostic Marker to Discriminate Childhood Apraxia of Speech (CAS) from Speech Delay (SD): The Pause Marker

[Tilkens et al., 2017]

PART III. ADDITIONAL FINDINGS FOR THE PAUSE MARKER, THE SUPPLEMENTAL PAUSE MARKER SIGNS, AND THE PAUSE MARKER INDEX

Table 1. Description of participants in 15 speaker groups (*n* = 592) including groups with Childhood Apraxia of Speech (CAS), Adult-onset Apraxia of Speech (AAS), Complex Neurodevelopmental Disorders (CND), and Speech Delay (SD).

Table 1 includes demographic information for 15 cohorts of participants for whom PM information was available (in addition to data reported in Shriberg et al. (2017a, 2017b, 2017c, and 2017d) at the time the present technical report became available. Participants in the Speech Delay groups were from four databases, including a random sample of participants who had been assessed at the University of Wisconsin-Madison (SD1) and three cohorts (SD2-SD4) who had participated in collaborative research projects in Speech Sound Disorders (Mabie & Shriberg, 2017). The three Childhood Apraxia of Speech (CAS) cohorts included participants suspected positive for CAS (CAS-S), participants with idiopathic CAS (CAS-I), and participants with CAS associated with neurogenetic origins (CAS-N). The two Adult-onset Apraxia of Speech (AAS) groups include one with neurological damage conventionally termed Apraxia of Speech (AOS) and a second with neurodegenerative disease termed Primary Progressive Apraxia of Speech (PPAOS). The Complex Neurodevelopmental Disorders (CND) groups include the following six

Table 1. Description of participants in 15 speaker groups (*n* = 592) including participants with Childhood Apraxia of Speech (CAS), Adult-onset Apraxia of Speech (AAS), Complex Neurodevelopmental Disorders (CND), and Speech Delay (SD).

Group	Cohort	Sample Identifier	*n*	Age (yrs)			% Males
				M	SD	Range	
Speech Delay (SD)	Random Cohort	SD1	88	4.3	1.3	3-9	72.7
	Research Cohort	SD2	23	5.5	0.6	5-7	73.9
	Research Cohort	SD3	84	4.0	0.7	3-5	73.6
	Research Cohort	SD4	30	4.5	0.9	3-7	46.7
	Total		225	4.3	1.1	3-9	68.9
Childhood Apraxia of Speech (CAS)	Suspected CAS	CAS-S	48	7.8	3.1	3-15	79.2
	Idiopathic CAS	CAS-I	40	8.7	4.2	4-23	67.5
	Neurogenetic CAS [a]	CAS-N	20	10.9	5.1	4-25	50.0
	Total		108	8.7	4.1	3-25	69.4
Adult-onset Apraxia of Speech (AAS)	Apraxia of Speech	AOS	16	62.9	11.5	45-82	75.0
	Primary Progressive Apraxia of Speech	PPAOS	17	71.7	9.2	53-84	58.8
Complex Neurodevelopmental Disorders (CND)	22q11.2 Deletion Syndrome	22q	19	10.1	3.1	5-18	57.9
	Autism Spectrum Disorder	ASD	42	6.0	1.2	4 – 8	78.6
	Down Syndrome	DS	50	14.0	2.5	8-20	58.0
	Fragile X Syndrome	FXS	30	16.1	3.1	11 – 22	100.0
	Galactosemia	GAL	31	8.8	2.9	5 – 16	64.5
	Traumatic Brain Injury	TBI	54	7.1	3.0	3-12	57.4
	Total		226	10.1	4.5	3-22	68.1
	Total		33	67.5	11.1	45-84	66.7

[a]Includes participants with copy number variants (n=10) identified in related research, and participants with neurodevelopmental disorders associated with disruptions in *FOXP2* (n=2), 4q;16q translocation (n=3), 16p11.2 microdeletion syndrome (n=2), terminal deletion of chromosome 22 (n=1), Joubert syndrome (n=1), and Prader Willi syndrome (n=1).

participant cohorts: (1) 22q11.2 Deletion Syndrome (22q; Baylis et al., 2017); (2) Autism Spectrum Disorder (ASD; Shriberg et al., 2011); (3) Down syndrome (DS; Wilson et al., 2017); (4) Fragile X syndrome (FXS; Keller-Bell & Abbeduto, 2007); (5) Galactosemia (GAL; Shriberg, Potter, & Strand, 2011); and (6) Traumatic Brain Injury (TBI; Campbell, Dollaghan, & Shriberg, 2017).

