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Original Scientific Paper

WORD PROCESSING ABILITIES IN SUBJECTS AFTER STROKE OR TRAUMATIC BRAIN INJURY

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SUMMARY – Acquired language disorder is a common consequence of stroke and traumatic brain injury (TBI). Following the logogen model, this study investigated word processing abilities of post-stroke and post-TBI patients. Within- and between-group differences in word comprehension, naming, and reading were observed, as well as predominant errors in performance. Twenty-two post-stroke and 22 post-TBI patients were tested using tasks from the Comprehensive Aphasia Test-HR (CAT-HR). Post-TBI patients outperformed post-stroke patients in naming and reading. Both groups exhibited neologisms, phonological, semantic and unrelated errors, although in different proportions. In word comprehension and naming, post-TBI patients primarily exhibited semantic errors, whereas post-stroke patients had equally distributed phonological and semantic errors. In reading, both groups predominantly produced phonological errors. Error distribution differed only in naming, with post-TBI patients exhibiting more semantic errors than post-stroke patients. Therefore, performance in naming differentiated these groups most. Although error analysis is rather insightful, one cannot expect a particular profile of language disturbances in post-stroke and post-TBI patients. The findings obtained bear concrete clinical implications, especially those related to the role and meaning of the errors produced by the patient to determine the exact location of the processing deficits.

Key words: *Stroke; Traumatic brain injury; Word processing; Error analysis; Logogen model*

Introduction

According to the World Health Organization (WHO)[1], neurological disorders constitute 6.3% of the global burden of disease and, in 2005, contributed to 92 million disability-adjusted life years (DALYs), which is projected to increase to 103 million by the year 2030 (an approximate increase by 12%). Moreover, neurological disorders are a significant cause of mortality. In 85% of neurological disorders, the cause of death is attributed to cerebrovascular disease and traumatic brain injury (TBI), making them the leading cause of years of healthy life lost as a result of disability. Such high percentages justify the importance of investigating the consequences of various neurological disorders. The present study goes in line with the growing body of medical and neurological literature that aims to describe and compare the phenomenology of two neurological disorders of different causes, stroke and TBI[2,3], and contributes to the insufficient literature on these two acquired disorders in the field of speech-language pathology.

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Stroke is a clinical syndrome characterized by sudden development of a focal neurological deficit of vascular etiology[4]. WHO[1] reports that in developed countries, 75%-80% of strokes are attributed to brain ischemia, 10%-15% represent primary intracerebral hemorrhage, and approximately 5%-10% are subarachnoid hemorrhage. Stroke is the second most common cause of mortality worldwide, the third most common in more developed countries after coronary heart disease and cancer[5,6], and the first cause of death in Croatia, as well as the first cause of disability in both Croatia and the world[7]. Nearly half of all stroke survivors are dependent on someone else's help. In almost all countries, stroke incidence increases with age, with the highest rates in the ≥85 age group[8], and it is somewhat more frequent in men than in women. Nevertheless, stroke can affect men and women of any age, and in recent years the age limit of persons experiencing stroke has started to decrease.

Traumatic brain injury is a head injury caused by physical trauma or external forces, which results in impaired brain function[9-11]. According to the WHO[1], TBI is the leading cause of death and disability in children and young adults around the world and is involved in nearly half of all trauma deaths. The estimated European incidence of TBI in the last decade was 235:100,000 *per* year[12]. Estimates from the United States indicate that 1%-2% of the population, i.e., around five million people, live with a TBI disability[13,14]. Men are injured 2-3 times more often than women, and falls and traffic accidents are the leading cause of TBI[10]. Around half of survivors who experienced mild or moderate TBI, and three-quarters of survivors after a severe injury, become disabled[15]. Even among young patients with mild injuries and a good pre-injury status, one-third fails to achieve a satisfactory recovery.

Neurological disorders such as stroke or TBI are a major cause of long-term disability and potentially have an enormous emotional and socioeconomic impact on patients, their families, and health services. Persons affected either by stroke or by TBI have to suffer years of disability, and many years of their productive lives are lost due to the brain injury. Stroke and TBI survivors experience a large spectrum of consequences (i.e., motor, sensory, and cognitive difficulties, hearing, voice, speech and swallowing disorders, etc.), among which the acquired language disorder is rather common as well.

Language Abilities after Stroke and TBI

Acquired language disorder caused by brain damage that impairs a person's ability to understand, produce and use language is called aphasia[16,17]. Symptoms of aphasia are related to varying degrees of the disturbance of language skills (comprehension, production, reading, and writing) and language components (phonology, morphology, syntax, semantics, and pragmatics) making the affected population very heterogeneous. Persons with aphasia after stroke differ in their abilities of language production, and basic aphasia classification on fluent and non-fluent is based on these distinct properties[18]. Symptoms depend on the location and extent of injury, and on the situation in which communication takes place. Although non-linguistic abilities such as memory and executive functions can be sometimes preserved in post-stroke aphasia patients[8], there is a large body of evidence suggesting that most people with aphasia also have impairments in these abilities[19-23]. Accompanying sensory difficulties (auditory and visual agnosia and visual neglect), as well as additional diagnoses such as dysarthria, apraxia, dysphonia, and dysphagia, are rather frequent.

It is generally considered that language disorders of TBI patients are mild and that these individuals have greater difficulties in achieving successful communication, although the morpho-syntactic structure of their sentences is mostly preserved[10]. Pragmatics, i.e., the use of language, may be preserved in case of a minor TBI, whereas moderate and severe TBI can lead to pragmatic difficulties[11] such as linguistically confused speech, presence of paraphasia and perseverations, reduced or impaired verbal fluency, difficulties in initiating and turn taking during conversations, in topic selection and maintenance, in gaining clarity and precision in a narrative[10]. Other language difficulties may exist, such as auditory comprehension disturbances or reading and writing problems, but on top of those language disturbances, speech disorders such as dysarthria, hypernasality, impaired prosodic elements of speech, breathing difficulties and non-concomitant use of air currents during speech, voice disorders and speech fluency disorders, may be present as well[10,24]. Communication difficulties after TBI are more reflected in the graphic and gestural modality than in the verbal, and possibilities for a fast and successful recovery are greater in those two modalities than in the latter[25]. It has also been confirmed that a person who experienced TBI also has working memory difficulties at the central executive level, while phonological loop capabilities are most often well preserved[26]. Although a patient is able to spontaneously recover and gradually restore initial loss of language functions, spontaneous recovery does not occur in most patients[27].

