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Transition Deficit in Jordanian Arabic Stuttered Speech: An Acoustic Analysis of Word-Medial Geminate Consonants

Khalid Altamimi*, Badrulzaman Abdul Hamid, Hasherah Mohd Ibrahim
Speech Science Program, Center for Rehabilitation and Special Needs Studies, Faculty of Health Sciences, Universiti Kebangsaan Malaysia, Malaysia

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Abstract

This study investigates the effect of medial geminate consonants on those who stutter. F1, F2, and Voice Onset Time values were investigated in medial geminate consonants for adults who stutter (AWS). To understand how AWS control the temporal compensation between the geminate consonant and the vowel preceding it, the study recruited 20 healthy fluent Jordanian adult male speakers (FP) who acted as a control group and 20 Jordanian AWS. Participants were asked to produce minimal like pairs (/bataa/, /batta/ and /badaa/, /badda/) which differ in the middle consonants. Results show that those who stutter spend more time producing the target sounds because of the phonetic complexity of the sounds and the transition deficit AWS suffer from.

Keywords: Arabic, Geminates, Phonetic complexity, Stuttering, Transition deficit.

1. Introduction

Stuttering is a highly complex speech fluency disorder which involves abnormal behaviours that involuntarily disrupt the normal flow of speech sounds, syllables, or words. These "core stuttering" behaviours are repetitions, prolongations and pauses (Alm et al. 2013). The great majority of studies have clearly established that stuttering is a disorder of early childhood. It usually starts early in development but sometime occurs after language onset (Howell et al. 2008; Yairi and Ambrose 2004). The majority of studies do not report onset after age six; in most cases it occurs between 3 and 5 years of age (Reilly et al. 2013; Cavenagh et al. 2015).

Stuttering may often influence the persons' quality of life and their interpersonal relationships. It can also negatively affect their job opportunities and performance, the treatment can be time-consuming and expensive. The current studies show that adults who stutter appear to process language differently (Weber-Fox et al. 2013), have more language production inconsistencies (Coulter et al. 2009) and show poor language skills when compared to typically fluent peers (Ntourou et al. 2011). In general, language formulation appears to be mainly challenging for adults who stutter, (Maxfield et al. 2016). In addition to that, speech-motor coordination in children and adults who stutter is negatively affected by the linguistic complexity of the (MacPherson and Smith 2013).

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* Corresponding Author: **p113885@siswa.ukm.edu.my**

In addition to the core behaviours that people who stutter suffer from, they also experience affective, behavioral, or cognitive reactions to stuttering (Constantino et al. 2017). Although the exact cause of stuttering is uncertain, it is believed that stuttering is usually caused by a complex interplay of linguistic, genetic, physiological, behavioral, psychological and environmental factors (Postma and Kolk 1993). Most researchers agree that stuttering should be explained based on a multifactorial, dynamic nonlinear approach that takes into consideration the motor, linguistic and emotional factors (Smith and Weber 2017)

The typical age of stuttering onset is 30–48 months. It is estimated that 5%–8% of preschool children experience different aspects of stuttering (Bloodstein & Ratner 2021; Yairi & Ambrose 2004, 2013). 80% of these children recover without therapy (Yairi & Ambrose 2004). In the teenagers and adults' populations, the prevalence of stuttering is approximately 1% worldwide with males outnumbering females.

Currently, stuttering is diagnosed based on neuropsychologic (i.e., perceptual) clinical examination with the aid of clinical tests (Yaruss & Quesal 2006). However, clinical tests are qualitative; they depend heavily on the examiner's skills and experiences. To overcome this limitation, researchers adopt to a more objective approach for assessing stuttering; this is the acoustic analysis of stuttered speech (Saggio et al. 2022). Using acoustic analysis softwares (e.g. Praat), researchers analyze the acoustic features that are related to the temporal (segment duration, VOT, pause duration, etc.) and spectral characteristics (formant transitions) of sounds.

Based on these facts, the current study intends to examine the effect of complex sounds on stuttered speech. Literature reveals that AWS suffer from spectro-temporal restrictions. This being the case, how do then AWS produce highly complex geminate sounds that need extra muscular tension to be articulated correctly.

