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CORRELATION BETWEEN VOWEL CENTRALISATION AND INCOMPLETE STOP ARTICULATION IN INDIVIDUALS WITH TRAUMATIC BRAIN INJURY

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ABSTRACT

Traumatic brain injury (TBI) often results in dysarthria, a motor speech disorder. Two processes often linked with TBI dysarthria are vowel centralisation and incomplete stop articulation. It is not clear to what extent these two processes are interrelated and to what extent they might serve as indices of the severity of dysarthria secondary to TBI. The purpose of this study is to test the hypothesis that patients who centralise vowels will also have difficulties producing stop consonants with complete stricture. Polish dysarthric speakers post TBI (n=6) and ten age-matched healthy controls with normal speech (n=10) performed the Polish Dysarthria Test for TBI Patients (PDTTP) (Połczyńska-Fiszer and Pufal 2006). Three of the TBI subjects had moderate dysarthria and three mild dysarthria. The test investigates phonemes in isolation as well as in diverse phonetic contexts in different elicitation tasks, including spontaneous speech. The data from the PDTTP were transcribed phonetically and analysed acoustically. Vowel centralisation and incomplete stop articulation appear to be strongly correlated (r=0.90). It was found that the degree of TBI dysarthria correlates with the frequency of occurrence of these two processes. Thus, the two processes may serve as important indices of severity of dysarthria in TBI.

KEYWORDS: Traumatic Brain Injury; dysarthria; underacticulation; speech acoustics.

1. Introduction

It is estimated that 30% to 50% of individuals with traumatic brain injury (TBI) who recover from coma suffer from dysarthria (Duffy 1995; Pąchalska et al. 2004). This post

TBI dysarthria is a complex speech impairment, characterised by distorted articulation of vowels and consonants, and problems with phonation, prosody, and resonance; some of these problems have been attributed to impaired co-ordination of articulation and phonation (Cahill et al. 1996; Theodoros and Murdoch 1996; McHenry 2000; Połczyńska-Fiszer and Pufal 2006; Rosen 2006). Several acoustic analyses of post-traumatic dysarthria have been reported (e.g. Ziegler and von Cramon 1983; Weismer et al. 2001; Wang et al., 2005), but these acoustic methods are rarely used in the investigation of sound simplifications and reductions called "natural phonological processes".

Natural phonological processes which appear in first language (L1) acquisition (Stampe 1972) also occur in speech disorders (Grunwell 1987; Ingram 1990; Dressler and Dziubalska-Kołaczyk 1995; Tobin 1997, 2002), including dysarthria secondary to TBI and recovery from coma (Połczyńska-Fiszer 2006; Połczyńska-Fiszer and Pufal 2006). Processes used by the adult TBI population are more regular and easier to predict than the L1 acquisition processes used by children. Tobin (1997) observes that pathological errors are often idiosyncratic (rather than just the more frequent, natural functional processes found in typically developing children) and that they can be explained in direct relation to the given syndrome in question. In particular, individuals with TBI are unable to produce a full stricture of the articulators, most likely due to an undershoot of the articulators (tongue, lips, and jaw) and velopharyngeal incompetence, i.e., the inability to shut off the nasal passage during the production of oral sounds. These individuals with TBI use processes which have been called by the first author "Articulatory Patches" (APs). APs are phonetic errors made by speakers who have sufficient phonemic awareness of the features of the target sound but lack the sufficient articulatory motor control to produce those features (Połczyńska-Fiszer 2006). Children may not have a fully established phonological system while acquiring L1, whereas the phonology of adult TBI individuals is not damaged (Połczyńsk, in press). APs are impaired phonetic manifestations brought about by physiological deficits. These organically motivated AP processes are more consistent than the natural phonological processes that appear in L1 acquisition primarily because the phonology of individuals with TBI is not impaired, only the phonetic manifestations of this phonology are atypical due to the physiological deficits. Furthermore, APs are inherently involuntary and individuals with TBI have very little or no control over them. Hence, APs may differ from processes used by children in L1 acquisition who may not have developed fully established phonological systems.

The theory of Phonology as Human Behaviour (PHB; e.g. Diver 1979; Tobin 1997, 2002) has focused on new distinctive features which are directly related to human physiology, perception, cognition and behaviour. Some of these innovative distinctive features are based on muscle control relevant to the present study and include "mobility/stability" for consonants and "active articulators" for vowels:

(1) Regarding the spirantisation of stops/plosives and Incomplete Consonant Closure (ICC): the kinds of gestures required to produce sounds which differ in the

way they change the airflow rather than the traditional concept of "manner of articulation": e.g. in the formation of stops the active articulator must be in motion for closure and release of the consonant. The release of the consonant is associated and an explosion of pent-up air and the lip, apex and dorsum, respectively are violently displaced for /p, t, k/. Because of the dynamic nature of the process of stop/plosive closure and release, the stops/plosives are labelled *mobile* sounds. However in the formation of fricatives/spirants the articulatory organ employed in the production of the sound remains relatively stationary. This stationary posture and the partial occlusion the articulator forms allows the excitation of the resonant cavity as the air is forced through the incomplete occlusion to create the noise characteristic of the target fricative/aspirant. Thus, for example, the lip and apex respectively, are stationary during the production of /f, s/. Because of the relative stantionary position of the articulators during the production of the fricatives/aspirants, these phonemes are labelled *stable* sounds. (Diver 1979: 70; Tobin 1997: 34–35).