The existing literature has mostly focused on the descriptions of symptoms of these two neurological conditions separately, i.e., there was a tendency to observe the communication and language specificities of each[28,29]. This study partially followed that rationale, but its main purpose was to observe and compare in more depth the performance of individuals with brain damage resulting from different causes and to analyze their word processing abilities by focusing predominantly on error production.

Word Recognition Model and Word Processing Errors

One of the most common models that explains word processing is the logogen model[30-32]. The crucial term of the model is the logogen, a unit that is defined by its outputs, phonological, semantic, acoustic or visual. The central part of the model is the mental lexicon, i.e., a store of information about vocabulary items[33], surrounded by different representation levels among which different processes take place.

For example, there are three representation levels involved in the auditory word comprehension: 1) auditory sub-phonological level; 2) phonological input lexicon; and 3) semantic system. On the first level, speech sounds are discriminated and identified. The second level includes phonological coding of words, and on the third level, semantic, word meaning is activated in response to recognition on the previous level[32]. Therefore, in order to comprehend a word accurately and relatively fast, all three levels should be intact, as well as the interaction among them.

Oppositely, object/picture naming and reading, as productive skills, occur through the interaction of vision and language[34], and involve several representation levels. Both skills start on the visual representation level, but after the visual stimulus is discriminated and identified as either an object or a written word, the paths for the two diverge. The object presented visually (on a picture) or kinesthetically (as an actual object) will conceptually be clearly identified at the second object representation level. This identification is necessary to retrieve the correct lemma from the third, semantic level. The lemma is the trigger of phonological representation that ends with motor articulatory programming and, finally, correct articulatory performance, i.e., naming[5,32,34-36]. The second path after the initial visual representation level is reserved for reading of written words. Depending on their psycholinguistic features (such as frequency), there are two different routes of word reading, i.e., sub-lexical, which is based on phonological coding, and lexical, which is based on sight word recognition[32].

In conclusion, the logogen model attempts to explain word processing regardless of the modality through which a word is retrieved, by comprehension or production, in spoken or written input. The assumption is that if any of representation levels or an interaction between them is disabled, the system would fail in at least one language processing task. Therefore, the goal of the assessment, both for researchers and for clinicians, is to identify the disturbed and the intact processes, and to show interaction among different representation levels during word processing[32].

For example, if a person misunderstands a word, e.g., comprehends *kapa* (hat) instead of *kada* (bathtub), the examiner can conclude that there is either a disturbance on a sub-lexical phonological level, or at the levels of phonological lexicons. Additional examination with a task more appropriate for these two representation levels (e.g., auditory discrimination task, repetition of pseudowords, phonemic analysis task) would reveal the exact locus of disturbances. A person's performance and the nature of errors in certain tasks is another valid source of information that may be used to identify the locus of disturbance, and the quality of processing between the representation levels. For example, in comprehension, a phonological error occurs when a phonological distractor is chosen instead of the target word, due to the disruption between the level of phonological input lexicon and some other previously activated representation level. Choosing a semantic distractor would count as a semantic error which results from an impairment in the retrieval or activation of the appropriate lemma on the level of semantic lexicon.

Types of errors that may occur in previously described processes of word processing, i.e., comprehension, naming and reading, are as follows: 1) a failure to retrieve a word; 2) a phonological error or a response that is similar to the target in its phonological form; 3) a semantic error or a response that is semantically related to the target; 4) a neologism or a response that does not resemble the target word and has no meaning; and 5) a completely unrelated error or a word that does not share any phonological or semantic feature with the target word.

Studies that involve post-stroke subjects are numerous and confirm the existence of difficulties in comprehension on all language levels (phoneme, word, sentence, discourse) depending on aphasia type, language severity, and the location and extent of stroke[37-45]. Comprehension studies that involve post-TBI subjects mostly focus on comprehension of complex sentences indicating that post-TBI patients have difficulties processing complex, anomalous or uncanonical sentences[46-50]. There are significantly fewer studies on word level or lexical processing of post-TBI patients, and they mostly report that lower level processes are usually spared in this population[51].Boles[52] conducted a study in which he compared naming difficulties of post-stroke, post-TBI, and patients with Alzheimer's dementia. He found errors in all three groups, but phonological errors were more present in post-stroke group, semantic errors were present in both post-stroke and post-TBI groups, and the most common errors in general were semantic paraphasias.

Studies on word reading performance of different groups with acquired language disorders are rather scarce. Depending on the subtype of post-stroke aphasia, patient performance in reading aloud can vary substantially, i.e., from intact production and/or comprehension to very disturbed performance in terms of reading fluency and accuracy on the one hand, and comprehension on the other[10,53]. Reading research in persons with TBI has dealt mainly with reading comprehension of sentences and texts[54-56], or with the impact of oculomotor dysfunctions on reading abilities due to which persons with TBI make errors in reading mainly in the form of skipping lines, tracking reading places, switching to a new line, or have an impaired perception of one half of the paper due to neglect[57,58], but research on single word reading in TBI are lacking. Few studies have only proven that poorer performance is found in severe than in mild and moderate TBI, and that these difficulties may be present for at least one year after the injury[59,60]. However, none of these studies explains the language processing background of difficulties.

Study Design

Current exploratory study aimed to provide additional understanding of word processing ability in two groups of patients, those who suffered stroke (post-stroke) and traumatic brain injury (post-TBI). Following the rationale of the logogen model, special attention was paid to the errors they produce in different modalities. To examine participant performance, as well as within- and between-group differences, several questions were formed:

1) Are there between-group differences in performance on each examined task?
2) Which types of errors (phonological, semantic, neologisms, and unrelated errors) dominate in each group?
3) Are there between-group differences in the proportion of each type of errors across the four tasks?