2. Literature Review

Generating speech fluently requires the efficient coordination of oro-facial muscles and the vibration of the vocal cords; these skills are mostly deficient in individuals who stutter (Sassi & Andrade, 2004). Physiological research has indicated that people who stutter witness difficulties in initiating voicing (Craig-McQuaide et al. 2014); they also suffer from inappropriate vocal cord positions (Kikuchi et al. 2018) during instances of stuttering. They seem to have more physiological and temporal inconsistencies in their speech processing ability than non-stutterers. These inconsistencies cause disturbances in the coordination of the articulators and the initiation of discourse (Max and Gracco 2005). Thus, there have been an ever-increasing number of researchers who analyze voice onset time (VOT) among stutterers (Arenas et al. 2012) to experimentally view how these inconsistencies are realized. The effect of VOT can be a vital parameter for researching time-related characteristics of speech. Measuring VOT can bring more attention to the instability of articulation in people who stutter (Wiltshire et al., 2021).

VOT is the interval between the stop release and the beginning of the vocal cords' vibration (phonation) (Groll et al. 2021). It served as a device for measuring voicing in stops (Lisker & Abramson 1964; AlDahri 2012). VOT values can be divided into three types (Lisker & Abramson 1964):

1- Zero VOT: the vocal cords start to vibrate simultaneously with the release of plosive constriction

2- Positive VOT: vocal-cords start to vibrate after the release of the stop closure; in this case we get "voicing lag"

3- Negative VOT: the onset of vocal cord vibration precedes the release of the stop closure which gives rise to "voicing lead".

Accordingly, stop consonants are subdivided into three production ranges: the short-lag positive range (VOT of 0 to + 25 milliseconds); the long-lag positive range (VOT of 50+ milliseconds); and the long-lead negative range (VOT of 50+ milliseconds). In their 1964 pioneering work, Lisker and Abramson divided languages into two classes: group (A) languages with a long lag VOT exceeding 50 milliseconds; and group (B) languages with a short lead VOT that is less than 25 milliseconds for voiceless stops and long lead VOT exceeding 50 milliseconds for voiced stops (e.g. Arabic).

English and Arabic vary in their VOT patterns (Alghamdi 2004). In English, voiceless stops have a long lag VOT, while voiced stops have a short lag VOT. The main cue for voicing initial stops in English is the timing difference between glottal and supraglottal events (Ladefoged & Maddieson 1996; Abramson & Whalen 2017). Arabic, on the other hand, follows a binary system with the voiceless stops falling within the range and direction of the English voiced stops and the voiced stops occurring in the closure phase of the stops (Al-Tamimi & Howell 2021).

Voice onset time is an extremely critical time-related aspect of speech, particularly for voiced and voiceless stop consonants in English and other languages (Jiang et al. 2006; Llewellyn 1994). Research on VOT and its role in stuttering can provide significant resources for comprehending the articulatory mechanisms of the disorder. Therefore, this current study confines to this tendency, providing acoustic measurements of VOT to distinguish between word medial voiced and voiceless geminate stops produced by Jordanian adult speakers who stutter and who do not stutter. Producing contrastive VOT requires complicated timing and coordination of the glottal and supraglottal actions (Kong et al. 2011).

Since it is believed that stuttering involves difficulties in articulatory transition (AL-Tamimi & Howell, 2021), incidents of stuttering are expected to increase with the linguistic complexity of the sound. Researchers usually examine the first and second formant frequencies, i.e. F1 and F2, to acoustically investigate the spatial posterior vs. anterior (i.e. F2) and inferior vs. superior (i.e. F1) movements of the tongue during the production of linguistically complex sounds (i.e. later acquired sounds requiring higher level of articulator coordination and phonological knowledge) and linguistically less complex sounds (i.e. early acquired sounds) (Gierut 2001). Klich and May (1982) examined the steady-state of F1 and F2 in CVC productions of seven stuttered adults. Results showed that stutterers' values of F1 and F2 were lower compared to FP. Researchers attributed these results to the restricted articulatory adjustments used by the stutterers. Similar results were noted by Robb and Blomgren (1997). They examined F2 to evaluate and compare the effects of coarticulation in the speech of a group of stutterers and nonstutterers. The authors found that F2 slopes in stuttered speech were consistently lower than those for the control group.