Table 2. Number and duration of a sample of appropriate and inappropriate pauses in three speaker groups.

Table 2 includes the number and durations of a sample of appropriate and inappropriate between-words pauses in three speaker groups: participants with CAS, CND, and AAS. All participants in the three groups were classified as PM+ using procedures described in PM I (Shriberg et al., 2017a).

Table 3. Number and duration of a sample of Type I and Type II inappropriate pauses in three speaker groups. As described in Shriberg et al. (2017a), pauses may meet classification criteria for more than one type of inappropriate pause.

Table 3 includes the number and durations of the four Type I and the four Type II inappropriate between-words pauses for participants in the CAS, CND, and AAS groups. All participants in the three groups were classified as PM+.

Table 4. Pause Marker Index (PMI) classifications for participants in 12 speaker groups.

Table 4 includes the percentages of participants in 12 cohorts with Mild, Mild-Moderate, Moderate-Severe, and Severe classifications on the Pause Marker Index (PMI). All participants' PM scores met non-marginal criteria for CAS (i.e., CAS+).

Table 5. Percentage of occurrence of inappropriate pause types by PMI classification in three speaker groups. All participants in each group met non-marginal PM criteria for apraxia of speech.

Table 5 includes occurrence percentages for Type I and Type II inappropriate pauses for participants classified as Mild, Mild-Moderate, Moderate-Severe, and Severe on the PMI. All

Table 2. Number and duration of a sample of appropriate and inappropriate pauses in three speaker groups.

Group		**Pause Occurrences**			**Pause Duration (ms)**	
		Pause Type	*n*	%	*M*	*SD*
Childhood Apraxia of Speech (CAS)		Appropriate	396	39.6	489	363
		Inappropriate	605	60.4	552	414
		Total	1,001			
Complex Neurodevelopmental Disorders (CND)		Appropriate	704	55.3	552	437
		Inappropriate	569	44.7	618	467
		Total	1,273			
Adult-onset Apraxia of Speech (AAS)		Appropriate	444	49.9	553	343
		Inappropriate	446	50.1	713	463
		Total	890			

Table 3. Number and duration of a sample of Type I and Type II inappropriate pauses in three speaker groups. As described in Shriberg et al. (2017a), pauses may meet classification criteria for more than one type of inappropriate pause.

Group	Inappropriate Pauses				Pause Duration (ms)	
	Type	Subtype	*n*		*M*	*SD*
Suspected Childhood Apraxia of Speech (SCAS)	I	Abrupt	217		509	371
		Alone	60		460	264
		Change	56		508	291
		Grope	21		852	606
		Total	354			
	II	Long	55		1326	556
		Repetition	60		497	328
		Breath	19		546	189
		Addition	8		358	153
		Total	142			
Complex Neurodevelopmental Disorders (CND)	I	Abrupt	289		524	368
		Alone	38		494	292
		Change	59		492	305
		Grope	14		764	506
		Total	400			
	II	Long	75		1338	504
		Repetition	46		505	348
		Breath	7		775	449
		Addition	9		562	268
		Total	137			
Adult-onset Apraxia of Speech (AAS)	I	Abrupt	166		616	340
		Alone	58		581	218
		Change	36		673	387
		Grope	56		863	520
		Total	316			
	II	Long	69		1412	497
		Repetition	56		660	392
		Breath	13		713	337
		Addition	9		549	509
		Total	147			

Table 4. Pause Marker Index (PMI) classifications for participants in 12 speaker groups.

