Original research article

Emotional prosody expression in acoustic analysis in patients with right hemisphere ischemic stroke

Konstanty Guranski *, Ryszard Podemski

Department of Neurology, Wroclaw Medical University, Wroclaw, Poland

ARTICLE INFO

Article history:
Received 25 January 2015
Accepted 12 March 2015
Available online 22 March 2015

Keywords:
Emotional prosody
Right hemisphere
Acoustic speech analysis

ABSTRACT

Objectives: The role of the right cerebral hemisphere in nonverbal speech activities remains controversial. Most research supports the dominant role of the right hemisphere in the control of emotional prosody. There has been significant discussion of the participation of cortical and subcortical structures of the right hemisphere in the processing of various acoustic speech parameters. The aim of this study was an acoustic analysis of the speech parameters during emotional expression in right hemisphere ischemic strokes with an attempt to reference the results to lesion location.

Materials and methods: Acoustic speech analysis was conducted on forty-six right-handed patients with right-middle cerebral artery stroke, together with 34 age-matched people in the control group. We compared the results of acoustic studies between patients with varying infarct locations and the control group.

Results: Variations in fundamental frequency during verbal expression of joy, anger and sadness were significantly smaller in the patient group than in the control group. Cortical lesion caused more restrictions in fundamental frequency variation in the expression of joy and a lower voice intensity in expressions of anger and joy compared to those patients with subcortical lesions.

Conclusions: Cortical lesion was associated with a more impaired expression of emotional prosody than subcortical lesion. The results indicate the leading role of the cortical structures of the right hemisphere in the expression of emotional prosody.

© 2015 Polish Neurological Society. Published by Elsevier Sp. z o.o. All rights reserved.

1. Introduction

The right hemisphere plays an important role in verbal communication, as it is mostly responsible for speech prosody and its emotional aspects. The majority of studies have indicated the domination of the right hemisphere in expression of emotional prosody and the superiority of the left hemisphere in the expression of linguistic prosody (functional hypothesis). These functional differences may be connected to the selective dominance of the right or left hemisphere in particular acoustic parameters of speech (physical hypothesis). The right hemisphere predominates in control of the fundamental frequency, the variations of which determine the corresponding levels of
the expression of emotions [1–9]. The left hemisphere pre-
dominates in the control of the duration of speech and pauses,
which determine the appropriate structure of the utterance
[5,10–15]. The role of the right hemisphere in control of voice
intensity in emotional prosody expression remains uncertain.
According to Ross [2,16,17] only Fo variation is a sensitive
indicator of emotional prosody expression, while the intensity
of the voice is less important. Other studies highlight the
importance of voice intensity (mean values) especially during
the expression of anger [9,18]. Similarly vague is also the
influence of the location of damage to the non-dominant
hemisphere on emotional expression and maintenance of
acoustic parameters of speech, such as Fo, their intensity and
duration. Shapiro and Danly [6] showed smaller fundamental
frequency variations during emotional expression in patients
with vascular damage of the right frontal lobe, compared to the
control group of healthy people and patients with damage to the
left hemisphere. Blonder et al. [19] evaluated a patient with
prosodic impairment caused by an extensive cortico-subcortical
right hemisphere ischemic stroke. Ross and Monnot [20]
described disturbances of emotional prosody expression in
patients with ischemic cortical and subcortical lesion. These
abnormalities were more severe in patients with cortical
damage. Based on his own results, Ross [21] hypothesized that
the functional and anatomical organization of the right
hemisphere in terms of emotional prosody is highly similar
to the organization of language functions in the left hemisphere.
Ross then proposed a distinction of emotional prosody
analogous with the classification of aphasia. Therefore, he
distinguished, among others, motor, sensory and global
aprosodia, combining the types with damage to relevant part
of the right hemisphere. However, a verification of Ross’s
hypothesis gave ambiguous results. Some of the studies
confirmed the impairment of the expression of emotional
prosody in patients with damage to the right frontal lobe as well
as impairment of perception in cases of damage to the right
temporoparietal lobe [22–25]. Although other studies did not
show such a relationship, in the majority of patients dis-
turbances in prosody could have been related to Ross’s
classification [26–29]. Other studies revealed the significant
role of subcortical structures in prosodic emotional expression
and perception. Cancelliere [27] described emotional dysprosody
following subcortical damage without respect to cerebral
laterality. Starkstein et al. [25] found disturbances in the
perception of emotional prosody in patients with damage to
the basal ganglia. Van Lancker Sidtis et al. [30] demonstrated
reduced F0 variability in acoustic speech analysis of two
patients with isolated basal ganglia damage. Moreover, the
participation of subcortical structures in the control of prosody
seems to be confirmed by disturbances in the melody of speech
in other diseases of the extrapyramidal system, such as
Parkinson’s disease [31–33]. There are several concepts on the
pathogenesis of dysprosody in damage of the subcortical
structures. Subcortical aphasias are explained mainly by the
occurrence of diaschisis, where the subcortical damage causes
secondary lesions in the cortical areas responsible for linguistic
functions. An analogous mechanism may concern the prosody
disorders, where the subcortical focus influences the cortical
areas of the right hemisphere in a depressive manner, inhibiting
their activity. All this may cause restrictions of the fundamental
frequency variations, which is one of the basic elements of
dysprosody. Another considered mechanism of subcortical
dysprosody relates to the pathomechanism of dysarthria,
where the motor coordination of the articulatory apparatus
may be impaired. This results in changes in the duration of
the verbal sequences and impairment of the coordination of
the motor functions of speech. Other authors point out the
important role of the corpus callosum in the control of speech
prosody, the supplementary motor area and the frontal part of
the cingulum of the right hemisphere [34–36]. The damage to the
corpus callosum may impair interhemispheric communication,
which integrates the prosodic functions, controlled by the
right hemisphere, with speech abilities, processed by the left
hemisphere [17].