Recent studies have provided experimental evidence associating speech complexity with stuttering. The aim of these studies was to highlight the main linguistic features (e.g. phonetic, phonological, morphological, syntactic, etc.) Underlying stuttering (Throneburg et al. 1994). Indices measuring these complexities objectively were proposed by Throneburg et al. (1994) and Jakielski (1998). The main finding~~s~~ of these studies show that stuttering increases as speech item complexity increases (MacPherson & Smith 2013). Adults who stutter (AWS) have variously been reported to witness defect muscular transitions between segments, inappropriate timing of articulatory movements (Van Riper 1982) and restricted temporal and spatial adjustments of articulators. In other words, with stuttered speech "the flow of fluent speech is disrupted as the nervous system fails to generate the appropriate command signals to drive the muscles involved in speech production" (Smith et al. 2012, 345).

Studies that examined the association between complex speech items (e.g. sounds, syllables, words, sentences) and stuttering found an increase in stuttering episodes as speech items become linguistically more complex. For example, an increase in the length of the utterance results in more stuttering episodes (Kleinow & Smith 2000). In addition to that, the occurrence of late-acquired consonants and consonant clusters results in higher incidents of stuttering (Gierut & Morrisette 2012). It is worth noting that most of these studies were conducted on English or European language speakers. However, there are several complex sounds in Arabic that are acquired late and might incite stuttering episodes in the speech of AWS. Geminates are one of these sound categories that are considered phonetically complex.

Geminates are long or doubled consonants which contrast phonemically with short or singleton consonants, e.g. /sa**m**a/ (sky) vs. /sa**m.m**a/ (he named). From a phonetic point of view, gemination is mainly manifested as lengthening of the consonant (Payne 2005) in word-medial position and shortening of the preceding vowel within the frame of a phonetic phenomenon referred to as "temporal compensation". Esposito and di Benedetto (1999) emphasize the role of two acoustic parameters in discriminating between geminates and singletons perceptually. These are consonant closure length and preceding vowel length, with the first parameter playing the major role. The differences in duration between singleton/geminate consonants are language-specific (Ladefoged & Maddieson 1996). The ratios of singleton–geminate duration in Berber and Finish (Aoyama 2002), on the one hand, and Japanese, Italian and Turkish (Aoyama 2002) and Payne (2005), on the other, are 1 to 3 and 1 to 2, respectively. In other words, geminate consonants might be double or triple the time of the singleton counterpart.

In Arabic, the ratio is shorter than that found in other languages. Al-Tamimi's (2004) experimental study shows that the singleton-geminate ratio in Jordanian Arabic is 1 to 1.5. Different studies have reported that the duration of the vowel preceding the consonant interacts with the duration of the consonant itself. This feature is referred to as "temporal compensation". Vowels preceding singletons are longer than those preceding the geminates. The muscular tension accompanying the production of the geminates is the reason behind this difference. The opposite is true when the consonant has a weak force of articulation (Ridouane 2022).

Mitchell (1993, 92) states that “all types of gemination reveal not only an increase of duration over non-gemination but also greater muscular tension and pulmonary pressure, a more extensive spread of tongue-palate contact”. This tension or strength is the main feature in articulating geminates. “The intensity of the pronunciation leads to a natural lengthening of the duration of the sound, which is why strong (consonants) differ from weak ones by greater length” (Ladefoged & Maddieson 1996, 97). Maddieson (1985, 208) states, “A shorter vowel before geminate than before singleton consonants is known to occur at least in Kannada, Tamil, Telugu, Hausa, Italian, Icelandic, Norwegian, Finnish, Hungarian, Arabic, Shilha, Amharic, Galla, Dogri, Bengali, Sinhalese, and Rembarrnga”. He views this pattern as a universal property of natural language. With this background in mind, one may wonder if the timing of geminate consonants and their adjacent vowels is difficult for Arab AWS to control.