In line with previous literature, it is expected that post-stroke patients will be less accurate than post-TBI patients on all tasks and that their errors will be manifested in higher proportions of phonologically conditioned errors. On the other hand, it is expected that post-TBI will be more accurate in general, and that they will have a larger proportion of semantically conditioned errors. Therefore, significant differences between the two groups were expected, with the prevalence of phonological errors in post-stroke patients and of semantic errors in post-TBI patients.

Patients and Method

Sample selection

The sample consisted of two groups of adult speakers, i.e., 22 post-stroke and 22 post-TBI subjects. In order to have two mutually comparable groups and to make valid conclusions about differences in their language performance, we tried to match them on demographic characteristics as much as possible. The groups were completely comparable at the level of education (measured with years of education completed) (4 subjects ≤8 years, 16 subjects 9-12 years, and 2 subjects >12 years of education) and time post-injury (12 subjects in acute phase and 10 subjects in post-acute phase of recovery). It was very difficult to perfectly match the groups across all demographic variables, therefore slight differences were evident in their gender distribution (16 male and 6 female subjects in the post-stroke group *vs*. 18 male and 4 female subjects in the post-TBI group), and mean age within each group (post-stroke 53.29 years and post-TBI 40.13 years) despite a similar age range (Table 1).

Table 1. Demographic characteristics (gender, age, time post-injury, and education level) in post-stroke and post-TBI groups

	Post-stroke (N=22)	Post-TBI (N=22)
Gender, n (%)		
Male	16 (72.73%)	18 (81.82%)
Female	6 (27.27%)	4 (18.18%)
Age (years)		
Mean	53.23 (SD=9.03)	40.14 (SD=18.08)
Range	32-66	18-66
Time post-stroke/TBI, n (%)		
≤3 months	12 (54.45%)	12 (54.45%)
>3 months	10 (45.45%); range 4-12 months	10 (45.45%); range 4-12 months
Education level, n (%)		
≤8 years	4 (18.18%)	4 (18.18%)
9-12 years	16 (72.73%)	16 (72.73%)
>12 years	2 (9.09%)	2 (9.09%)

Post-stroke = subjects having suffered stroke; Post-TBI = subjects having sustained traumatic brain injury

To test whether these slight differences according to gender and age distribution between the two samples were significant, t-test for proportions and χ^2-test were performed, respectively. No differences were found in the proportion of male/female participants in the two groups (t=-0.06; p>0.05), or in the frequency distribution according to age (χ^2=31.7; p>0.05).

Our samples were therefore rather homogeneous, although Caplan and Hildebrandt[62] suggest that a between-group age discrepancy may not be significantly relevant, as age is not a factor that influences language abilities of neurologically healthy adults. On the other hand, the level of education is a rather strong predictor of the speed of information processing after brain injury, regardless of its type and severity, i.e., people with higher education levels process information more quickly[56]. This is why education level was considered a more powerful criterion for sample selection than age, and greatest effort was put on matching the groups on this variable.

Within the post-stroke group, only individuals with right-hand dominance who experienced an ischemic stroke in the left-brain hemisphere were included in the research. Information about the type and localization of brain injury of patients in the post-stroke and post-TBI groups was obtained from medical histories and computed tomography (CT) scan records (Table 2).

As seen in Table 2, the groups were rather heterogeneous. Out of 22 patients in the post-TBI group, 11 had brain injuries as a result of traffic accidents (in the car, motorcycle, or as a pedestrian), 9 had injuries from falls, and 2 were hit by a blunt object, all of which represented non-penetrating injuries. All patients were right-handed, except for two post-TBI. Hemiparesis was present in 17 post-stroke and 7 post-TBI patients. Dysarthric symptoms were present in four post-stroke and two post-TBI patients. One subject in the post-stroke group exhibited symptoms of both apraxia and dysarthria, whereas one exhibited

Table 2. Information on type and localization of brain injury in study sample

	LH										RH			Bilateral				Diffuse
	F	FT	T	P	TP	PO	M	ACM	CR	ACI	T	TP	PO	F	FT	FP	M	FT
Post-stroke	2		2	1	3		5	7	1	1								
Post-TBI		1			2	1	1				1	1	1	2	1	1	2	8

Post-stroke = subjects having suffered stroke; Post-TBI = subjects having sustained traumatic brain injury; LH = left hemisphere; RH = right hemisphere; F = frontal; FT = frontotemporal; T = temporal; P = parietal; TP = temporoparietal; PO = parieto-occipital; M= multifocal; ACM = arteria cerebri media; CR = corona radiata; ACI = arteria carotis interna; FP = frontoparietal

only apraxia symptoms. Four post-TBI subjects exhibited visual neglect, whereas none in the post-stroke group exhibited such symptoms. All participants in both groups were monolingual speakers of Croatian.

The sample was collected in different hospitals and polyclinics in different regions of Croatia (28 participants in Krapinske Toplice Hospital for Medical Rehabilitation, 7 in SUVAG Polyclinic, 3 in Rijeka University Hospital Center, 3 in Osijek University Hospital Center, one participant in Sveti Duh University Hospital, one in Split University Hospital Center, and one in Šibenik General Hospital). All participants gave their informed consent for the administration of Comprehensive Aphasia Test-HR (CAT-HR) in accordance with ethical standards of the institutional or regional responsible committee on human studies and with the Helsinki Declaration from 1975, as revised in 1983. Most individuals signed the consent form themselves, but family members signed the form on behalf of those who lost their writing ability.