(2) Regarding vowel centralisation: "front" and "back" vowels indicate the relative position of the anterodorsum (blade) and posterodorsum (back) of the tongue – the active articulators of phonemes of aperture (vowels). The traditional terms "open" and "close" and very often "high," "mid", and "low" refer to different degrees of aperture resulting from the position and movement of the lips and tongue (Tobin 1997: 84–85). Thus, PHB gives the vowels the traditional consonantal feature of active articulator. Polish lacks central vowels and the vowel which is the closest to a mid-central region is /ɨ/. The remaining vowels /i, ɛ, a, o, u/ have a more peripheral position (for the Polish vowel chart, see the left side of Figure 3).

(3) Polish individuals with TBI tend to centralise the five vowels by producing a schwa or /ɨ/ (Połczyńska, 2006).

Natural Phonology (NP) (e.g. Stampe 1972; Dressler 1985; Dziubalska-Kołaczyk 2002) and PHB (Tobin 1997, 2002) classify the L1 natural functional and idiosyncratic processes into three major groups:

(1) *Substitutions* of distinctive features such as articulators, manners of articulation or voicing/nasalisation: spirantisation, stopping of fricatives, deaffrication, affrication of plosives, nasalisation of consonants and vowels, denasalisation, vowel neutralisation, vocalisation, gliding, gliding of fricatives and affricates, spirantisation of glides, glottalisation of /x/, fronting and backing of consonants, fronting, backing, raising and lowering of vowels.

(2) *Assimilations*: devoicing, prevocalic voicing, consonant harmony, vowel spirantisation.

(3) *Changes in a syllable structure*: unstressed vowel deletion, stressed vowel deletion, consonant deletion, consonant cluster reduction, vowel epenthesis, consonant epenthesis, unstressed syllable deletion, stressed syllable deletion, syllable addition, reduplication and metathesis.

Połczyńska-Fiszer (2006) extended the classification in TBI speech by adding two additional groups of processes specifically related to the organic difficulties found in this population:

(4) *Underarticulations*: incomplete consonant closure and consonant approximation, as well as vowel centralisation. All these APs involve an undershoot of the articulators used to produce the intended target phoneme.

(5) *Articulatory force changes*: strong and quiet. Physiologically, underarticulation is usually referred to as the inability of the articulators to reach their targets, due to the weakness of the articulators (which might be due to muscle paresis or paralysis, hypotonia, or to reduced "drive" (abulia) and vigilance). Quite articulation is a soft articulation or a whisper. It occasionally occurs in patients with poor phonation in word-final positions. Strong articulation is hyperarticulation. Some individuals with TBI, being aware of their speech problems, might try to articulate sounds very clearly, to the extent that they exaggerate their articulation. Quiet articulation can but does not have to be correlated with undearticulations.

The purpose of this study is to test the hypothesis that patients who centralise vowels will also have difficulties producing stop consonants with complete stricture. Both processes are very common in post-traumatic dysarthria (Połczyńska-Fiszer 2006). Physiologically, the two phenomena are likely to be related to weakness and slowness of the articulators. Individuals with TBI tend to articulate vowels as central and with a smaller degree of opening because they have problems achieving maximum aperture and reaching extreme front and back positions. According to the theory of PHB, vowel centralisation would denote a lower point on the hierarchy of stricture to aperture of sounds ranging from zero (the complete closure of oral stops) to five (the maximum aperture for the vowel /a/) (Tobin 1997: 60). Vowel centralisation has been described in several studies on dysarthria, relative to typical speakers (Zeiger and con Cramon 1983; Weismer et al. 2001; Bunton and Weismer 2001; Higgins and Hodge 2002; Liu et al. 2005; Turner et al. 2005; Sapir et al. 2007). Vowel centralisation is fundamentally parallel to two processes found in consonants – (1) the spirantisation of stops and (2) Incomplete Consonant Closure (ICC) of stop consonants which require complete closure, where in both processes patients have trouble achieving this zero minimum stricture. Spirantisation of stops is caused by the inability to form a complete closure of the articulators, e.g. *tak* /θak/ (Pol. 'yes'), *go* /ɣo / (Pol. 'him'). In the production of incomplete stops – ICCs – the articulators approach but do not reach the target of closure completely. Yet, the intended consonant can still be discriminated, e.g. *bath* /p̯̆aθ̯̆/, *pies* /p̯̆jɛs/ (Pol. 'dog'), *garnitur* /kar̯̆ˈɲitur̯̆/ (Pol. 'a suit'). In the above processes, TBI individuals who lack the muscle control to produce a precise, refined and complete articulatory gesture go as far as they can to produce a complete articulatory gesture within their post-coma limitations to produce a stop consonant. ICC can be viewed as a "post-process" since an intended consonant phoneme is produced. However, none of the common or familiar functional processes is applied to produce the target consonant, yet, there is a sufficient – albeit an inefficient – approximation of the complete closure of articulators and alternative allophones within the phonemic class of stop is still maintained (Połczyńska 2006).

We postulate that TBI individuals who centralise vowels will also have difficulties achieving complete stricture in stops resulting in incomplete stop production because both processes are directly related to the weakness of the tongue. It is expected, therefore, that the correlation between these two processes found in the atypical production of both vowels and stops should be stronger in patients with more severe types of post-traumatic dysarthria because of their common organic origin.