The aim of this study was the characterization of the basic
parameters of speech – the fundamental frequency, duration of
the test utterance and the intensity during controlled emotional
expression in patients with acute ischemic damages to the right
hemisphere and in the control group, with reference of the
emotional prosody to the location of the stroke.

2. Materials and methods

2.1. Participants

Forty-six right-handed patients with right middle cerebral
artery stroke, including 16 females (35%) and 30 males (65%),
hospitalized in the Department of Neurology, Wroclaw Medical
University between October 2003 and December 2008 were
evaluated. The average age of the patients was 58 ± 12.31 years
old (22–74 years old). The native language of all the patients
was Polish. Diagnosis of the ischemic stroke was made based
on clinical symptoms and brain CT image. The degree of
neurological deficit was evaluated using the National Institute
of Health Stroke Scale (NIHSS) on the day of the acoustic speech
exam which was performed within 7–14 days after symptoms of
the stroke were shown. It was assumed that acoustic speech
analysis in an early ischemic stroke can detect potentially
reversible emotional dysprosody. The cognitive functions were
evaluated with the Mini-Mental State Examination (MMSE)
scale, and a result below 24 points was one of the criteria for
exclusion from the study. Communicative abilities were
assessed with the Goodglass-Kaplan scale. Other excluding
criteria were speech disorders hindering verbal communica-
tion, both aphasia and dysarthria alike, as well as a history of
previous strokes, psychiatric disorders, dementia, Parkinson’s
disease and acute internal illnesses (circulatory and respiratory
failures, renal and liver failures). The patients were divided into
subgroups depending on the location of the stroke in the CT
image – patients with: cortical stroke (lesion in the cortex or
cortex with white matter but without damage to the basal
ganglia or the internal capsule), subcortical stroke (lesion in the
basal ganglia and/or the internal capsule) and cortico-subcorti-
cal stroke. Multifocal ischemic strokes, leukoaraiosis and
hydrocephalus were other criteria for exclusion from the study.

The control group consisted of 34 right-handed people,
including 12 females (35%) and 22 males (65%), aged 35 up to
81 years old (mean age was 54.7 ± 11.13 years old) and without
any clinical symptoms of damage to the central nervous
system. None of the patients in the control group was diagnosed with speech disorders, psychiatric diseases or acute internal illnesses (circulatory and respiratory failures, renal and liver failures).

2.2. Procedure

The acoustic speech evaluations were conducted in constant conditions – in the Laboratory of Speech Acoustics, Department of Neurology, Wroclaw Medical University. The recordings were made within 7–14 days after the symptoms of the stroke were shown. During the exam, patients were sitting and the microphone was placed 5 cm from their mouths. Speech was recorded on the hard drive of a desktop computer with a Pentium 3.00 GHz processor, with 1GB RAM and a Sound Blaster Audity sound card. For the speech analysis and audio editing two programs were used: Medicom “Iris” and Steinberg WaveLab 6, both modified for the needs and purposes of the Laboratory of Speech Acoustics.