3. Methods and Participants

To determine the role of geminate consonants in increasing the incidents of stuttering in the speech of Jordanian AWS and the spatio-temporal aspects of the geminated consonants and the vowels preceding and following them, the current study recruited 40 Jordanian male subjects divided into 20 AWS and 20 FP (control group). AWS were contacted using the contact details of the Speech-Audiology Clinic at Jordan University of Science and Technology. All ethics protocols were abided by, and the ethics committee of UKM University approved the study with clearance number 112/2023. Subjects were briefed on the aim of the research and asked to sign consent forms. All AWS were male adults. Accordingly, the study excluded the female adults from the FP group to control for gender factor. They ranged in age from 16:0 to 50:0. All data collection and research procedures abided by the ethical regulations of the IRB committee of UKM University.

4. Study Aim and Questions

The current study aims at understanding how AWS produce phonetically complex geminate sounds in Jordanian Arabic. To achieve this aim, the current study intends to answer four questions. These are:

a- What are the VOT patterns of medial singleton-geminate consonants in the speech of AWS?

b- What are the F1 and F2 values of the vowels following medial singleton-geminate consonants in the speech of AWS?

c- Do VOT, F1, F2 values become atypical when AWS move from singleton to geminate consonants?

d- Is the temporal compensation relationship controlled by AWS?

5. Data Collection

The data for the current study was collected by recording the subjects’ productions of the words under study. Four words were produced by the speakers with a Sony ICD Mono Digital Voice Recorder, PX370, placed in front of the subjects. Speakers were asked to produce each of these words (Table 1) three times. The words under study were minimal like pairs differing with the medial singleton-geminate counterparts. Due to the lack of pictures representing these words, the words were written on a sheet of paper and the subjects were asked to memorize them and produce them loudly at a normal speech rate without looking at the sheet of paper. Each of the subjects repeated every word three times. Producing the words without reading them reduces the effect of writing. These words were:

Table 1: Study Words

Singleton	Geminate
/bataa/ (he stayed)	/batta/ (he decided)
/badaa (it became visible)	/badda/ (he gave priority)

5.1 Data Analysis

Using PRAAT 5.3.78 software, F1, F2 at the onset of the vowel following the medial singleton-geminate consonants, target consonants duration, duration of the vowel preceding the target consonant and VOT of voiceless and voiced /t/ vs. /tt/ and /d/ vs. /dd/ were examined. Lead VOT was measured from the onset of glottal vibration to the plosive burst, while lag VOT was measured from the onset of the plosive burst to the first visible glottal vibration pertaining. VOT duration was measured using waveform and wide-band spectrograms simultaneously. Each of the words under study was produced three times. The means of each of the three acoustic measurements, (1) positive VOT, (2) negative VOT, (3) F1 onset, (4) F2 onset, (5) target consonant duration and (6) preceding vowel duration for each of the four words produced by the 40 participants were calculated. 2,880 measurements were collected (6×4×40=2,880). To ensure accuracy, a trained phonetician remeasured the acoustic values for 10% of randomly chosen items from the token database measured previously. Pearson's correlation coefficient showed that both measurements were positively correlated (r = .96, p < .001). Data was compared according to the following scheme: medial singleton acoustic features vs. medial geminate acoustic features in the speech of AWS and FP as two separate groups (within the same group) and medial singleton acoustic features vs. medial geminate acoustic features in the speech of AWS and FP as compared to each other (across the two groups).

6. Results

Analysis of data reveals a clear effect of sound complexity in inciting stuttering. The acoustic features of geminate sounds appear different from their singleton counterparts in the productions of AWS themselves, as one group, and from those of FP as another group. The following results go in line with this general finding. Results will be presented according to the acoustic cues examined in the study.

6.1 Positive/lag VOT

Results (table 2) of positive VOT values of the voiceless stops /t, tt/ produced by AWS as

Table 2: Multiple Comparisons & t-test of /t, tt/ VOT Produced by AWS & FP

Multiple Comparisons

Dependent Variable	(I) Words	(J) Words	Mean Difference (I-J)	Std. Error	Sig.
FP: VOT/ ms	bataa	batta	1.1800	1.1892	.324
AWS VOT/ ms	bataa	batta	3.905	4.648	.004

Paired Samples T-test Results

DV	Group	Mean	T	A-B M Dif.	C-D M Dif.
VOT					
bataa	FP (A)	3.33	15.61	1.18	-
	AWS (C)	6.52	15.18	-	3.90
batta	FP (B)	2.15	-	-	-
	AWS (D)	10.43	-	-	-

one group and FP as another group show that there is a significant difference between /t/ and /tt/ VOT within the AWS group, while the difference between /t/ and /tt/ VOT is not significant within the FP group. On the other hand, AWS and FP have significantly shorter /t/ VOT than /tt/ VOT and insignificantly longer /t/ VOT than /tt/ VOT.