Group/Cohort		PM+	Mild		Mild-Moderate		Moderate-Severe		Severe	
		n	*n*	%	*n*	%	*n*	%	*n*	%
Speech Delay (SD)										
Random Cohort		1	1	100.0	0	0.0	0	0.0	0	0.0
Research Cohort		1	0	0.0	1	100.0	0	0.0	0	0.0
Suspected Childhood Apraxia of Speech (CAS)										
Suspected CAS		11	8	72.7	2	18.2	0	0.0	1	9.1
Idiopathic CAS		21	9	42.9	4	19.0	3	14.3	5	23.8
Neurogenetic CAS		13	6	46.2	2	15.4	4	30.8	1	7.7
Complex Neurodevelopmental Disorders (CND)										
22q11.2 Deletion Syndrome		3	1	33.3	2	66.6	0	0.0	0	0.0
Down Syndrome		11	5	45.5	6	54.5	0	0.0	0	0.0
Fragile X Syndrome		1	0	0.0	0	0.0	1	100.0	0	0.0
Galactosemia		5	3	60.0	1	20.0	0	0.0	1	20.0
Traumatic Brain Injury		2	1	50.0	0	0.0	0	0.0	1	50.0
Adult-onset Apraxia of Speech (AAS)										
Apraxia of Speech		9	4	44.4	2	22.2	2	11.1	1	22.2
Primary Progressive Apraxia of Speech		10	4	40.0	1	10.0	2	20.0	3	30.0

Table 5. Percentage of occurrence of inappropriate pause types by PMI classification in three speaker groups. All participants in each group met non-marginal PM criteria for apraxia of speech.

Group	PMI	Type I Inappropriate Between-Word Pauses											
Childhood Apraxia of Speech (CAS)		Abrupt			Alone			Change			Grope			Total	
		n	%		n	%		n	%		n	%		n	%
	Mild	4.8	4.8		1.5	1.4		1.5	1.7		0.5	0.4		7.9	7.8
	Mild-Moderate	7.0	7.9		2.2	3.0		1.0	1.3		0.8	0.7		10.5	12.4
	Moderate-Severe	11.9	11.7		2.9	2.9		2.1	2.3		0.3	0.2		16.9	16.8
	Severe	18.8	21.1		1.7	1.6		3.5	3.3		1.5	1.5		24.7	26.7
	All	9.1	9.7		1.9	2.0		1.9	2.1		0.7	0.6		13.2	13.8
		Type II Inappropriate Between-Word Pauses													
		Long			Repetition/ Revision			Breath			Addition			Total	
		n	%		n	%		n	%		n	%		n	%
	Mild	1.5	1.4		2.4	2.3		0.5	0.5		0.3	0.4		4.5	4.4
	Mild-Moderate	1.8	2.9		1.8	2.5		1.2	1.4		0.3	0.4		5.0	7.1
	Moderate-Severe	2.1	2.2		2.9	3.2		0.7	0.6		0.4	0.5		6.1	6.5
	Severe	2.7	3.4		2.3	2.2		1.2	1.0		0.0	0.0		5.8	6.1
	All	1.9	2.2		2.4	2.5		0.8	0.8		0.3	0.3		5.2	5.6

(table continues)

Group	PMI	Type I Inappropriate Between-Word Pauses											
Complex Neurodevelopmental Disorders (CND)		**Abrupt**		**Alone**		**Change**		**Grope**		**Total**			
		n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**		
	Mild	5.7	5.7	0.8	0.8	1.0	1.2	0.4	0.3	7.3	7.4		
	Mild-Moderate	8.7	9.3	1.3	1.4	2.5	2.7	0.1	0.1	11.3	12.1		
	Moderate-Severe	17.0	13.8	1.0	0.8	1.0	0.8	1.0	0.8	20.0	16.3		
	Severe	21.3	21.8	1.3	1.2	3.3	3.2	1.7	1.7	25.0	25.0		
	All	8.4	8.6	1.0	1.0	1.7	1.9	0.4	0.4	10.6	10.8		
		Type II Inappropriate Between-Word Pauses											
		Long		**Repetition/ Revision**		**Breath**		**Addition**		**Total**			
		n	%	n	%	n	%	n	%	n	%		
	Mild	1.0	1.0	1.2	1.2	0.0	0.0	0.0	0.0	2.0	2.0		
	Mild-Moderate	2.6	2.6	1.3	1.1	0.2	0.2	0.1	0.1	3.9	3.8		
	Moderate-Severe	5.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	5.0	4.1		
	Severe	3.3	2.9	0.7	0.8	1.0	1.3	2.0	2.3	6.7	6.8		
	All	1.8	1.8	1.2	1.1	0.1	0.2	0.2	0.2	3.1	3.1		