Materials and procedure

To address the aims of the study related to performance and type of errors in word comprehension, naming and reading, all participants were tested on the corresponding tasks from the adapted and normed in the Croatian language CAT-HR[63], an instrument with a range of tasks distributed across cognitive and language subtests, as well as a self-perceived disability questionnaire. Given that each of the language processing levels is represented by one or more tasks in the CAT-HR, participant achievement on each task and additional in-depth analyses of their responses and errors can provide a direct insight into the level or process which is disturbed[63,64]. We focused on four tasks that examine word processing skills in different modalities, as follows:

1) comprehension of spoken words: the task consists of 15 test items with the reliability coefficient r=0.79. Each item is represented by a picture surrounded with three distractor pictures – one phonologically related, one semantically related, and one unrelated to the target. Respondents were required to point to the picture that matched the word uttered by the examiner;
2) comprehension of written words: the task consists of 15 test items with the reliability coefficient r=0.91. Each item is written and surrounded with four pictures, one target and three distractor pictures – phonologically related, semantically related, and unrelated to the target. Respondents were required to point to the picture that matched the written word;
3) naming: the task consists of 24 test items with reliability coefficient r=0.95. Each item is presented by a picture. All items are nouns, half of which are high in frequency and imageability, and another half are low frequency and low imageability words. The respondent task was to provide accurate name of the object presented in the picture; and
4) reading words: the task consists of 24 test items with reliability coefficient r=0.97. In the item list, half were high- and half low-frequency words (e.g., *glava* (head) and *opna* (membrane)). Word imageability varied in the same way (*ananas* (pineapple) and *stoljeće* (century)). In addition, half of the items were short (single- and two-syllable words), and half were long words (with three or more syllables) (e.g., *klin* (wedge) and *pribadača* (pin)). The respondent task was to read each word aloud.

Each post-stroke and post-TBI subject was tested individually by speech-language pathologists in the above-mentioned medical or rehabilitation centers in different regions of Croatia.

Scoring

Type of responses and possible errors varied across the tasks. In two comprehension tasks and reading words task, participants could provide correct, incorrect, or no response. In the naming task, they could additionally provide a correct response after cueing. Cueing refers to providing a phonological or semantic cue to a person when he/she fails to name a picture on their own. The phonological cue refers to giving the initial sound or syllable of the target word, and its goal is to facilitate phoneme retrieval that underlies articulation of a word[61]. Semantic cueing consists of providing information that categorizes, describes or defines a word (e.g., 'you put it on your hands in winter' for gloves), thus targeting activation of the lexical-semantic association networks. Any such type of response was considered incorrect due to the initial inability to independently perform the task, and was not included in further analyses[63]. Considering that cueing represents the ingredient that speech-language pathologists use to promote performance of people with acquired disorders, the participant responses regarding ingredients were not analyzed, as it did not correspond to the aim of this study.

Each response was scored 0 (response after a cue, incorrect or no response) or 1 (correct response). The examiner noted all incorrect responses provided by each participant. This procedure allowed for further error analyses. Errors were classified as phonological, semantic, neologisms, or unrelated errors. As already mentioned, a phonological error is a response that differs from the target word in one or more sounds or syllables while retaining the similarity of the phonological form of the target word, e.g., *klokan* (kangaroo) – *klovan*; a semantic error is a response that is semantically related to the target, e.g., *noga* (leg) – *ruka* (arm); a neologism is a response that does not resemble the target word and has no meaning, e.g., *djevojčica* (girl) - *isemine;* and an unrelated error is a word that does not share any phonological or semantic features with the target word, e.g., *olovka* (pen) – *trešnja* (cherry). The two comprehension tasks allowed for all errors but neologisms, while in the two remaining tasks, naming and reading words, a subject could produce all four types of errors.

Data analyses

Between-group comparison of the number of correct responses in each task was performed using *t*-test for independent samples, with Cohen's *d* for effect size provided. The proportions of responses within each of the four tasks were obtained for each group. Incorrect responses were classified in more detail depending on the type of errors (phonological errors, semantic errors, unrelated errors and neologisms) and proportions of each type of errors were calculated as an incidence of a particular type of error from the total number of errors *per* participant in a task, for both groups. The proportions were then compared within and between groups using *t*-test for proportions. Due to multiple comparisons, a significance criterion of 1% was used and effect size values (Cohen's *h* for proportions) were provided. Only subjects who produced incorrect responses on particular tasks were included in the corresponding analyses, consequently leading to different numbers of participants in each analysis. Data analyses were performed using IBM SPSS Statistics version 23.0[66].

Results

Between-group performance in correct responses

Descriptive data on all response types are presented. Figure 1 shows these proportions within each task for both groups, and indicates that post-TBI group had a higher proportion of correct responses in all examined tasks than post-stroke group. In the comprehension of spoken words, there was a slightly higher proportion of correct responses provided by post-TBI group (0.89) than by post-stroke group (0.82). Differences are more obvious in the remaining three tasks. In the comprehension of written words, post-stroke group had a smaller proportion of correct responses (0.65) than post-TBI group (0.85), or they provided no response (0.19), most likely due to the presence of reading disabilities. In the naming task, both groups exhibited all four types of responses, with post-stroke group having smaller proportions of correct responses (0.40) than post-TBI group (0.80), as well as greater proportion of no response (0.09). Finally, in reading words, a smaller proportion of correct responses (0.45) and greater proportion of no response (0.33) was again evident in the post-stroke group compared to post-TBI group (0.90 for correct responses and 0.04 for no response), probably as a consequence of greater reading disabilities in the post-stroke group.

Post-TBI patients generally obtained higher scores than post-stroke ones. A between-group comparison confirmed that these differences were significant for two out of four tasks. Namely, post-stroke group (M(SD)=9.50(8.00)) had significantly fewer correct responses in naming (t=-4.82; p=0.000; Cohen d=1.45) than post-TBI group (M(SD)=19.32(5.22)). Also, post-stroke group (M(SD)=10.68(9.16)) showed the same profile in reading words (t=-4.84; p=0.000; Cohen d=1.46) as compared with post-TBI group (M(SD)=21.59(5.28)). No significant differences were found in comprehension of spoken and written words.

Error analyses

In this section, proportions of each type of errors within incorrect responses across all four tasks are provided. As previously explained, only participants who made errors in a particular task were included in error analysis (total N for each task is shown in Tables 3-6). As seen in Figure 2, both groups made the same types of errors in each task, but produced them to a different extent, resulting in different proportions of errors. Within- and between-group differences in the proportion of each type of error are shown in Figure 2 for each task separately.