2. Methods

Six native-speaking Polish individuals with TBI (five males and one female) and a matched Control Group (PCG) with no history of brain pathology participated in the study. There were ten subjects in the control group – five males and five females. Their biomedical information is summarized in Table 1. The mean age of the TBI Group was 26 years (SD = 5.58) and that of the PCG was 29 years (SD = 6.75).

According to standardised clinical tests used in Poland, three TBI individuals (P4, P5, P6) had moderate post-traumatic dysarthria (henceforth, moderate dysarthria group, or MOD), and three (P1, P2, P3) had mild dysarthria (henceforth, mild dysarthria group, or MILD).

As depicted in Table 1, the two youngest patients were 22 years old and the oldest TBI participant was 38 years old. Coma duration ranged between three weeks and two months. The shortest time since awakening from a comatose state was one year and the longest was five years. All the TBI subjects had extensive severe TBI with the concussion of the brain stem. Three patients (P1, P3 and P4) suffered right hemisphere damage and three patients had their frontal lobes injured (P4, P5, P6) (see Table 1 for details concerning motility problems).

Table 1. Clinical data for the six individuals with TBI.

Patient	Age	Coma duration	Time after awakening	Type of cerebral trauma (Computer Tomography)	Mobility	Type of dysarthria
P1	27	1.5 month	1 year	Intracerebral haematoma of the right temporo-parietal lobe with a perforation of the ventrical system.	Spastic quadriparesis, stronger on the left side, increased muscle tonus, no reflexes in the lower limbs, contracture in the upper limbs, superficial sensibility decreased on the left side, unable to walk.	Light
P2	22	2 months	5 years	Extensive brain oedema.	No problems.	Light
P3	25	1.5 month	2 years 7 months	A trace of blood in the right parietal horn. A small hypodense region in the semiovale centre (right side).	Spastic quadriparesis, increased muscle tonus, no reflexes in the lower limbs, contracture in the upper limbs, decreased superficial sensibility, unable to walk.	Light
P4	23	3 weeks	1 year 4 months	Subdural haematoma of the right fronto-temporal lobe.	Spastic quadriparesis, increased muscle tonus, no reflexes in the lower limbs, contracture in the upper limbs, superficial sensibility decreased on the left side, unable to walk.	Moderate
P5	22	3 weeks	1 year 6 months	Subdural haematoma of the biletaral frontal lobe.	Spatic quadriparesis, stronger on the left side, increased muscle tonus, reduced motility of the left hand, unable to walk.	Moderate
P6	38	1 month 3 weeks	1 year 5 months	Haemorrhagic foci in the frontal regions and in the 3rd ventricle.	Spatic quadriparesis, stronger on the right side, increased muscle tonus, no reflexes in the lower limbs, superficial sensibility decreased on the right side, flexion contracture in the right elbow joint (full stretch 60°), a clamped palm, unable to walk.	Moderate

The recordings of the speech sample were made in a quiet hospital room, with a Philips SBC MOD110 microphone, located 30 cm from the speaker and connected to a computer (Fujitsu-Siemens AMILO Pro V2030D). The subjects performed the Polish Dysarthria Test for TBI Patients (Połczyńska-Fiszer and Pufal 2006). This test investigated various aspects of spoken language, such as:

(a) Polish vowels /a/, /ɛ/, /i/, /o/, /u/, /ɨ/ produced in isolation.

(b) Consonants in a single syllable and in a tri-syllabic string.

(c) Pronunciation of single words (naming pictures, phonological fluency task).

(d) Repetition of four short stories and, e.g. *Szczepan Szczygieł z grzmiących Bystrzyc przed chrzcinami chciał się przystrzyc* /ʃtʃɛpan ʃtʃɨɟɛw z gʒmjɔ̃tsɨx bɨstʃɨts pʃɛt xʃtɕinami xtɕaw ɕɛ pʃɨstʃɨts/ ‘Szczepan Szczygieł from thundering Bystrzyce wanted to get his haircut done before the day of baptism’.

(e) Spontaneous speech – retelling two short stories: about a severely ill king and a highlander and his dog – verification of fluency, phonation, qualitative sound analysis.

To verify the hypothesis that individuals with TBI with APs who centralise vowels will also have problems with incomplete stop production, all the recorded data were analysed in the following way:

(1) Frequency of APs in all the tasks in all the patients.

(2) Frequency of types of APs in all the tasks in each patient individually.

(3) Frequency of types of APs in all the tasks, measured in percentages.

(4) Frequency of types of APs in each patient individually, measured in percentages.

(5) Frequency of types of APs used in word-initial, -medial and -final position in all the tasks and all the patients, measured in percentages.

(6) Frequency of APs on mobile and stable consonants in all the tasks together and in word-initial, -medial and -final position, measured in percentages.