(table continues)

Group	PMI	Type I Inappropriate Between-Word Pauses													
Adult-onset Apraxia of Speech (AAS)		**Abrupt**			**Alone**			**Change**			**Grope**			**Total**	
		n	%		n	%		n	%		n	%		n	%
	Mild	5.1	3.8		1.0	0.7		0.5	0.4		3.4	2.9		10.0	7.7
	Mild-Moderate	3.7	3.6		5.0	5.1		1.3	2.0		2.7	2.4		12.3	12.7
	Moderate-Severe	9.3	11.4		2.0	2.3		2.8	2.8		2.0	2.4		15.0	18.1
	Severe	15.3	14.4		7.8	6.5		3.8	4.14		1.8	1.8		27.0	24.7
	All	7.9	7.6		3.3	3.0		1.8	1.9		2.6	2.5		15.0	14.3
		Type II Inappropriate Between-Word Pauses													
		Long			**Repetition/ Revision**			**Breath**			**Addition**			**Total**	
		n	%		n	%		n	%		n	%		n	%
	Mild	3.1	2.6		3.1	2.1		0.4	0.3		0.6	0.4		7.1	5.3
	Mild-Moderate	3.7	5.2		2.3	2.5		0.3	0.7		0.7	1.0		6.7	8.7
	Moderate-Severe	3.5	4.6		1.8	2.1		0.8	1.5		0.3	0.5		5.5	7.6
	Severe	3.3	2.8		3.3	3.4		1.5	1.6		0.3	0.3		8.0	7.8
	All	3.3	3.5		2.7	2.4		0.7	0.9		0.5	0.5		6.9	6.8

participants in the three speaker groups (CAS, CND, AAS) had non-marginal PM+ scores (i.e., met PM criteria for apraxia of speech).

Table 6. Speaking Rate, Articulation Rate, and Pause Time data for participants in three speaker groups classified by PMI level. All participants had non-marginal PM+ scores (i.e., met PM criteria for apraxia of speech).

Table 6 includes speech and pause rate data for participants in three groups (CAS, CND, and AAS) classified by their PMI level of severity. All participants had non-marginal PM+ scores. Speaking Rate includes both pause time and speaking time (syll/sec), whereas Articulation Rate includes only speaking time (i.e., pause times are subtracted). Pause Time/Syllable (ms), is the total pause time divided by the number of syllables.

PART IV. AN ACOUSTIC STUDY OF THE PAUSE MARKER

Part IV describes findings from an initial study towards developing an automated procedure for the Pause Marker. Consistent with study questions and findings in PM III, the focus in these studies was on the pause and speech elements of the Type I inappropriate between-words pause termed *abrupt.*

The significant, but modest effect sizes obtained, using different participant groups, different measures, and different temporal windows (see Table 7), indicated that more developmental work is needed toward the goal of automated scoring of the Pause Marker. Findings from this initial study are included in this technical report for their potential to aid in the development of an automated scoring system for the Pause Marker with the sensitivity and specificity needed for research and clinical applications.

Table 6. Speaking Rate, Articulation Rate, and Pause Time data for participants in three speaker groups classified by PMI level. All participants had non-marginal PM+ scores (i.e., met PM criteria for apraxia of speech).