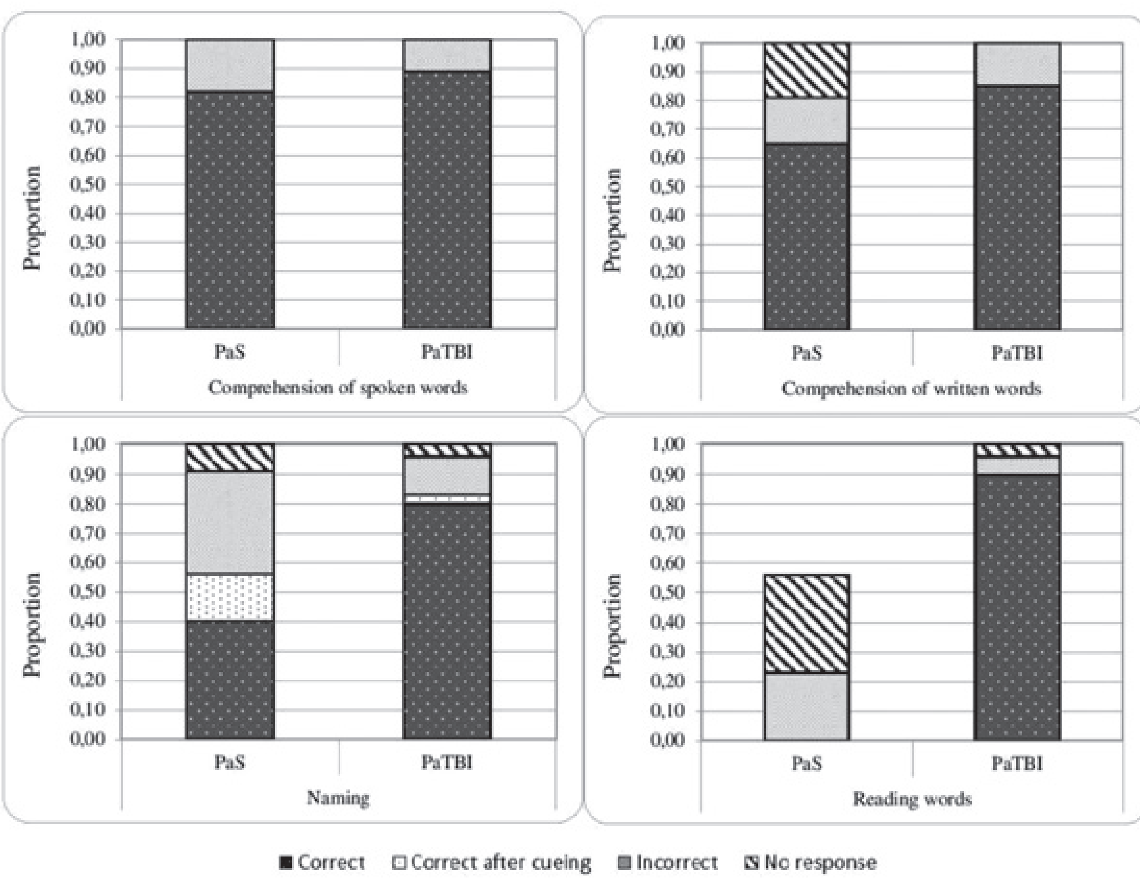

Fig. 1. Distribution of response types.

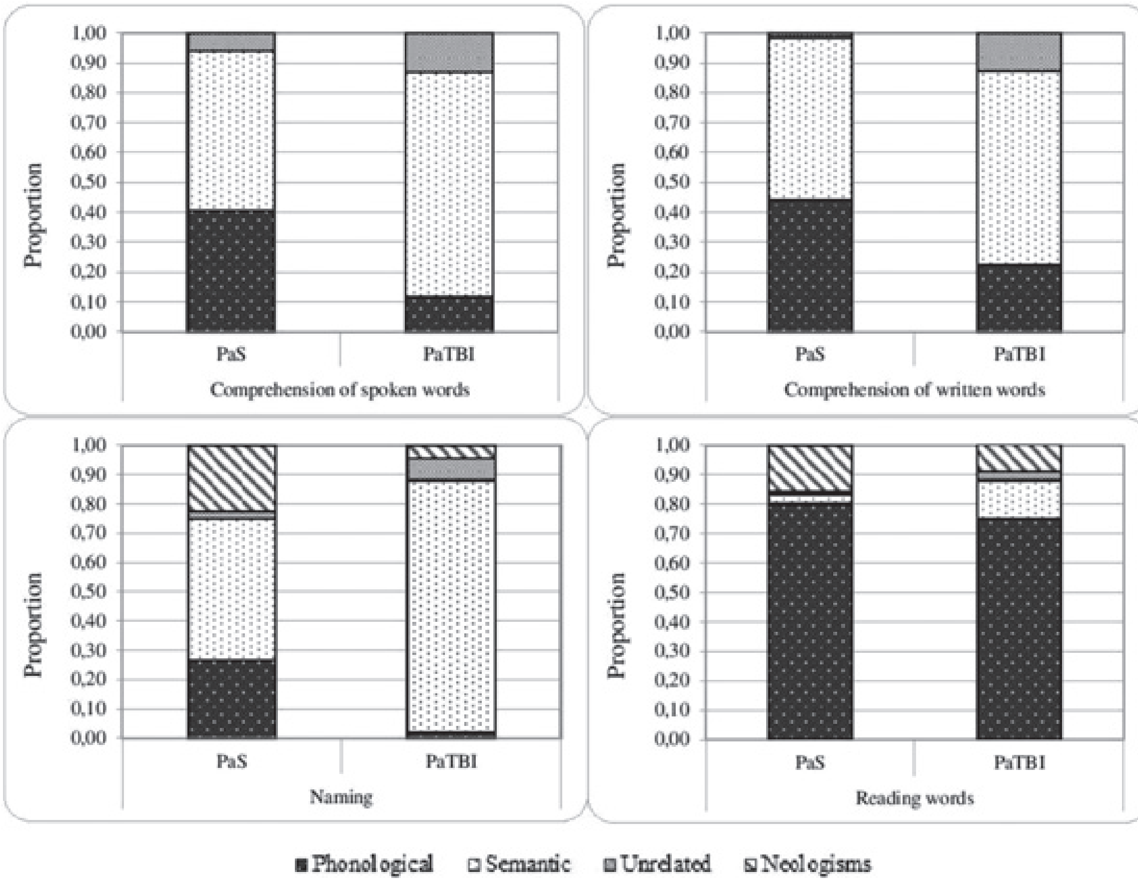

Fig. 2. Distribution of error types.