6.2 Negative/ lead VOT

Results (Table 3) of negative VOT values of the voiced stops /d, dd/ produced by AWS as one group and FP as another group show that the two groups produce /d/ VOT significantly shorter than /dd/ VOT. FP produce /dd/ VOT almost 1.5 times longer than /d/ VOT. However, AWS produce /dd/ almost 2.5 times longer than /d/ VOT. On the other hand, /d, dd/ VOT of AWS is significantly longer than /d, dd/ VOT of FP.

Table 3: Multiple Comparisons & t-test of /d, dd/ VOT Produced by AWS & FP

Multiple Comparisons

Dependent Variable	(I) Words	(J) Words	Mean Difference (I-J)	Std. Error	Sig.
FP: VOT/ ms	badaa	badda	-19.6000	1.1892	.002
AWS VOT/ ms	badaa	badda	-116.190	4.648	.000

Paired Samples T-test Results

DV	Group	Mean	T	A-B M Dif.	C-D M Dif.
VOT					
badaa	FP (A)	50.15	-30.13	-19.60	-
	AWS (C)	85.00	-21.87	-	-116.19
badda	FP (B)	69.75	-	-	-
	AWS (D)	201.19	-	-	-

6.3 F1 ONSET

F1 was measured at the onset of the vowel following /t, tt/ and /d, dd/. The differences (Table 4) between /t, tt/ (.037) and /d, dd/ (.041) in the speech of AWS are marginally significant. On the other hand, FP have highly significant differences between /t, tt/ (.000) and /d, dd/ (.022).

Table 4: F1 Values of /t, tt, d, dd/ Produced by AWS & FP

Multiple Comparisons					
Dependent Variable	**(I) Words**	**(J) Words**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**
FP: F1	bataa	batta	16.70000	8.450	.000
	badaa	badda	55.55000	8.2871	.022
AWS: F1	bataa	batta	44.14286	7.877	.037
	badaa	badda	21.42857	8.0874	.041

Paired Samples T-test Results					
DV	Group	Mean	T	A-B M Dif.	C-D M Dif.
F1					
bataa	FP (A)	495.00	9.08	16.70	-
	AWS (C)	420.43	9.68	-	44.14
batta	FP (B)	478.30	-	-	-
	AWS (D)	376.29	-	-	-
badaa	FP (A)	555.75	7.696	55.55	-
	AWS (C)	384.52	3.79	-	21.43
badda	FP (B)	500.20	-	-	-
	AWS (D)	363.10	-	-	-

6.4 F2 ONSET

It is clear that FP and AWS have significant difference (Table 5) between /bataa vs. batta/ and /badaa vs. badda/.

Table 5: F2 Values of /t, tt, d, dd/ Produced by AWS & FP

Multiple Comparisons					
Dependent Variable	**(I) Words**	**(J) Words**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**
FP: F2	bataa	batta	-445.600	8.911	.000
	badaa	badda	-226.150	8.911	.000
AWS: F2	bataa	batta	-68.667	25.462	.009
	badaa	badda	-120.48	4.648	.000

Paired Samples T-test Results					
DV	**Group**	**Mean**	**T**	**A-B M Dif.**	**C-D M Dif.**
F2					
bataa	FP (A)	1597.80	-68.21	-445.60	-
	AWS (C)	1500.19	-2.59	-	-68.67
batta	FP (B)	2043.40	-	-	-
	AWS (D)	1568.86	-	-	-
badaa	FP (A)	1250.70	-36.97	-226.15	-
	AWS (C)	1500.29	-15.87		-120.48
badda	FP (B)	1476.85	-	-	-
	AWS (D)	1620.76	-	-	-

6.5 Target consonant duration

FP and AWS produce the geminate target consonants significantly longer than their singleton counterparts (table 9). FP produce the geminate /tt, dd/ almost 1.5 times longer than the singleton /t, dd/, while AWS produce the geminates sounds two times and a half longer than their singleton counterparts.