		Speaking Rate (syll/sec)			Articulation Rate (syll/sec)			Pause time/syll (ms)	
	n	***M***	***SD***		***M***	***SD***		***M***	***SD***
Childhood Apraxia of Speech (CAS)									
Mild	15	3.0	0.6		3.3	0.6		39	21
Mild-Moderate	6	2.6	0.3		3.2	0.5		74	38
Moderate-Severe	5	2.5	0.5		2.9	0.7		59	21
Severe	5	2.1	0.4		2.6	0.6		102	46
All	31	2.7	0.6		3.1	0.6		59	37
Complex Neurodevelopmental Disorders (CND)									
Mild	19	3.2	0.8		3.6	0.8		42	30
Mild-Moderate	12	2.7	0.6		3.3	0.6		77	57
Moderate-Severe	1	3.2	*		5.2	*		120	*
Severe	3	1.9	0.5		2.4	0.7		134	66
All	35	2.9	0.8		3.5	0.8		63.7	51.4
Adult-onset Apraxia of Speech (AAS)									
Mild	8	2.3	0.4		3.0	0.6		99	60
Mild-Moderate	3	2.2	0.2		2.8	0.1		98	23
Moderate-Severe	4	2.0	0.5		2.6	0.6		121	60
Severe	4	1.4	0.5		2.1	0.4		250	100
All	19	2.1	0.5		2.7	0.6		135	87

Method

Transcripts from participants positive for apraxia of speech in the CAS and AAS groups, as well as a group termed Complex Neurodevelopmental Disorders (CND) described in PM III, were inspected for occurrences of abrupt inappropriate pauses. For each occurrence of an inappropriate abrupt pause, we attempted to identify an occurrence of one of the other seven types of inappropriate pauses in which the post-pausal word began with the same word, or the same feature in the word-initial sound (e.g., a high vowel), or at least a sound in the same linguistic class (i.e., a monophthong, diphthong, or consonant). For all such within-participant word pairs as originally identified by the acoustic analysts (i.e., a word with an inappropriate abrupt onset and a word with an inappropriate non-abrupt onset), acoustic measures were made of the duration of the pause measured from the waveform and the time aligned spectrogram. Pause duration was measured from the last pre-pausal indication of a speech related event (e.g., glottal pulse for a voiced segment, high frequency noise for a fricative, release burst for a stop) to the first post-pausal indication of a speech related event (e.g., onset of voicing, onset of high frequency noise).

Next, a power plot was calculated for each post-pausal phoneme using the appropriate function in the acoustics software described in PM I, titled TF32 (Milenkovic, 2001). The function averaged amplitude samples over a 5 ms window, initially moving at 1 sample steps (1/44 ms). The power plot was automatically evaluated to determine the point in time (post-Pause) that an amplitude maximum and following plateau was reached, the measure termed “ms-to-peak.” This evaluation examined amplitude values starting at the onset of the post-pausal event and moving in 1/44 ms steps. This step size was considered too small, given that the default step size for most acoustic algorithms that produce power, formant, or pitch plots use

steps sizes as large as 10 ms (e.g. Wavesurfer, Praat). Thus, determination of ms-to-peak was also run using step sizes of 1 and 2 ms. Following this, the derived measure was the slope of the amplitude contour (i.e. dividing the determined amplitude maximum by the ms-to-peak, yielding dB/ms).

Results

Acoustic correlate of the pause element of the PM. Table 7 includes acoustic findings for the duration of pauses perceived by the acoustic analysts as occurring before words with abrupt (AB) speech onsets compared to the durations of inappropriate pauses not classified as having non-abrupt onsets (NAB), which included each of the other seven types of inappropriate between-words pauses, and similarly for the derived dB/ms measure. For each of three participant groups described elsewhere (CAS, AAS, and CND; Shriberg, Strand & Mabie, 2017), Table 7 includes several descriptive statistics, including for each variable and step size, number of tokens, mean and standard deviation for NAB and AB, and columns that provide the difference between the NAB and AB values. The right-most three columns include effect size findings similar to Cohen's d, and confidence intervals around the effect size. Bolded, significant effect sizes have similar algebraic signs for the lower and upper boundaries of the confidence interval.