*Phonological, semantic and unrelated errors occurred in all four tasks, while neologisms occurred only in naming and reading words.

Spoken word comprehension

In the comprehension of spoken words task, 17 post-stroke and 10 post-TBI subjects exhibited some type of error, while other individuals performed correctly on all items within the task. Within-group comparison of the proportion of each type of revealed that post-stroke subjects had a significantly higher proportion of semantic errors than of unrelated ones (t=3.19; p=0.003; Cohen h=1.1), but there were no significant differences between the proportion of phonological and semantic errors, or between phonological and unrelated ones. On the other hand, post-TBI subjects had a significantly higher proportion of semantic errors than phonological (t=2.90; p=0.009; Cohen h=1.4) and unrelated errors (t=2.79; p=0.01; Cohen h=1.4), the proportion of which was similarly low.

Although there was a greater proportion of phonological errors in post-stroke than in post-TBI group, and a greater proportion of semantic and unrelated errors in the post-TBI group, differences between the two groups in a particular type of error were not significant (Table 3).

Written word comprehension task

In the comprehension of written words task, 14 post-stroke and 15 post-TBI patients exhibited some type of error, while other individuals performed correctly on all items within the task. Within-group comparisons showed that post-stroke group had a significantly smaller proportion of unrelated errors than phonological (t=2.95; p=0.006; Cohen h=1.2) and semantic (t=3.62; p=0.002; Cohen h=1.4) ones, while the proportions of phonological and semantic errors

Table 3. Proportion of type of errors in the comprehension of spoken words task

Proportion	Post-stroke					Post-TBI						
	n	Min	Max	M	SD	n	Min	Max	M	SD	t	p
Phonological	17	0.00	1.00	0.41	0.28	10	0.00	0.40	0.12	0.16	1.84	0.06
Semantic	17	0.00	1.00	0.53	0.30	10	0.33	1.00	0.75	0.28	1.20	0.22
Unrelated	17	0.00	0.50	0.06	0.14	10	0.00	0.67	0.13	0.22	0.58	0.57

Post-stroke = subjects having suffered stroke; Post-TBI = subjects having sustained traumatic brain injury

Table 4. Proportion of error types in the comprehension of written words task

Proportion	Post-stroke					Post-TBI						
	n	Min	Max	M	SD	n	Min	Max	M	SD	t	p
Phonological	14	0.00	1.00	0.44	0.38	15	0.00	1.00	0.22	0.35	1.29	0.20
Semantic	14	0.00	1.00	0.54	0.38	15	0.00	1.00	0.65	0.39	0.60	0.55
Unrelated	14	0.00	0.11	0.02	0.04	15	0.00	1.00	0.13	0.27	1.16	0.25

Post-stroke = subjects having suffered stroke; Post-TBI = subjects having sustained traumatic brain injury

did not differ significantly. In the post-TBI group, the proportion of semantic errors was significantly higher than the proportion of unrelated errors (t=2.82; p=0.007; Cohen h=1.1), but there were no significant differences in the proportion of phonological and semantic errors, or between phonological and unrelated ones.

Although post-TBI subjects made more semantic and unrelated errors, and less phonological errors than post-stroke subjects, between-group differences again did not reach statistical significance (Table 4).

Naming

In the naming task, 21 post-stroke and 16 post-TBI patients made some type of error, while other individuals performed correctly on all items within the task. Both groups exhibited naming difficulties to some extent as all types of errors were present in both groups.

Within-group comparisons showed that post-stroke group only had a significantly higher proportion of semantic errors than unrelated errors (t=3.63; p=0.001; Cohen h=1.2). Although the proportion of semantic errors dominated over all other types of errors, those differences did not reach statistical significance. Unlike post-stroke group, post-TBI group had a significantly higher proportion of semantic errors than all other types of errors (phonological: t=7.79; p<0.001; Cohen h=2.1; unrelated: t=5.53; p<0.001; Cohen h=1.8; neologisms: t=6.23; p<0.001; Cohen h=1.9).

Difference between the groups was only obtained in the proportion of semantic errors (more semantic errors in post-TBI group than in post-stroke group; t=2.65; p=0.01; Cohen h=0.84), despite the fact that semantic paraphasias dominated over all other error types in both groups (Table 5). There were no significant between-group differences in the proportion of phonological errors, neologisms, and unrelated errors.

Reading words

In the reading words task, 21 post-stroke and 13 post-TBI subjects made some type of error, while others performed correctly on all items within the task. Within-group comparisons pointed to a similar pattern in both groups. Post-stroke group had a significantly higher proportion of phonological than semantic errors (t=6.12; p<0.001; Cohen h=1.9), unrelated errors (t=7.09; p<0.001; Cohen h=2.0) and neologisms (t=3.34; p=0.002; Cohen h=1.4). In post-

Table 5. Proportion of error types in naming task

Proportion	Post-stroke					Post-TBI						
	n	Min	Max	M	SD	n	Min	Max	M	SD	t	p
Phonological	20	0.00	1.00	0.27	0.29	15	0.00	0.17	0.02	0.05	2.37	0.02
Semantic	20	0.00	1.00	0.48	0.38	15	0.28	1.00	0.86	0.22	2.65	0.01
Unrelated	20	0.00	0.14	0.03	0.05	15	0.00	0.50	0.07	0.14	0.53	0.59
Neologisms	20	0.00	0.95	0.22	0.31	15	0.00	0.56	0.05	0.14	1.64	0.10

Post-stroke = subjects having suffered stroke; Post-TBI = subjects having sustained traumatic brain injury

Table 6. Proportion of error types in the reading words task

Proportion	Post-stroke					Post-TBI						
	n	Min	Max	M	SD	n	Min	Max	M	SD	t	p
Phonological	15	0.00	1.00	0.80	0.29	13	0.00	1.00	0.75	0.39	0.32	0.75
Semantic	15	0.00	0.38	0.03	0.10	13	0.00	1.00	0.13	0.30	0.97	0.33
Unrelated	15	0.00	0.11	0.01	0.03	13	0.00	0.20	0.02	0.06	0.22	0.83
Neologisms	15	0.00	0.96	0.16	0.26	13	0.00	1.00	0.09	0.28	0.57	0.57

Post-stroke = subjects having suffered stroke; Post-TBI = subjects having sustained traumatic brain injury

TBI group, the proportion of phonological errors was also significantly higher than the proportion of semantic errors ($t=3.18$; $p=0.004$; Cohen $h=1.4$), unrelated ones ($t=5.08$; $p<0.001$; Cohen $h=1.7$) and neologisms ($t=3.74$; $p=0.001$; Cohen $h=1.5$). There were no significant differences in semantic errors, unrelated errors and neologisms in the post-stroke group and post-TBI group.