Vowel centralisation and incomplete stop articulation were both determined perceptually and acoustically. A given vowel was perceptually classified as centralised when it

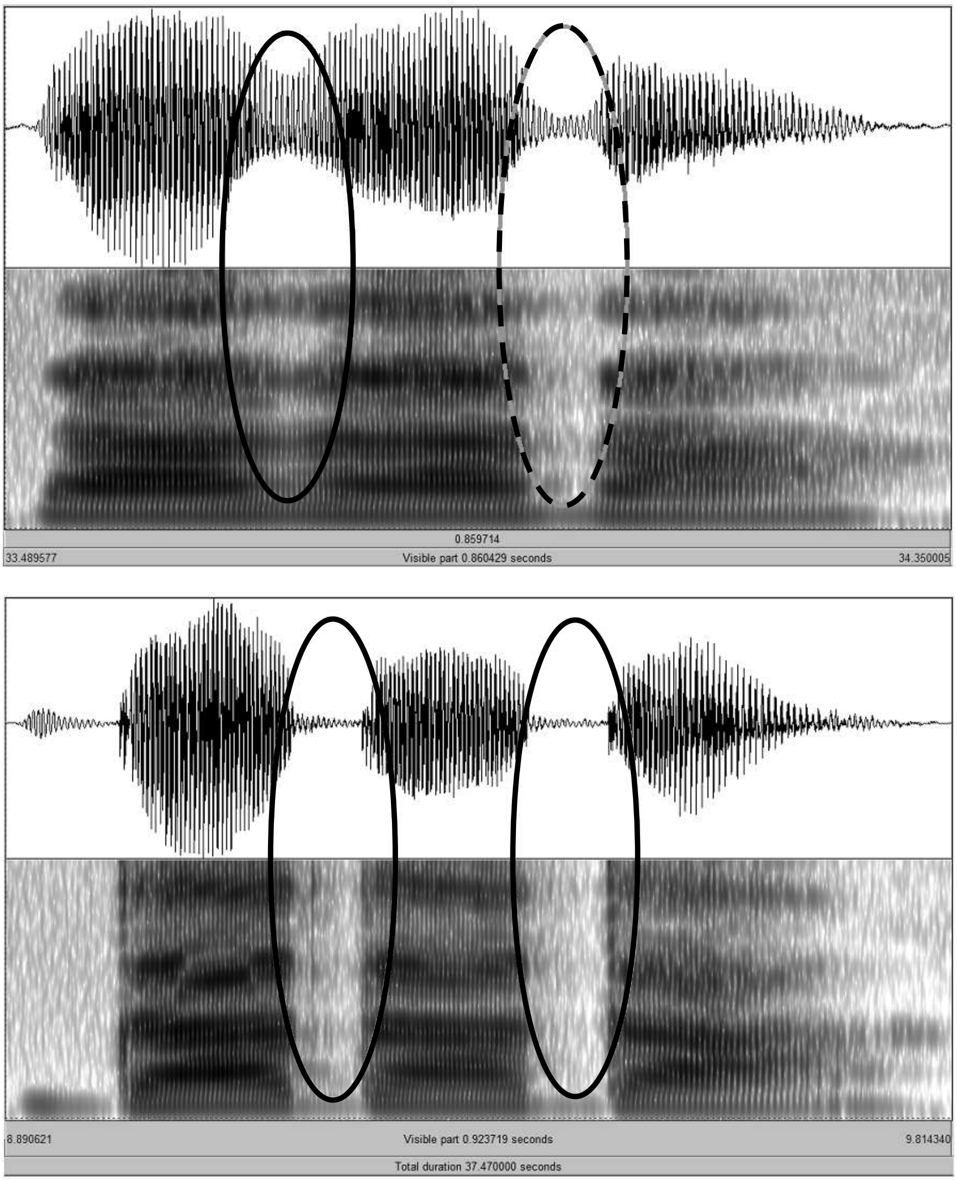

Figure1. ICC and spirantisation in the trisyllabic string ‘dadada’. **Top:** The phrase ‘dadada’ produced as /ðaðaď̯a/ by a TBI patient. Spirantisation is marked with a solid line, and ICC with a dashed line. ICC has a higher degree of sound wave approximation than spirantisation. Spirantisation, in turn, had a darker and more irregular signal on the spectogram than ICC. The signal pattern for ICC was less intense. **Bottom:** The phrase ‘dadada’ produced by a control subject. The solid line indicates voiced stops with no processes. Sound wave approximation is very small and there is a very light pattern on the spectorgam.

was realised as /ə/ or /ɨ/. In acoustic analysis, we looked at values of the first (F1) and the second (F2) formant of a vowel. If, for example, a vowel /o/ was produced within standard average formant values of /ə/ or /ɨ/ (see Figure2), it was assessed as being centralised. Incomplete closure of the articulators for stop consonants was determined in the following cases:

(1) Spirantisation – when a stop consonant was produced as a fricative.

(2) ICC for mobile (stop) consonants – when a stop consonant had an insufficient closure and a more refined approximation of articulators was made. However, an intended stop was still discriminated by a listener because it was produced within the phonemic boundaries of the target stop consonant. Thus, perceptually, with ICC the intended stop was still easily recognised as a stop, whereas with spirantisation, the stop consonant was articulated as a homorganic fricative. In acoustic terms, ICC has a higher degree of sound wave approximation than spirantisation (the degree is the highest for stop consonants). Spirantisation, in turn, has a darker and more irregular signal on a spectogramme than ICC. The signal pattern for ICC is intense, with a very limited signal for voiceless stop phonemes and an even weaker signal for their voiced counterparts (see Figure 1).

