PHONETIC PROCESSES AND THEIR INFLUENCE ON SPEECH INTELLIGIBILITY IN DYSARTHRIC SPEECH AFTER TRAUMATIC BRAIN INJURY: A LONGITUDINAL CASE STUDY

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ABSTRACT

Significant changes in dysarthric speech can be achieved many years post-onset of traumatic brain injury (TBI). Individuals with TBI dysarthria frequently apply phonetic processes (PPs) that are viewed as speech errors. This study reports the results of two Examinations (E1, E2) of PPs and their influence on the speech intelligibility rate at 12 (E1) and 50 (E2) months post-coma in ML, a 26-year-old Polish individual with TBI dysarthria. ML performed the *Polish Dysarthria Test for TBI Patients.* The recordings were transcribed phonetically and analysed acoustically. We also carried out a perception study in which 48 naïve native Polish listeners judged ML's speech intelligibility based on recordings from E1 and E2. The results show a significant improvement in ML's intelligibility. The frequency of occurrence of PPs in E1 and E2 was nearly the same, as was the number of types of PPs. However, in E2 ML applied more types of PPs that had a higher communicative force [16], and were less radical [9]. To conclude, considerable speech improvements in TBI dysarthria may still be achieved several years post-trauma.

Keywords: dysarthria, TBI, phonetic processes, intelligibility

1. INTRODUCTION

Dysarthria after severe Traumatic Brain Injury (TBI) may lead to a variable combination of impairments of the speech musculature affecting articulation, phonation, respiration and resonance [4, 15, 18, 19]. TBI individuals have temporal and spatial difficulties in speech production that may be attributed to distorted speech motor control, impaired accuracy, increased articulatory effort, reduced oral tactile and/or kinesthetic sensation of articulators, and impaired co-ordination of articulatory gestures [1, 5].

TBI individuals with dysarthria frequently apply Phonetic Processes (PPs) [7, 8]. PPs are speech errors that involve simplifications of those speech sounds that are difficult to articulate. PPs are idiosyncratic and they mirror the articulatory difficulties of the speaker [16].

According to Natural Phonology (e.g., [14]) and Phonology as Human Behaviour (e.g., [16, 17]) and a combination of both theories [11] processes are divided into: (1) *Substitutions* (e.g., stopping), (2) *Assimilations* (e.g., consonant harmony), and (3) *Changes in syllable structure* (e.g., consonant cluster reduction). Based on her research on clinical populations, Połczyńska (e.g., [7]) added three more types of PPs: (4) *Underarticulations* (e.g., Incomplete Consonant Closure, ICC), (5) *Changes in articulatory force* (e.g., hyperarticulation), and (6) *Consonant Approximation* (CA). CA denotes only a slight approximation of articulators appearing in contexts where a consonant phoneme is expected. It is a pre-process since it is an indicator of a consonant that can only be observed with acoustic instrumentation.

PPs differ in terms of communicative force and can be categorised from the highest to the lowest communicative power based on the following four levels presented according to their descending order of communicative force:

Level 1: underaticulations and changes in articulatory force,
Level 2: substitutions and assimilations,
Level 3: syllable structure changes,
Level 4: CA [cf. 10, 12, 16].

TBI dysarthria may persist for years post-coma [6]. The aim of this study was to investigate PPs and their influence on speech intelligibility in a dysarthric TBI individual.

2. METHODS

2.1. The subject

ML is a native Polish speaking 26-year-old male TBI individual with dysarthria. At the age of 21, ML studied dentistry. He suffered traumatic brain injury due to a sports injury. He was comatose for three weeks. A CT scan showed brain stem damage and subdural haematoma of the right fronto-temporal lobe. The first of the two examinations (E1) was performed 12 months post-coma. ML was then diagnosed with moderate post-traumatic dysarthria and moderate post-traumatic aphasia. Since awakening from coma until the second examination (E2), 58 months post-coma, ML underwent an intense holistic rehabilitation programme (four to six hours a day) that included speech therapy. Every six months he participated in a two-week-programme in a rehabilitation centre. After each programme ML received a new set of exercises from his speech therapists. ML had one meeting with his language-speech therapist a week. Each day for 20 to 30 minutes he performed exercises that involved loud articulation of phonemes in different phonetic contexts (syllable strings, polysyllabic words, sentences). Six times a week ML had face-articulator massages by his caretakers for 15 minutes. Fifty-eight months post-coma ML suffered from mild post-traumatic dysarthria and no aphasia.