Table 6: TCD of /t, tt, d, dd/ Produced by AWS & FP

Multiple Comparisons

Dependent Variable	(I) Words	(J) Words	Mean Difference (I-J)	Std. Error	Sig.
FP: TCD	bataa	batta	-1.62	.2687	.000
	badaa	badda	-3.0900	.2687	.000
AWS: TCD	bataa	batta	-3.3	.404	.000
	badaa	badda	-6.095	.404	.000

Paired Samples T-test Results

DV	Group	Mean	T	A-B	C-D
TCD					
bataa	FP (A)	3.05	-20.36	-1.62	-
	AWS (C)	3.37	-25.16	-	-3.3
batta	FP (B)	4.67	-	-	-
	AWS (D)	6.67	-	-	-
badaa	FP (A)	2.22	-21.52	-3.09	-
	AWS (C)	4.19	-23.69	-	-6.10
badda	FP (B)	5.31	-	-	-
	AWS (D)	10.29	-	-	-

6.6 Preceding Vowel Duration

The vowel preceding the target consonant is longer in the vicinity of the singleton than in the vicinity of the geminate consonant. It is clear that when the target consonant is geminate, the preceding vowel is shortened. The degree of shortening is significantly different within FP and AWS (Table 7). This shows that AWS produce the vowels preceding singletons and geminates with durations longer than those of FP.

Table 7: V1D of /t, tt, d, dd/ Produced by AWS & FP

Multiple Comparisons

Dependent Variable	(I) Words	(J) Words	Mean Difference (I-J)	Std. Error	Sig.
FP: V1D	bataa	batta	20.000	1.082	.000
	badaa	badda	18.300	1.082	.000
AWS: V1D	bataa	batta	9.619	2.348	.000
	badaa	badda	11.381*	2.348	.000

Paired Samples T-test Results

DV	Group	Mean	T	A-B	C-D
V1D					
bataa	FP (A)	67.35	25.38	20.00	-
	AWS (C)	88.52	12.07	-	9.62
batta	FP (B)	47.35	-	-	-
	AWS (D)	78.90	-	-	-
badaa	FP (A)	65.25	18.01	18.30	-
	AWS (C)	85.90	14.55	-	11.38
badda	FP (B)	46.95	-	-	-
	AWS (D)	74.52	-	-	-

7. Discussion

In this study, the researchers attempted to answer the following questions:

1- What are the VOT patterns of medial singleton-geminate consonants in the speech of AWS?

2- What are the F1 and F2 values of the vowels following medial singleton-geminate consonants in the speech of AWS?
3- Do VOT, F1, F2 values become atypical when AWS move from singleton to geminate consonants?
4- Is the temporal compensation relationship existing between the medial geminate consonant and the vowel preceding it controlled by AWS?

As for the first question, results show that AWS and FP differ with regard to the duration differences between /t/ and /tt/ VOT. The duration of /t/ VOT decreases significantly when FP moves towards /tt/, while its duration increases significantly when AWS move towards /tt/. With regard to the voiced singleton consonant /d/ and voiced geminate consonant /dd/ VOT durations, results show that /d/ VOT is significantly shorter than /dd/ VOT for AWS and FP. The significant differences between the two groups with regard to the positive and negative VOT for the singleton and geminate consonants are greater on the side of AWS since the means differences for them between /t vs tt/ and /d vs dd/ were more than the means differences for the same sounds produced by FP.

It is clear that gemination plays a crucial role in AWS's production of VOT. A major finding is that AWS have longer VOT than FP. This means that there is a general trend for AWS to slow their VOT productions; accordingly, longer VOT occurs. In neuromotor terms, slower articulation in the speech of AWS can be due to the dysfunction in speech processing (Postma & Kolk 1993). It has been found (Alm 2004) that AWS's dysfunction in the basal ganglia affects the flow of information between Broca’s area (speech programming) and the motor cortex (speech execution). This general trend is in line with the general finding that AWS have more activity in the right hemisphere and less activity in the left hemisphere areas that are typically responsible for speech production (Bothe & Ingham, 2012); with this less activity and dysfunction and slow flow of information that AWS have in the basal ganglia, slow rates of production resulting in longer production durations are expected.