Before the recording, patients were given a list of the test sentences and subsequently oral instructions were given detailing the performance of particular phases of the study. The initial action was the longest possible vocalization of the sound “a”, which was used for evaluation of the technical conditions of the exam (the quality of the recorded sound, appropriate settings for the technical parameters of the acoustic program and the positioning of the microphone). The exam task was to repeat the phase “there is no” (in Polish “nie ma”) with different emotional coloring four-fold in each emotion. The first statements were supposed to be neutral, the following ones expressing anger, sadness and joy, with the strongest possible emotional involvement. None of the phases of the test, including the oral instructions, indicated how the exam task was supposed to be performed, and this was aimed at elimination of any kind of model imposition by the investigator. The recorded samples were stored on the hard drive of the desktop computer and later used in the computer acoustic analysis. All the calculations conducted on the collected material were done automatically by the computer program. From each of the four recorded repetitions, only recordings number 2 and 3 were used in the acoustic analysis. In each variant of the test utterance, the following acoustic parameters were analyzed:

a) the variation of the fundamental frequency (Fo), determined by the standard deviation of Fo (Hz)

We did not perform a log on transformation of Fo (such as converting the Hz data into semitones) or a co-efficient of variation measurement, because of the similar gender distribution among the patients and in the control group.

b) the mean voice intensity in decibels (dB)

c) the duration of the utterance.

For each of the evaluated parameters in every patient subgroups and in the control group mean values with standard deviation (SD) were calculated. For verification of the statistical differences between the patients (with cortical, subcortical and cortico-subcortical strokes) and the control group the following tests were employed:

1. Kolmogorov-Smirnov Test with Lilliefors’s correction in order to evaluate whether the distribution of the assessed characteristics was consistent with the normal distribution
2. Other tests comparing the expected values for characteristics consistent with the normal distribution in order to find the statistically important differences between the patients and the control group:

- The Fisher-Snedecor Test – to compare the compatibility of variances
- The Student t-Test – to compare the expected values (equal variances)
- The Cochran–Cox Test – to compare the expected values (different variances).

To verify the statistical differences of particular acoustic parameters obtained during the utterances made with various emotional expressions by the patients and controls the one-way ANOVA test was employed. In cases of statistically important differences, the next step was to use the Schiffe post hoc test which enabled the identification of which of the compared pairs differed significantly in the expected (mean) values. p ≤ .05 was assumed as the statistically important level. For the statistical analysis STATISTICA 7.0 PL was used.

3. Results

3.1. The clinical characteristics

In the analyzed group of patients the average point score on the NIHSS was 4.26 (range between 2 and 9 points). The CT brain images showed: cortical stroke in 22 patients (48%), subcortical stroke in 20 patients (43%) and cortico-subcortical stroke in 4 patients (9%).

3.2. The acoustic parameters of speech in patients and the control group

In order to evaluate the influence of the ischemic damage of the right hemisphere on the expression of emotional prosody, variations of fundamental frequency, intensity of speech and time parameters were compared in patients and the control group.

Variations in fundamental frequency during verbal expression of joy, anger and sadness were significantly smaller than in the control group (Table 1). The alternations of Fo during the neutral utterance did not differ significantly in either group.

Analysis of the fundamental frequency during emotional expression showed that both in patients and in controls the direction of the changes of the voice frequency was consistent with the expression of the particular emotional state. Variations in the fundamental frequency in the expression of joy were significantly larger in both groups compared to the neutral and sad utterance. Changes in the Fo in the expression of anger were bigger compared to the neutral utterance (Fig. 1). Moreover, in the control group significant variations in Fo were found in the expression of anger compared to sad-ness, which was not found in those patients with damage to the right hemisphere. Changes in fundamental frequency in expressions of the remaining emotions were similar.
Mean voice intensity values during expression of particular emotions did not differ significantly between the groups (Table 1). However, smaller – statistically insignificant (p = .0985) – differences were found between voice intensity during expression of anger in patients and the control group.