3. Results

As shown in Table 2 overleaf, the MOD group had an average value of 49.6 instances of incomplete stop production and 16.3 occurrences of vowel centralisation. In contrast, the MILD group produced incomplete stop articulation only 5.3 times and had no instances of vowel centralisation. All the subjects had more spirantisations than ICCs. In MOD, spirantisations were produced on average 28.3 times and ICC – 19.3 times. However, in MILD, spirantisation occurred on average only 5 times and ICC occurred 0.3 times. Two subjects from MILD did not produce ICC at all.

Table 3 overleaf presents the results in percentages obtained for the occurrence of vowel centralisation and incomplete stop articulation in relation to all the remaining types of APs used by the TBI subjects. In MOD incomplete stop articulation was applied 25.4% and vowel centralisation was used 8.5%. MILD produced incomplete stop articulation 29.8%, which is nearly one-third of all the APs used. Table 4 on p. 291 shows that MOD produced on average 26.3 types of APs, compared with MILD who produced only 8.6 types of APs.

Individuals with TBI produced more APs on mobile (58.1%) than on stable phonemes (41.9%), although the former group of consonants is smaller – it includes six stops and six affricates, as opposed to nine fricatives and six sonorants. It is not surprising however that there are more stable phonemes than mobile phonemes in Polish and

Table 2. Occurrence of vowel centralisation and incomplete stop articulation in the six individuals with TBI.

Patient	Process	No. of occur.	Vowel centralization vs. incomplete stop productions	Inter-group comparison (average values)
P1	Spirantisation	7	7	Incomplete stop articulation: 5.3 Vowel centralization: 0
	ICC mobile	0		
	Vowel centralisation	0	0	
P2	Spirantisation	6	6	
	ICC mobile	0		
	Vowel centralisation	0	0	
P3	Spirantisation	2	3	
	ICC mobile	1		
	Vowel centralisation	0	0	
P4	Spirantisation	22	42	Incomplete stop articulation: 49.6 Vowel centralization: 16.3
	ICC mobile	20		
	Vowel centralisation	23	23	
P5	Spirantisation	29	63	
	ICC mobile	24		
	Vowel centralisation	20	20	
P6	Spirantisation	19	33	
	ICC mobile	14		
	Vowel centralisation	6	6	

Table 3. Occurrence of vowel centralisation and incomplete stop articulation in % in relation to all the remaining types of processes in the six individuals with TBI.

Patient	Process	Occur. %	Vowel centralization vs. incomplete stop productions in %	Inter-group comparison (average values)
P1	Spirantisation	39.1	39.1	Incomplete stop articulation: 29.8 Vowel centralisation: 0
	ICC mobile	0		
	Vowel centralisation	0	0	
P2	Spirantisation	20.6	20.6	
	ICC mobile	0		
	Vowel centralisation	0	0	
P3	Spirantisation	20	30	
	ICC mobile	10		
	Vowel centralisation	0	0	
P4	Spirantisation	10.4	19.9	Incomplete stop articulation: 25.4 Vowel centralisation: 8.5
	ICC mobile	9.5		
	Vowel centralisation	10.9	10.9	
P5	Spirantisation	15.2	29.2	
	ICC mobile	14		
	Vowel centralisation	11.6	11.6	
P6	Spirantisation	18.8	27.3	
	ICC mobile	8.5		
	Vowel centralisation	3.1	3.1	

Table 4. Number of types of processes used in the speech of the six individuals with TBI.

Patient	Number of types of ariculatory patches	Type of dysarthria	Average no. of types of processes per group
P1	10	Mild	
P2	8	Mild	8.6
P3	8	Mild	
P4	31	Moderate	
P5	26	Moderate	26.3
P6	22	Moderate	

other languages. If we take fricatives as the quintessential stable phonemes and stops as the quintessential mobile phonemes we observe both on the IPA chart and in the phoneme inventories of most languages a larger number of fricatives than stops. This is probably because not all adjacent active articulators can actually physically touch each other to achieve complete closure while they can approach each other to modify the flow of air with various degrees of stricture. It is further interesting to note that in typical L1 acquisition stops are easier to acquire than fricatives and are acquired earlier than their homorganic fricative (and affricate) counterparts. The atypical TBI dysarthric population under discussion here differs from typical L1 speakers in that they find it more difficult to achieve complete closure. It is well-known that one of the earlier and most common L1 processes for typical populations is "stopping": i.e. the substitution of fricatives (and affricates) by stops which is the opposite of spirantisation. This tendency was present irrespective of the position in the word – in initial position there were 51.3% of operations on stops, in medial position – 56% and in the final position – 65.6% (see Tables 3, left, and 5, overleaf).

Concerning word position, incomplete stop articulation occurred most frequently in word-initial position – 30.8%, followed by 22% in word-medial position and 7.7% in word-final position. ICC mobile was applied 12.7% in word-initial position, 10% in word-medial and 5.1% in word-final position. Spirantisation occurred 18.1% word-initially, 12% word-medially and 2% word-finally. Vowel centralistion did not occur in word initial position and it was used 10% in word-medial and final positions. Figure 2 overleaf depicts vowel centralisation word-medially in *spodnie* /spodɲɛ/ 'trousers' produced as /pədɲɛ/ by patient P4. The mid back vowel /o/ was centralised to schwa. The distribution of processes in various positions of the word is illustrated in Table 5.