2.2. Procedure

2.2.1. Articulation study

Recordings of ML's speech for E1 were conducted with a Fujitsu-Siemens AMILO Pro V2030D computer. In E2 we used an Asus Eee PC Seashell computer. The microphone was located 30 cm from the speaker. Each recording procedure lasted ~ 25 minutes.

During each examination ML performed the *Polish Dysarthria Test for TBI Patients* [8]. The obtained speech samples were analysed with Praat [2] and transcribed phonetically. PPs on vowels were investigated based on formant values. ML's formants were measured in reference to the mean F-values of Polish speakers [3]. PPs occurring in consonants were analysed spectrographically (manner and place of articulation) and by sound wave (the degree of opening/closure of the oral tract for consonant phonemes and the degree of voicing). PPs were analysed according to the extended six-category taxonomy [7] in all word positions. We calculated the total number of PPs in each study. Next, we counted the frequency of occurrence of a given PP (x%) in relation to all the PPs applied (100%). We also applied the measure of the number of PPs per 100 phonemes (PPs/100 phon).

2.2.2. Speech intelligibility study

We randomly selected 11 samples of spontaneous speech from both E1 and E2. The samples from the two examinations both contained a total of 79 words. The number of words in a single sample ranged between four to twelve. The samples were judged by 48 naïve native Polish listeners (mean age 20,47 years; SD = 2,93). The participants were asked to write down all the words that they could identify. They listened to each sample three consecutive times. All the samples were played in a random order.

We measured the amount of words recognised by the specific number of listeners in each sample to analyse ML's speech intelligibility rate. We then calculated 100% speech intelligibility for each examination by multiplying the maximum number of recognised words (79) by all 48 naïve listeners. This amounted to 3792.

3. RESULTS

3.1. Articulation study

We analysed 726 phonemes both in E1 and E2. Overall, ML applied 25 types of PPs in E1 and 27 types in E2. We found 234 PPs (32,23PPs/100phon) in E1 and 230 PPs (31,68PPs/100phon) in E2.

The most common types of PPs in E1 were: (1) substitutions – 35,40%, (2) syllable structure changes – 29%, (3) underarticulations – 22,20%, (4) assimilations – 7,20%, changes in articulatory force – 3,40%, and (5) CA – 2,50%. The most frequent subtypes of PPs were: (1) ICC – 12,82%, (2) consonant cluster reduction: 10,68%, (3) spirantisation, vowel centralisation – 9,40%, (4) consonant deletion – 8,97%, (5) devoicing – 6,41%, (6) unstressed vowel deletion (4,70%), (7) stopping of fricatives – 4,27%, (8) vowel nasalisation – 2,99%, (9) vowel fronting, vowel raising, hyperarticulation – 2,56%, (10) glottalisation – 1,70%. The remaining PPs occurred 1,28% or less (see Table 1).

Table 1: Frequency of occurrence of phonetic processes applied ML at 12 months post-coma (E1) and at 58 months (E2).

Phonetic Process	E1	E2
Spirantisation of stops	9,40%	9,56%
Deaffrication	6,41%	3,91%
Glottalisation	1,70%	2,60%
Stopping	4,27%	1,73%
Consonant fronting	2,56%	1,73%
Consonant backing	0,85%	0%
Vowel nasalisation	2,99%	2,17%
Gliding	0%	0,43%
Gliding of obstruents	0,85%	0,43%
Spirantisation of sonorants	0%	0,43%
Vocalisation	0,85%	0,43%
Vowel backing	0%	0,43%
Vowel fronting	2,56%	0,43%
Vowel raising	2,56%	0,43%
Vowel neutralisation	0,42%	0%
ICC	12,82%	27,80%
Vowel centralisation	9,40%	19,10%
Sibilant imprecision	0%	6,52%
CA	2,56%	4,34%
Consonant cluster reduction	10,68%	3,04%
Vowel epenthesis	0,42%	1,30%
Consonant epenthesis	0%	1,30%
Unstressed vowel deletion	4,70%	3,04%
Consonant deletion	8,97%	0,86%
Stressed syllable deletion	2,99%	0,86%
Reduplication	1,28%	0%
Devoicing	6,41%	0,86%
Voicing	0,85%	2,17%
Consonant harmony	0%	1,30%
Hyperarticulation	2,56%	2,60%
Weak articulation	0,85%	0%