The question that remains untackled is that why are the differences between FP and AWS singleton and geminate positive VOT either marginally significant (FP /bataa/ vs AWS /bataa/) or nonsignificant (FP /batta/ vs. AWS /batta/), while the differences between FP and AWS singleton (FP /badaa/vs AWS /badaa/) and geminate (FP /badda/vs AWS /badda/) negative VOT are highly significant? Some articulatory and sound development facts might explain the reason behind this positive vs. negative VOT difference.

Kewley-Port and Preston (1974, 205) explicitly state that “the articulatory gestures underlying short voicing lag stops are in specific ways less complicated than for the other types of stop. Voicing lead stops require muscle gestures in addition to those needed for short voicing lag stops.” At the acquisition level, short lag VOT is normally acquired before long lead VOT. This may be due to physiological and aerodynamic factors (Kewley-Port & Malcolm 1974). In lead VOT, the vocal cords vibrate when the supra-glottal air pressure is lower than the sub-glottal air pressure. This aerodynamic state is difficult to maintain with the oral closure gesture needed to produce the plosive (Kong et al., 2012). Accordingly, lead VOT is acquired after children can control and maintain these gestural and aerodynamic properties. These two facts help us answer the question raised earlier. The highly significant difference between singleton and geminate lead VOT in the production of AWS is due to the articulatory complexity required for producing voicing lead. This is why it is acquired late. This complexity makes AWS spend more time in lead VOT and extra time when this VOT precedes a complex geminate sound. The reason behind this is that the dysfunction in both the basal ganglia and in the information exchange that AWS have increases with the anticipation of sound complexity that they might feel. Accordingly, lead VOT would be extra longer as AWS are anticipating a complex geminate sound to come (Alm 2004, 2006; Giraud et al. 2008).

With regard to the second research question, results reveal that AWS have lower F1 values than those of FP for each of /t/, /tt /, /d/, and /dd/. The lower F1 values indicate restricted articulatory movements since there is a reduction in vowel space. This also indicates that AWS have reduced reliance on auditory feedback, resulting in difficulty in using auditory feedback to calibrate the speech production system (Daliri et al. 2018). Within the same frame, F2 is lower in the productions of AWS than FP. This simply means that AWS have oropharyngeal constriction that results in constricted tongue advancement. Similar results were found in previous studies (Howell & Vause 1986). Most of the previous studies that analyzed stuttered speech acoustically agreed that individuals who stutter experience sound-sound transition difficulty.

The third question of the current study focuses on whether VOT, F1, and F2 values change when AWS move from singleton to geminate consonants. This is to see to what extent the complexity of the sound incites stuttering. Results show significant changes compared to FP's values. These changes reflect the awareness of AWS that the sound they are about to produce is a complex sound from articulatory and aerodynamic points of view. It is believed that utterances with a higher degree of phonological complexity will be more likely to contain a disfluency than utterances with a lower degree of phonological complexity. This is based on the fact that the phonological and phonetic encoding play central roles in the production of fluent speech. Current models of speech planning and production suggest that utterance processing goes through different stages, including lexical selection, semantic representation, and articulatory execution (Levelt 1983). The first two stages are related to the planning frame of the utterance while the articulatory process is framed within the execution stage of the utterance. The planning stems from utterance mental encoding that ends up with execution that takes into consideration the phonetic or articulatory complexity of the utterance. It is a motoric complexity required to produce the intended utterance (Levelt 1983). In Arabic, a geminate sound is a highly complex sound acquired late by children and executed through multimuscular configurations. Phonetically, geminates are treated as long sounds (Ladefoged & Maddieson 1996; Al-Tamimi 2004). "Greater muscular tension in the articulating organs" is needed to produce geminates and "to hold the articulators and maintain a longer occlusion time for the geminate contoid" (Catford 1977 298). The duration ratio usually shows that intervocalic geminates are 1.5–3 times as long as singletons. In his 2004 study, Al-Tamimi reports that geminated consonants are produced with great muscular tension resulting in high oral pressure. The high oral pressure is considered 'indicative of a higher articulatory effort accompanying the act of moving and holding the articulators to maintain a longer occlusion time for the geminate contoid (Catford 1977, 298).