Spirantisation was the most frequently applied AP among the 25 processes appearing in this position. If we add ICC mobile, which as the third most commonly applied AP (12.7%), incomplete stop articulation will constitute nearly one third (30.8%) of

Table 5. Occurrence of vowel centralisation and incomplete stop articulation in % in word-initial, -medial and -final position in the six individuals with TBI.

Position in the word	Process	Nr of occurrences in % (in relation to all the remaining processes)	Vowel centralization vs. incomplete stop productions in % (in relation to all the remaining processes)
	Spirantisation	18.1	30.8
Initial	ICC mobile	12.7	
	Vowel centralisation	0	0
	Spirantisation	12	22
Medial	ICC mobile	10	
	Vowel centralisation	10	10
	Spirantisation	2	7.7
Final	ICC mobile	5.1	
	Vowel centralisation	10	10

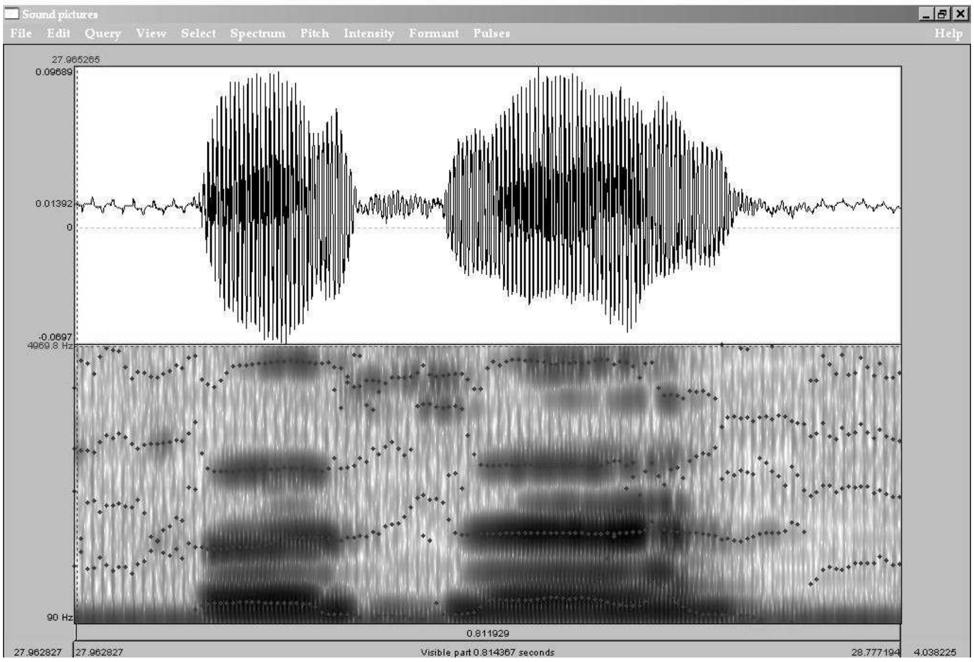

Figure 2. Centralisation of the vowel /o/ in the word *spodnie* /spodɲɛ/ 'trousers' produced as /pədɲɛ/ by the patient P4.

APs occurring word-initially. Thirty-six APs were applied in word-medial position with spirantisation again being the most frequent in word-medial position. ICC mobile and centralisation were the second most commonly used APs in this position. Only 19 APs were applied word-finally. Here, consonant deletion was the most frequent process with 25.7%. Vowel centralisation was the second most frequent AP (16.4%). ICC and spirantisation were the least frequent in this position (see Table 4).

There was a strong correlation between vowel centralisation and incomplete stop production – r = 0.90. The correlation between vowel centralisation and spirantisation was 0.89, and between vowel centralisation and ICC – 0.93. The correlation between spirantisation and ICC was 0.97 (see Table 6).

Table 6. Correlations between processes in six individuals with TBI.

Process	Process	r =
Vowel centralisation	Spirantisation	0.89
Vowel centralisation	ICC	0.93
Vowel centralisation	Incomplete stop articulation	0.90
Spirantisation	ICC	0.97

4. Discussion

The results of the study confirm our hypothesis that individuals with TBI who produce vowel centralisation will also have problems articulating complete closure in stop consonants. The individuals with MILD did not centralise vowels and produced only a few instances of incomplete stop articulation, whereas the individuals with MOD produced both APs much more frequently, as well as in relation to all the remaining APs used by the TBI patients.

As previously mentioned, there were more APs performed on mobile (58.1%) than on stable phonemes (41.9%), in spite of the fact that the former group of consonants is much smaller. Mobile phonemes were modified the least in word-initial position. A possible explanation for this skewing, with respect to the theory of PHB, is that mobile stops provide a more extreme acoustic signal (a break rather than the more random, often relatively weak, turbulence of stable fricatives) in the stream of speech and they were retained in initial position – the position that carries the highest load of communication (Diver 1979; Tobin 1997). Moreover, stops are favoured in initial position because it is easier to open a syllable with a stop (Tobin 1997). The APs on stops were the most frequent in word-final position where the communication load is the lowest (Diver 1979; Tobin 1997), in spite of the fact that there are more fricatives in general and in the coda position in particular since it is easier to close a syllable with a fricative (Tobin

1997). Thus, it appears that word position, as well as the degree of communicative strength, influence the distribution of APs in post-traumatic dysarthria.