The proportions of the same errors were compared between the groups, but differences were not statistically significant (Table 6).

Discussion

The purpose of this exploratory study was to broaden insights into details of language performance of post-stroke and post-TBI patients on the word processing level in different modalities (word comprehension – spoken and written, and word production – naming and reading). Following the rationale of the logogen model, quantitative and descriptive error analyses were conducted. Specific aims were to explore 1) whether there are between-group differences in the performance on tasks that examine comprehension of spoken and written words, naming and reading words; 2) which types of errors (phonological, semantic, neologisms, and unrelated) dominate in incorrect responses within each group; and 3) whether there are between-group differences in the proportion of each type of errors across the four tasks.

In accordance with the evidence provided in many studies which state that post-TBI subjects have more difficulty in pragmatics than in other aspects of language, contrary to the generally reduced language abilities in post-stroke subjects[10,11], we expected post-TBI subjects to perform better than post-stroke ones on all examined language tasks. Our hypothesis was partially confirmed because our sample of post-TBI subjects significantly outperformed post-stroke subjects in naming and reading, but not in comprehension of spoken and written words. This finding was surprising since numerous studies show that post-stroke subjects have difficulties in single word comprehension[37-40,42,44], while, to our knowledge, no studies explicitly indicate the existence of the same difficulties in post-TBI subjects. Certain authors claim that post-TBI subjects do not have difficulties in single word comprehension[51], but that their comprehension difficulties are evident on higher levels, i.e., on the sentence level[46-50], discourse level[67,68], and in comprehension of metaphor, sarcasm and irony[69-71]. Based on the presented literature, we can assume that the lack of differences in word comprehension abilities lies in the localization of injury in both groups. More precisely, only two patients had a stroke in the temporal area which is thought to be responsible for auditory word comprehension[72,73], and three in the temporoparietal area. Other patients had a stroke in the areas which are not directly responsible for word comprehension processes (frontal, parietal, multifocal, in the corona radiata or in the supply area of arteria cerebri media and arteria carotis interna). Similarly, only one post-TBI patient had a brain injury in the temporal, one in the frontotemporal, and one in the temporoparietal area, whereas other patients mostly had diffuse brain injuries or injuries that were sporadically located frontally, frontoparietally, parieto-occipitally, and multifocally (see Table 2). Importantly, post-TBI patients mainly had diffuse lesions, whereas post-stroke patients mostly had focal lesions. Therefore, we assume that the localization of brain injury (either stroke or TBI) did not affect word comprehension abilities of most patients in both groups.

To address the second question, we investigated which types of errors dominated in incorrect responses within each group. In accordance with studies that claim well preserved phonological processing in post-TBI subjects[26], and impaired phonological processing in post-stroke subjects[38,39,44,74], we expected that post-stroke group would have the highest proportion of phonological errors compared to other types of errors in all examined tasks, and that post-TBI group would mostly produce semantic errors. Post-stroke subjects produced significantly more phonological errors than other types of errors only in reading. Contrary to our predictions, they even exhibited more semantic than unrelated errors in naming and word comprehension, and there were no differences in the proportions of phonological and semantic errors in those tasks. It follows that there is no single dominant type of error in post-stroke subjects, but unrelated errors were the least prevalent error type in this group. In post-TBI group, semantic errors dominated over phonological and unrelated errors in spoken word comprehension task, over unrelated errors in written word comprehension, and over all other errors in naming. Some examples of semantic errors in naming were swans, birds (instead of goose); music, trumpet (instead of saxophone); tree, branches (instead of wind). On the other hand, phonological errors were more prevalent in reading. Therefore, we can partially confirm our assumptions and conclude that post-TBI subjects predominantly produce semantic errors in naming, comprehension of spoken words, and partially in comprehension of written words as well. The dominance of semantic errors in naming in both groups is an indication of difficulties on the level of semantic lexicon, such as difficulties in the access to semantic lexicon, word retrieval, or word finding deficits.

Since according to the literature, word-reading difficulties occur only in severe TBI[59,60] but are very common in post-stroke patients, a similar pattern of reading errors obtained in both groups (i.e., dominance of phonological errors) requires special attention here. To relate the distributed errors with word processing levels, it is important to explicitly indicate how certain types of items are processed (depending on the parameters that were controlled as they affect reading accuracy, i.e., frequency, imageability, and length). High-frequency words are expected to be read *via* a direct lexical route by recognizing the word in the orthographic lexicon. On the other hand, it is expected that a person will rely more on the sub-lexical route (i.e., phonological coding) when reading low-frequency words. A high incidence of incorrect responses found when reading both high- and low-frequency words in post-stroke patients points to the conclusion that both routes are impaired. It seems that even the words that are highly frequent cannot be recognized in the orthographic lexicon, so these individuals have to rely on phonological coding when reading any type of word regardless of its features. Put differently, they read both high- and low-frequency words *via* a sub-lexical route. Nevertheless, a relatively large proportion of phonological errors indicates that reading *via* this route is also inadequate. Surprisingly, the same pattern was found in the post-TBI group. Based on the data obtained, we can conclude that no error is specific for a particular group, either post-stroke or post-TBI. The significant prevalence of phonological errors indicates that errors may also depend on the type of task, and not just on the type of brain injury.