The fourth question that the current study answers is related to how AWS manage the temporal compensation relationship existing between the medial geminate consonant and the vowel preceding it. To answer this question, one needs to consider results of the target consonant and the preceding vowel durations. Results show that AWS and FP produce the target geminate consonants significantly longer than their singleton counterparts of FP for the same sounds. On the other hand, FP differ significantly from AWS with regard to the durations of the singleton and geminate consonants. The paired samples T-test shows that the mean difference for FP group between /bataa vs. batta/ is longer than the mean difference between /badaa vs. badda/. However, the mean difference for AWS group between /bataa vs. batta/ is shorter than the mean difference between /badaa vs. badda/. The higher the mean difference the longer the duration is. On the other hand, FP shortens the vowel preceding the target geminate consonant significantly. The mean difference of the vowels preceding /bataa/ and that preceding /batta/ is longer than the mean difference between the vowel preceding /badaa/ and that preceding /badda/. As for AWS, the mean difference of the vowels preceding /bataa/ and that preceding /batta/ is shorter than the mean difference between the vowel preceding /badaa/ and that preceding /badda/. This shows that AWS have abnormal temporal compensation relationship. These findings come in line with findings of other studies that state that AWS suffer from a timing problem during auditory-motor behavior, something that also appears to extend to non-speech (Sares et al. 2019). AWS spend more time in the target consonant as a result lack of temporal coordination. This is why their target consonants are longer than those of FP.

Findings of the current study indicate that PWS have restricted articulatory movement resulting in longer time of production. These results have clinical implications for speech-language therapists (SLT) working with PWS to know how they can manage, treat and predict outcomes. The current results can provide baseline prognostic information for clinical success. Understanding the effect of complex sounds on increasing the possibility of stuttering enhances the therapeutic efficacy that SLTs design. Therapeutic techniques and fluency enhancing strategies used should take into consideration how complex sounds can be dealt with to minimize or avoid stuttering incidents.

Conclusion

The current study reveals that AWS show abnormal speech sound productions due to neuromotor dysfunction manifested in a defect in sound transition. This abnormality increases with the increase in the phonetic complexity of the sound. Speech-language therapists who treat Arab AWS should consider in their therapy plans the nature of the Arabic language and its linguistically complex items.

Transition Deficit in Jordanian Arabic Stuttered Speech: An Acoustic Analysis of Word-Medial Geminate Consonants

عجز الانتقال في الكلام المتلعثم في اللغة العربية الأردنية: تحليل صوتي للحروف الساكنة المزدوجة في الكلمة الوسطى

خالد التميمي، بدرالزمان عبدالحميد، هاشيرا محمد
الجامعة الوطنية الماليزية – ماليزا

الملخص

تبحث هذه الدراسة تأثير الحروف الساكنة المتماثلة في وسط الكلمة على الذين يتلعثمون. تم التحقيق في قيم زمن، F1 وF2 والصوت، لدى البالغين الذين يتلعثمون. لفهم كيفية تحكم الأشخاص الذين يتلعثمون في التعويض الزمني بين الحرف الساكن المتماثل والحرف المتحرك الذي يسبقه، شارك في الدراسة 20 شخص من الأردنيين البالغين الأصحاء الذين يجيدون التحدث بطلاقة و20 من البالغين الأردنيين الذين يتلعثمون. أنتج المشاركون أزواجًا متشابهة إلى حد ما /bataa/ و/batta/ و/badaa/ و/badda/. وجدت النتائج أن أولئك الذين يتلعثمون يقضون وقتاً أطول في إنتاج الأصوات المستهدفة؛ بسبب التعقيد الصوتي للأصوات وعجز الانتقال الذي يعاني منه الذين يتلعثمون.

Endnotes

Arab adult stutters can face huge challenges when faced with medial geminate sounds. They need approximately double the time to produce the same words compared to normal Arab speakers.

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Appendix (1)
List of word list

Singleton	Geminate
bataa	batta
badaa	badda

Appendix (2)
List of Acronyms

Adults who stutter	AWS
Fluent speakers	FP