Post-coma individuals exhibit problems with the control over their articulatory musculature. This lack of control results in difficulties with the production of stop phonemes. Stops are considered the easiest consonants to produce because they are the first consonants acquired in L1. Stops also have maximum contrast with vowel sounds which emerge first in L1 (Vihman 1996). Conversely, fricatives require more accuracy and articulatory control in order to maintain a relatively narrow separation between articulators. Therefore in L1 acquisition stops are acquired first followed by homorganic fricatives and affricates. Sustaining a stationary or stable gesture without altering the degree of aperture is difficult for TBI individuals who have less muscle control resulting in more limited articulatory skill. Therefore, they consequently produce stops as homorganic fricatives which most strongly resemble stops among all the other consonants phonemes available to them, i.e., post-traumatic dysarthric individuals have the opposite order of acquisition than that found in L1. It should be further mentioned that TBI individuals still maintain a phonemic distinction between their spirantised stops and their fricatives; thus, their phonemic system is complete; hence, their spirantisation of stop consonants is a phonetic rather than a phonemic error. While spirantisation is infrequent in child speech, stopping, which is the opposite process, is one of the most common processes found in L1 acquisition (cf. Tobin 1997).

ICC is an AP reflecting the inability of TBI individuals to produce precise movements of the tongue, leading to the underarticulation of a given consonant, with the phoneme still being discriminated. Therefore, the ICC process may be considered as a milder version of spirantisation. A sample of spontaneous speech task with an extensive usage of ICC and spirantisation is presented below.

(1) *Baca wybrał się za swoim psem po nowy garnitur. Zostawił go u przyjaciela. Kupował garnitur. Wrócił po niego... wrócił po psa, ale pies go nie... nie poznał – był tak ubrany... stare, góralskie rzeczy... Pies go... Cieszył się i go rozpoznał.*

/ˈbaˈtsa̯ (0.39) ˈvɨˈɣ̯̆ř̯o (0.25) ʃɛ̃ sə ˈsfoɪ (0.47) foim psɛm (0.44) po novɨ karˈɲitŭ̯ ‖ (0.62) zoˈstaviw̯̆ ˈxu pʃɨjəˈɕtɕɛla ‖(1.9) kụˈpoᶠɣ̯̆oᶠ kař̯ˈɲituř̯ ‖ (0.52) ˈɣ̯̆ř̯uʃɕi ɣ̯̆ ˈɲɛ̃ko (0.34) ˈvř̯ᶠutɕu (0.32) po pə̣ˈsa | ˈalɛ pjɛz ko ɲɛ (0.33) ɲɛ ˈpoˈznaʊ (0.84) ɣ̯̆ɨl̯̆ θak ub̯̆ˈř̯an (0.5) ˈtuˈw̯̆ɛɕɛ (0.30) ˈstař̯ə | (0.39) kəˈř̯alskjɛ (0.35) ʃɛt̯̆ʃ (0.46) ‖ pjɛs ɣŏ̯ (0.25) ‖ ˈtɕɛʒɨw ɕɛ̣ (0.44) ɕɛ̃ (0.77) ‖ i ɣo rəsˈp̯̆ɨᶠznaw̑/

Vowel centralisation is another idiosyncratic process among children who generally neutralise vowels to /a/, the vowel which is both the simplest to produce as well as the most common across the world's languages (cf. Stemberger 1992). Vowel centralisations in L1 acquisition have been reported by Kent and Murray (1982) who observed that the majority of vocalic utterances produced by the child between three to nine months of age have a central or a mid-front location, which corresponds to schwa in adult speech. However, at this stage of development, the child has anatomical limitations resulting in a very tiny vowel space that corresponds to central and mid-front phonemes of adults (Kent and Murray 1982; Vihman 1996; Vorperian et al. 2005). Although the articulatory anatomy of TBI individuals is usually intact, they tend to produce vowels as central, just as infants between three to nine months of age. This is because TBI individuals suffer from a muscular debility of the articulators caused by a partial damage to cranial nerves that innervate the articulatory musculature, specifically, the hypoglossal nerve (tongue movements), facial nerve (lip movements), trigeminal motor nerve (jaw movements), as well as other nerves innervating the extrinsic tongue muscles (e.g. styloglossus, palatoglossus, geniohyoid). Hence, they are unable to produce processes involving alternations of the positions or the placement of the tongue, such as lowering, rising, backing and fronting. Instead, they centralise their vowels. However, just as they retain a difference between their spirantised stops and their fricatives, TBI individuals maintain a phonetic distinction between centralised vowels versus phonemic central vowels. This is especially evident in less complex tasks in which the subjects were asked to produce vowels in isolation or in monosyllabic words, where the overall number of APs was relatively smaller compared to more complex tasks, such as repetitions of short stories or spontaneous speech. The following are examples of vowel centralisation:

(2) P4: *kama ma makaka* /xamə mə məkaka/, *makaka ma kama* /makəkə ma xama/

(3) P5: *mamama* /ˈmam̺̆əm̺̆əm̺̆əm̺̆ə/, *nanana* /ˈnan̺̆ən̺̆ən̺̆ə/, *góralskie* /kəˈr̺̆alskjɛ/, *rozpoznał* /rəsˈp̺̆ɨznaw/, *makaka ma kama* /makaka m̺̆əm̺̆am̺̆a/, *dama ma makaka i kakadu ma* /͡ˈdam̺̆ə m̺̆a ˈkaxa i ˈkaxaðuˈ˘͜a/