Finally, we aimed to explore between-group differences in the proportion of errors across the four tasks. The assumption that post-stroke patients will exhibit significantly more phonological errors than post-TBI ones, and that post-TBI patients will have significantly more semantic errors than post-stroke ones, was not confirmed. The only significant difference was obtained in the proportion of semantic errors in naming, which was significantly higher in post-TBI group, although these errors dominated in both groups. Although post-TBI group significantly outperformed post-stroke group in naming, a higher incidence of semantic errors in this group confirms that nominal difficulties are one of the consequences of TBI, as reported in many previous studies[11,18,75-79]. Despite the absence of significant differences in the proportion of phonological errors between the groups, our tendencies are interesting as they again follow Boles's findings[35]. He has reported a higher occurrence of phonological errors in naming in post-stroke than in post-TBI subjects, and post-stroke group in our sample also exhibited a higher proportion of phonological errors than post-TBI group, which almost reached significance. A more homogeneous group of participants and bigger sample size could potentially increase statistical power. Despite the lack of differences in the proportion of other types of errors, neologisms were present in 11 post-stroke patients (*bubanj* (drum) - *poplan; telefon* (telephone) - *tenkokos; piramida* (pyramid) - *brinjeta; klokan* (kangaroo) - *plopla,* etc.) as opposed to only one post-TBI patient. This individual had a focal injury located in the temporal lobe, and consequently symptoms very similar to those seen in post-stroke individuals.

Based on the differences obtained, presumably post-TBI subjects do not have difficulties in the retrieval of phonological representation, but their difficulties in naming may be caused by an impairment in the semantic access. Unlike post-TBI subjects, the lack of differences between phonological and semantic errors in naming in post-stroke subjects would suggest that, according to the logogen model[31], their difficulties in naming can be equally a consequence of the disruption at the level of semantic access and the phonological output lexicon.

Finally, we can conclude that post-stroke subjects need not necessarily perform worse on all linguistic aspects compared to post-TBI subjects. We also argue that TBI does not imply intact lower levels of language processing. Therefore, even though a comprehensive error analysis can be insightful, certain types of errors cannot be expected in particular groups. It seems that only naming can differentiate the two groups as the errors produced by post-TBI subjects are significantly more semantically conditioned than those produced by post-stroke subjects.

Study limitations

Current exploratory study provides a comprehensive overview of the disturbed word processing levels following the logogen model in two groups of patients with different neurological disorders, stroke and TBI. Despite its extensiveness, the study had certain limitations. First, our sample size was relatively small. Furthermore, data on the location and extent of lesion were only presented in the description of participant demographic characteristics, and were not controlled for. We are aware of the heterogeneity of this variable in both groups and its possible impact on the existence of between-group differences. However, we were guided by firm conclusions of certain authors[80] that the type of injury was more important and consequently required more control than the lesion site itself. For this reason, as well as due to the mentioned sample size limitation, analysis of the relation between lesion site and language performance was not conducted. Finally, despite a relatively comprehensive overview of word processing levels taken in the current study, in order to determine the exact locus of impairment, one should assess word processing abilities on several levels using additional discriminative tasks (e.g., letter recognition and identification, nonword reading or written word-nonword discrimination for determination of the locus of impairment in reading).

Clinical implications

Current research has several important implications for future studies, as well as for clinical work. Most importantly, it shows the informativeness of errors produced by individuals involved in research or clinical procedures. When performing an assessment, one should go beyond the mere correct/incorrect dichotomy and focus on error analyses. When error types are analyzed and observed jointly with information about the cause of brain damage, the site and extent of lesion, they may indicate the exact locus of processing deficits, consequently allowing for a more appropriate diagnostics, individually-based therapy planning, and faster, more stable and functional recovery.

Finally, our data suggest that researchers and clinicians should not expect a unified profile of language disturbances in post-stroke patients, and another completely different profile in patients who sustained TBI. Too many factors impact one's individual performance on different language processing levels. Hence, participant recruitment for research purposes and an individual assessment for therapeutic purposes should both rely on a compilation of data, i.e., on individual demographic characteristics, cognitive functioning, specificities on language performance on different processing levels, as well as on the cueing strategy a person predominantly relies on.

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Sažetak

SPOSOBNOST OBRADE RIJEČI U OSOBA KOJE SU DOŽIVJELE MOŽDANI UDAR ILI TRAUMATSKU OZLJEDU MOZGA

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Stečeni jezični poremećaj uobičajena je posljedica moždanog udara (MU) i traumatske ozljede mozga (TOM). Slijedeći model logogen ovaj rad je istraživao jezičnu obradu na razini riječi osoba nakon MU i TOM. Promatrajući razlike u razumijevanju, imenovanju i čitanju riječi unutar i između ovih dviju skupina, jedan od ciljeva bio je definirati pogreške koje prevladavaju u njihovoj izvedbi. Dvadesetdvije osobe nakon MU i 22 osobe nakon TOM ispitane su zadatcima iz Sveobuhvatnog testa za procjenu afazije (CAT-HR). Osobe s TOM nadmašile su one s MU u imenovanju i čitanju. Obje su skupine proizvele neologizme, fonološke, semantičke i nepovezane pogreške, iako u različitim omjerima. U razumijevanju i imenovanju riječi osobe s TOM proizvodile su prvenstveno semantičke pogreške, dok su one s MU proizvodile i fonološke i semantičke pogreške. Tijekom čitanja obje skupine proizvodile su pretežito fonološke pogreške. Distribucija pogrešaka razlikovala se samo u imenovanju; osobe s TOM proizvodile su više semantičkih pogrešaka nego one s MU. Može se zaključiti da je sposobnost imenovanja najviše razlikovala ove dvije skupine. Analiza pogrešaka vrijedan je izvor informacija, ali dominantnost pojedine vrste pogreške ne može se pripisati samo jednoj skupini ispitanika. Dobiveni rezultati imaju konkretne kliničke implikacije, osobito one povezane s ulogom i značenjem pogrešaka koje bolesnik proizvodi, kako bi se utvrdilo točno mjesto narušene obrade.

Ključne riječi: *Moždani udar; Traumatska ozljeda mozga; Obrada riječi; Analiza pogrešaka; Model logogen*