Analysis of the sound intensity showed that both patients and controls were able to change it according to the type of emotion (Fig. 2). Voice intensity during expression of anger was statistically significantly bigger compared to sadness and neutral expression. However, no significant difference between the remaining utterances was found.

Moreover, no differences were found between the duration of the phrase “there is no” with different emotional expressions in patients and controls (Table 1).

Nevertheless, in patients the duration of the expression of sadness was longer than the expression of anger (Fig. 3). The durations of the remaining utterances in patients and all utterances in controls were similar.

### 3.3. Changes in the acoustic parameters of speech in patients with vascular damage to the right hemisphere with reference to the location of stroke in the CT brain image

In order to evaluate the influence of the location of the stroke on the expression of emotional prosody, variations of the fundamental frequency, the intensity of speech and time parameters were analyzed in patients with cortical, subcortical and cortico-subcortical strokes and in the control group.
Variations of Fo were significantly smaller in patients with subcortical strokes during expression of joy, anger and sadness compared to the control group. Variations of Fo were significantly smaller in patients with cortical strokes in the expression of joy and anger and in patients with cortico-subcortical strokes – in the expression of joy, compared to the controls (Table 2). Moreover, in patients with cortical strokes smaller variations in the fundamental frequency were observed in the expression of joy in comparison to those patients with subcortical strokes.

Voice intensity was significantly smaller during expression of anger in patients with cortical and cortico-subcortical strokes compared to the control group. In patients with cortical strokes a smaller voice intensity was also found in expressions of anger and joy in comparison to patients with subcortical strokes (Table 3).

The duration of the neutral utterance was longer in patients with cortico-subcortical strokes compared to the controls. Patients with subcortical strokes showed a longer duration in the expression of joy than patients with cortical strokes (Table 4).

### 4. Discussion

Previous studies on the acoustics of speech suggest that impairment of the expression of emotions in injury to the right hemisphere is caused mostly by reductions of variations of the

---

**Table 2 – Fundamental frequency variation (mean ± SD) during emotional expression in patients with cortical, subcortical, cortico-subcortical strokes and the control group.**

<table>
<thead>
<tr>
<th></th>
<th>Neutral (Hz)</th>
<th>Joy (Hz)</th>
<th>Sadness (Hz)</th>
<th>Anger (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical stroke</td>
<td>17.64 ± 14.022</td>
<td>21.21 ± 15,478</td>
<td>21.74 ± 15,675</td>
<td>28.57 ± 20,431</td>
</tr>
<tr>
<td>Cortico-subcortical</td>
<td>16.8 ± 5611</td>
<td>17.69 ± 11,044</td>
<td>64.25 ± 35,200</td>
<td>48.46 ± 25,692</td>
</tr>
<tr>
<td>Controls (n = 34)</td>
<td>17.69 ± 11,044</td>
<td>16.8 ± 5611</td>
<td>64.25 ± 35,200</td>
<td>48.46 ± 25,692</td>
</tr>
</tbody>
</table>

* p ≤ .05 in comparison to control group
* p ≤ .05 in comparison to patients with subcortical strokes

**Table 3 – Voice intensity (mean ± SD) during emotional expression in patients with cortical, subcortical, cortico-subcortical strokes and the control group.**

<table>
<thead>
<tr>
<th></th>
<th>Neutral (dB)</th>
<th>Joy (dB)</th>
<th>Sadness (dB)</th>
<th>Anger (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcortical stroke</td>
<td>56.74 ± 6043</td>
<td>58.72 ± 5601</td>
<td>56.66 ± 5864</td>
<td>61.11 ± 5290</td>
</tr>
<tr>
<td>Cortical stroke</td>
<td>53.77 ± 5657</td>
<td>55.56 ± 5419</td>
<td>53.93 ± 5514</td>
<td>57.37 ± 6038</td>
</tr>
<tr>
<td>Cortico-subcortical</td>
<td>50.60 ± 4215</td>
<td>52.76 ± 2744</td>
<td>52.12 ± 2792</td>
<td>54.75 ± 2785</td>
</tr>
<tr>
<td>Controls (n = 34)</td>
<td>54.52 ± 6201</td>
<td>57.27 ± 6076</td>
<td>54.54 ± 6534</td>
<td>60.43 ± 5048</td>
</tr>
</tbody>
</table>