(4) P6: *mamama* /m̺̆əm̺̆əmã/, *zazaza* /səsasa/

(5) *???[1] koszulę ??? wysłał (...) król ??? wysłał (...) król był chory ??? nie znalazł ??? ??? nie mógł założyc ? król koszulę całego ??? ??? ???*

(6) /na tsa k̺̆ɨ ˈʃɛˈʒɨw ˈwɨˈsɨ (4.7) kuː ˈbɨʊˈɣ̺̆oː ˈtɨˈtɨˈw̺̆ɨˈʃɨˈtɨ̃ː ɲɛ zãs ɲiʃʧ̆ ˈʒɨ̃ʃɨˈʃɨ̃ˈt̺̆o ˈn̺̆ɛ̃͜˘ɛ̃ˈsɛ̃ˈsɛ̃̆sə tsu ku͜˘ ˈkɨˈʃɛ ˈtsw̺̆ɛɣo aˈpɛˈw͡ɨʃɨʃəwoː ˈʃɨˈzɨ̃ʃɨ͜˘ɛ̃ a tˈsaːˈɣ̺̆o ͡ˈtsɛˈtsoˈɣ̺̆õː ˈʧɨɛ̃ ˈtsuˈɣ̺̆ɛ̃ː ˈsaɣ̺̆ɨn̺̆ã ɛ̃/

Figure 3 illustrates vowel centralisation of patient P6 in the form of a vowel chart. It is quite evident that the vowel space of the subject is considerably centralised, compared to a vowel chart of Polish speakers without dysarthria (Bogacka et al. 2006).

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[1] This is a sample from a spontaneous speech task. *?* stands for incomprehensible productions. The patient centralises many of his vowels to /ɨ/ and /ə/.

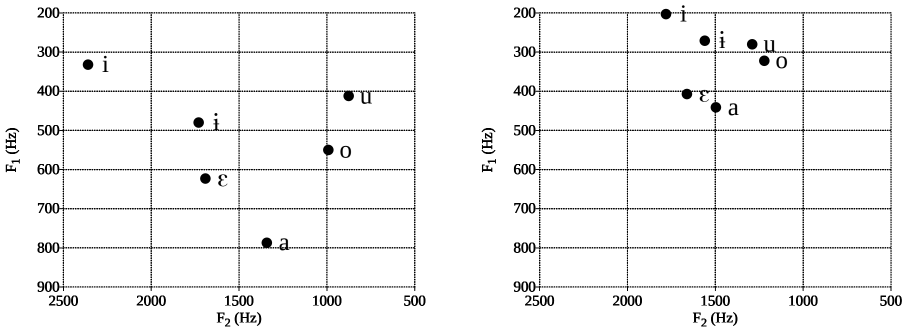

Figure 3. The Polish vowel chart (left, based on Bogacka et al. 2006) and a vowel chart for patient P6 (right), showing vowel centralisation.

The results have shown that incomplete stop articulation (spirantisation and ICC mobile) was the most frequent AP in word-initial position. This finding indicates that in a position in which the force of communication is the highest, TBI individuals applied APs that are not radical (many features of the target sound are still retained). These two APs were less commonly used in word-final position, where deletion, which is a much more extreme AP, was applied with the highest frequency. Word-final position carries the lowest amount of communicative force, therefore, more radical APs are found. Similarly vowel centralisation did not occur in word-initial position and was a common AP in word-medial and final positions. Another reason why vowel-centralisation was absent word-initially might be that the basic syllable is CV and consequently there are fewer words which begin with a vowel, hence operations on consonants were more frequent in this position. Here, again, word position and the force of communication influenced the distribution of APs.

Although the results suggest a clear correlation between incomplete stop articulation and vowel centralisation in moderate dysarthria, further research including a greater number of subjects is necessary to clarify at which point of speech recovery after TBI underarticulations become the most common process. We have shown that in MOD incomplete stop production and vowel centralisation constituted together one third of all the applied processes. It appears that subject P5, whose pronunciation was assessed as more comprehensible according to standard tests used in Polish clinics, had the strongest ratio of underarticulations in relation to all the remaining processes (40.8%). The remaining two subjects from MOD were generally less comprehensible and had a slightly lower ratio: P4 – 30.8%, P6 – 30.4%. We hypothesise that there is a certain point in the post-TBI recovery process at which there is a particularly strong correlation between incomplete stop production and vowel centralisation. As the patients further improve their articulation, vowel centralisation becomes less frequent and the link between the two processes becomes weaker. Further research should be carried out to examine this hypothesis.

5. Conclusions

In the present study, we investigated the hypothesis that TBI individuals who centralise vowels will also have difficulties with producing stop consonants. MOD produced a considerably higher number of vowel centralisations and incomplete stop productions than MILD. MOD produced a considerably higher number of incomplete stop productions and vowel centralisations, whereas MILD used incomplete stop articulation only occasionally and had no instances of vowel centralisation. The present findings are consistent with the hypothesis that TBI individuals who centralise vowels also have problems with incomplete stop production. These two APs are very common in individuals with MOD. MILD subjects who produce just a few types of APs do not centralise vowels and only produce incomplete stops rather occasionally. Individuals with TBI performed more APs on mobile than on stable phonemes, although the former group of consonants is smaller.

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