As shown in Table 7, for the CAS, CND, and CND groups, respectively, the inappropriate between-words pauses preceding words with abrupt onsets were consistently shorter than the inappropriate pauses preceding words with non-abrupt onsets. For CAS the average difference in time was 128 ms, for CND 244 ms, and for AAS 218 ms. The same trend is shown in Table 7 for the derived measure dB/ms. The amplitude at the start of the post pausal speech event rose faster when the pause had been judged to be followed by an abrupt speech

Table 7. Means and standard deviations for db/ms and pause length (in ms) for pauses perceived as followed by a non-abrupt speech onset (NAB) or by an abrupt speech onset (AB). Statistically significant effect sizes are bolded.

Group[a]	Variable	Step size	No. Tokens		Mean (SD)				Confidence Interval	
			NAB	AB	NAB	AB	Difference NAB-AB	Effect Size (d)	Lower	Upper
CAS	dB/ms	1/44 ms	196	204	1.97 (1.58)	1.97 (1.74)	0	0.00	-0.20	0.20
	Length (ms)				651 (472)	526 (364)	125	**0.32**	0.12	0.52
	dB/ms	1 ms	205	212	1.31 (1.12)	1.61 (1.24)	-.30	**-0.25**	-0.45	-0.06
	Length (ms)				637 (470)	518 (371)	119	**0.28**	0.09	0.47
	dB/ms	2 ms	200	226	1.17 (1.03)	1.49 (1.39)	-.32	**-0.26**	-0.45	-0.07
	Length (ms)				650 (468)	522 (356)	128	**0.31**	0.12	0.50
CND	dB/ms	1/44 ms	138	259	1.59 (.95)	1.91 (1.25)	-.32	**-0.28**	-0.48	-0.07
	Length (ms)				783 (536)	546 (363)	237	**0.55**	0.34	0.76
	dB/ms	1 ms	136	255	1.52 (.99)	1.81 (1.24)	-.29	**-0.25**	-0.46	-0.04
	Length (ms)				778 (535)	539 (355)	239	**0.56**	0.35	0.77
	dB/ms	2 ms	138	255	1.43 (1.00)	1.74 (1.37)	-.31	**-0.25**	-0.45	-0.04
	Length (ms)				783 (536)	539 (355)	244	**0.57**	0.36	0.78
AAS	dB/ms	1/44 ms	210	142	1.76 (1.22)	2.14 (1.32)	-.38	**-0.30**	-0.51	-0.09
	Length (ms)				818 (483)	608 (316)	210	**0.49**	0.28	0.71
	dB/ms	1 ms	207	143	1.26 (.75)	1.52 (.75)	-.26	**-0.35**	-0.56	-0.13
	Length (ms)				826 (483)	608 (316)	218	**0.51**	0.30	0.73
	dB/ms	2 ms	207	143	1.12 (.76)	1.37 (.81)	-.25	**-0.32**	-0.53	-0.10
	Length (ms)				826 (493)	608 (316)	218	**0.51**	0.29	0.72

[a] CAS = Childhood Apraxia of Speech; CND = Complex Neurodevelopmental Disorders; AAS = Adult-onset Apraxia of Speech.

event than it did when followed by a non-abrupt speech event. The averaged differences for the three participant groups were .32 db/ms faster for CAS participants, .31 dB/ms faster for CND participants, and .25/ms faster for AAS participants.

As shown in the last three columns in Table 7, 17 of the 18 effect sizes for non-abrupt (NAB) and abrupt (Abrupt) pauses were statistically significant. Their pattern support the perceptually-based PM distinction between non-abrupt and abrupt inappropriate pauses. The magnitudes of the associated effect sizes, however, ranged from -0.25 to 0.57 with the largest effect size classified at the low end of Cohen's conventional Medium effect size range (.50-.79). We interpret findings as promising, but not sufficient for use in automated procedures to classify speakers as positive or negative for CAS. As described in the introduction, information from this study is included in this technical report for its potential to inform development of an automated PM scoring system.

Summary

The findings reviewed in this section provide some information toward a possible acoustic measure to identify the occurrence of abrupt inappropriate pauses, the most frequent of the four subtypes of inappropriate pauses in the PM. Collaborative research using alternative instrumental methods is needed to automate the PM for increased reliability and efficiency.

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