* p ≤ .05 in comparison to control group.
* p ≤ .05 in comparison to patients with subcortical strokes.
fundamental frequency [2,6,37,38]. In our materials these observations were confirmed, importantly showing a narrower range in the variations of the fundamental frequency during verbal expression connected to particular emotions in patients with ischemic damage to the right hemisphere, compared to the control group. The biggest difference in the variations of the fundamental frequency in patients and in controls revealed itself during expression of joy, and a bit smaller in expression of anger. Nevertheless, the direction of the variations to fundamental frequency was maintained, i.e. patients with strokes in the right hemisphere were able to change the fundamental frequency according to the assumed emotional coloring of the test sentence. However, it was done with significantly lower efficiency than by the controls, which indicates the quantitative, not qualitative, nature of emotional expression dysprosody in patients. On the basis of the CT brain image, patients with cortical and subcortical lesion in the right hemisphere were distinguished, showing a correlation between the locus of the stroke and the expression of emotional prosody. The largest deficit in the expression of the emotional prosody was caused by the cortical damage, which was presented by reduction of the Fo variations during expression of joy compared to the patients with subcortical strokes. Earlier studies that used a computer acoustic speech analysis were conducted on small groups of patients with various locations of the strokes in the right hemisphere. To our knowledge, no previous studies have compared the expression of emotional prosody in patients with isolated cortical and subcortical lesions. In this situation, it was impossible to establish a correlation between the location of the ischemic lesion (cortical vs subcortical) and expressive dysprosody. The biggest of the acoustic studies on affective prosody published so far, where the patient group was homogenous in terms of the location of the stroke, was conducted by Ross and Monnot [20]. The authors revealed expressive dysprosody deficits in patients with mainly cortical ischemic strokes of the right hemisphere. However, there were no patients with isolated subcortical damage. Our comparative analysis of Fo variability in patients with isolated cortical and isolated subcortical strokes showed larger deficits in patients with cortical damage.

The role of the right hemisphere in the control of voice intensity remains unclear. This parameter is rarely the subject of clinical trials, acoustic studies or functional neuroimaging [16,39-41]. According to Ross et al. [17], this parameter plays a less important role than Fo in the expression of emotional prosody. Gandour et al. [42] did not identify changes in the voice intensity (RMS energy measurement) during expression of joy and anger. Similarly, in our own studies no significant difference in voice intensity during emotional expression was observed either in patients, or in controls. The highest voice intensity was registered during expression of anger in both groups. However, analysis of the intensity in patients with damage to cortical and subcortical structures showed a lower intensity of the voice during the expression of anger and joy in patients with cortical strokes compared to the patients with subcortical strokes. Moreover, the intensity of the voice in patients with subcortical strokes was not significantly different compared with the control group. A dominant role of the right hemisphere cortex in the expression of voice intensity, which was shown in own studies, has not been evaluated previously.

Previous studies argue against the important role of the right hemisphere in the control of the durational features (e.g. phrase length, tempo, rhythm) [37,43]. Similarly, in our study, there were no significant differences in the duration of the test tasks between the patients and controls. In the cases of subcortical lesion, the duration of the joyful utterance was longer than in patients with cortical strokes, but similar to that in the control group. These changes are not sufficient to indicate the predominance of cortical or subcortical structures in the control of speech timing.

Our own studies indicate that cortical and subcortical structures of the right hemisphere have an important role in the control of emotional prosody. Injury to these structures caused the impairment of the fundamental frequency variation that was more pronounced in patients with cortical lesions. Furthermore, only damage to cortical structures produced a deficit in voice intensity.

5. Conclusions

The presented study, based on computer acoustic speech analysis, confirmed the important role of the right hemisphere in the expression of emotional prosody. In a precise and objective manner, the directions of changes of prosodic parameters of speech were shown, also in correlation to the location of ischemic damage to the non-dominant hemisphere. In particular, attention was drawn to the dominant role of the fundamental frequency in modulation of emotional expression. The results obtained from acoustic analysis indicate the integrative nature of the cortico-subcortical activities connected to the verbal expression of emotional
prosody. Nevertheless, the dominant role in this process belongs to the cortical structures of the right hemisphere.

Conflict of interest

None declared.

Acknowledgement and Financial support

None declared.

Ethics

The work described in this article has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans: Uniform Requirements for manuscripts submitted to Biomedical journals.

REFERENCES