The most frequent types of PPs in E2 were: (1) underarticulations – 53,40%, (2) substitutions – 25%, (3) syllable structure changes – 10,40%, (4) assimilations, CA – 4,30%, and (5) changes in articulatory force – 2,60%. The most commonly applied subtypes of PPs were: (1) ICC – 27,80%, (2) vowel centralisation – 19,10%, (3) spirantisation – 9,56%, (4) sibilant imprecision – 6,52%, (5) CA – 4,34%, (6) deaffrication – 3,91%, (7) consonants cluster reduction, stressed vowel deletion – 3,04%, (8) glottalisation, hyperarticulation – 2,60%, (9) vowel nasalisation, voicing – 2,17%, (10) stopping, consonant fronting – 1,73%. The remaining PPs occurred 1,30% or less (see Table 1).

Hence, ML employed different PPs comparing E1 and E2 which indicate improved articulation. This was further supported by the results of the perception study.

3.2. Perception study

The results of the perception study of the 11 speech samples from E1 showed 447 “zero words recognised”, 26 “one word recognised”, and 33 “two words recognised”: i.e., 92 recognised words out of 3792 words. ML’s intelligibility rate in E1 was 2,40%.

The analysis of the 11 speech samples from E2 show 92 “zero words recognised”, 110 “one word recognised, 65 “two words recognised”, 33 “three words recognised”, 45 “four words recognised”, 34 “five words recognised”, 24 “six words recognised”, 20 “seven words recognised”, 9 “eight words recognised”, and 6 “nine words recognised”: i.e., 985 recognised words out 3792 words. ML’s intelligibility rate was 25,90%.

4. DISCUSSION AND CONCLUSION

In this study we investigated PPs and their influence on speech intelligibility in a dysarthric TBI individual 12 and 50 months post-coma. The frequency of occurrence of PPs in E1 and E2 was nearly the same as was the number of types of PPs applied by ML in both studies. Yet, ML significantly improved his speech intelligibility over the investigated period, which was demonstrated by comparing and contrasting both E1 and E2.

The results of E1 clearly indicate that more communicative PPs were applied in E2 compared to E1. ML employed 25,6% of Level 1 (the most communicative) PPs in E1. This result doubled in E2 – 56%. Level 3 and 4 (the least communicative) PPs occurred 31,5% in E1 and only 14,7% in E2. Thus, we observed a major shift from PPs with the lowest communicative force to PPs with the highest communicative power (the most common PPs in E2).

A closer analysis of the subtypes of PPs shows that the most common PPs in E1 were ICC, consonant cluster reduction, spirantisation, vowel centralisation and consonant deletion. The PPs represent different levels of communicative force and were applied with a comparable frequency (appr. 10%). In E2, on the other hand, ICC (PP with the highest communicative force) was employed as many as 27,80%. At the same time, PPs with the lowest communicative level were applied marginally (4,34% or less). This improvement in communicative force was confirmed by the results of the perception study.

In the perception study we observed a significant difference in ML’s intelligibility rate between E1 and E2. The rate increased from 2,40% in E1 to 25,90% in E2. This result demonstrates that the occurrence of different PPs in dysarthric speech may lead to different intelligibility ratings by listeners.

According to Safaz, et al. [13] group studies of TBI individuals are uncommon because the pattern and severity of dysarthria extensively vary in this population. Indeed, in a study investigating dysarthria in six TBI individuals, every patient had a different combination of standard dysarthria types [8]. At the same time, significant changes in speech can still be achieved many years post-onset of TBI [20, 21]. This has been observed in our study.

To conclude, our data indicate that considerable speech improvements in post-TBI dysarthria may still be achieved several years post-trauma. In the course of 38 months, our subject improved his speech intelligibility by applying a higher number of the most communicative phonetic processes and significantly reducing the occurrence of the least communicative processes.

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