VISUAL FEEDBACK BASED ON EXPIRED CO₂ AS A THERAPY METHOD FOR RESPIRATORY DISTURBANCES IN STUTTERING

B. STANKIEWICZ, K. ZIELIŃSKI, M. DAROWSKI
Institute of Biocybernetics and Biomedical Engineering
Polish Academy of Sciences
Ks. Trojdena 4, 02-109 Warszawa, Poland
e-mail: barbara.stankiewicz@ibib.waw.pl

B. ADAMCZYK
Maria Curie-Skłodowska University
Institute of Physics
Pl. Marii Curie-Skłodowskiej 1, 20-031 Lublin, Poland

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A new CO₂-based visual feedback therapy method (VF) for respiratory disturbances in stuttering was preliminarily assessed. Sound and expired CO₂ signals were registered in 12 stutterers and 12 fluent speakers while speaking without and with VF to control breathing as well as during rest respiration, before each utterance. In stutterers, the end-tidal CO₂ (ETCO₂), the area under CO₂/a time curve (SCO₂), and the average emission of CO₂ (ECO₂ = SCO₂/t_breath_cycle) for the CO₂ peaks connected with the phrases containing tonic errors (with reference to rest respiration) were higher than those connected with fluent phrases ($p < 0.000001$). Thus, a tendency to hypoventilation caused by tonic errors was observed. The factors of breath ergonomics while speaking FE (based on both signals) of stutterers were lower than those in fluent speakers ($p < 0.001$). Using VF by stutterers increased FE ($p < 0.005$) and decreased stuttering intensity.

Key words: stuttering, respiratory disturbances, therapy, analysis of acoustic and CO₂ signals, visual feedback.

1. Introduction

Respiratory disturbances in stuttering appear as a lack of coordination between chest and abdominal movements while breathing, and the loss of the majority of inspired air before the start of speaking, speaking after the end of expiration, and shallow breathing [5]. These disturbances can be combined with the lack of coordination in respiration, phonation and articulation, with higher level of activity, hypertonia, clonic or tonic cramps of the muscles in the respiratory, phonation or articulation apparatus, and can lead to the impairment of gas exchange in alveoli, hypoventilation or hyperventilation [2–5, 8]. Aberrant Vital Capacity and Residual Volume were observed during spiro-
metric measurements, and decreased value of partial pressure of oxygen in the arterial blood (PaO$_2$) during gasometry in Pruszewicz’s study [5]. The results of the simulative study of Adamczyk indicated that the ratio of CO$_2$/O$_2$ in exhaled air while stuttering differed from that obtained during fluent speech [1]. Some of the hypothetical reasons for a decrease in PaO$_2$ in stutterers indicated by Pruszewicz included alveolar hypoventilation, ventilatory-diffusive disturbances and an increase in diffusive resistance.

Lung ventilation changes can be detected and assessed by means of the parameters of the capnographic curve (CO$_2$/a time signal) [3, 6, 7]. A newly designed computer controlled system for the therapy of respiratory disturbances in stuttering consisted of a capnograph, notebook, headset, microphone and specialist software for transmitting, storing, and analyzing registered acoustic and capnographic time curves. This application makes it possible to conduct a therapy of respiratory disturbances in stuttering by means of visual feedback method based on CO$_2$ registered during an utterance. The signal together with the lower and the upper standard limits for end-tidal CO$_2$ (ETCO$_2$) are visible on the computer screen on-line. To control breathing while speaking with VF method, the rhythm and depth of inspirations and expirations ought to match individual values of end-tidal CO$_2$ of the capnographic curve of an utterance within the marked standard range.

2. Subjects and method

12 stutterers and 12 fluent speakers, aged 14–37, took part in the test of a new therapy method of respiratory disturbances in stuttering. The test consisted of 1) speaking, 2) speaking with end-tidal CO$_2$ based visual feedback to control breathing as well as rest respiration before each utterance. During the test acoustic and CO$_2$ signals in time were recorded. On the basis of the signals recorded 1) the end-tidal CO$_2$ (ETCO$_2$), 2) the area under CO$_2$/a time curve (SCO$_2$), 3) the average emission CO$_2$ (ECO$_2$ = SCO$_2$/t$_{breathing\_cycle}$), and 4) the factor of breath ergonomics while speaking (FE) were determined (Fig. 1). In addition to that, the intensity of stuttering for stutter-

![Diagram](image)

**Fig. 1.** Determining of the parameters of ETCO$_2$, SCO$_2$, ECO$_2$, and FE. Ph – the number of the CO$_2$ peaks connected with speaking, R – the number of the CO$_2$ peaks within the standard range for ETCO$_2$, A – the number of all the peaks of the capnographic curve [7].
ers’ utterances was calculated for each speaker. On the basis of rest respiration before speaking, the standard range for end-tidal CO₂ was determined.

3. Results

A 2-way MANOVA analysis was carried out to compare the results obtained for stutterers and fluent speakers while speaking and while speaking with CO₂ based visual feedback (VF). The GROUP factor had two levels i.e. 1 – stutterers, and 2 – fluent speakers. The CONDITION factor also had two levels, i.e. 1 – speaking, and 2 – speaking with VF. The following parameters were used as variables:

1) \( \Delta \text{ETCO}_2 = \text{ETCO}_2 \text{ (the utterance)} - \text{ETCO}_2 \text{ (rest respiration)} \),
2) \( \Delta \text{SCO}_2 = \text{SCO}_2 \text{ (the utterance)} - \text{SCO}_2 \text{ (rest respiration)} \),
3) \( \Delta \text{ECO}_2 = \text{ECO}_2 \text{ (the utterance)} - \text{ECO}_2 \text{ (rest respiration)} \),
calculated on the basis of full capnographic curves of the utterance and rest respiration, and
4) the FE factor of breath ergonomics while speaking,
determined on the basis of full capnographic and acoustic signals of the utterance.

The MANOVA analysis indicated that while the GROUP and CONDITION factors were significant, while their interaction was not (Table 1).

<table>
<thead>
<tr>
<th>Factor:</th>
<th>Wilks' lambda</th>
<th>R Rao</th>
<th>df 1</th>
<th>df 2</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUP</td>
<td>0.736</td>
<td>3.68</td>
<td>4</td>
<td>41</td>
<td>&lt; 0.05*</td>
</tr>
<tr>
<td>CONDITION</td>
<td>0.641</td>
<td>5.75</td>
<td>4</td>
<td>41</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>GROUP \times CONDITION</td>
<td>0.888</td>
<td>1.30</td>
<td>4</td>
<td>41</td>
<td>NS</td>
</tr>
</tbody>
</table>

The results of the post-hoc Tuckey tests indicated that only the FE factor had an effect on the GROUP and CONDITION factors significance, i.e. an effect on the significance of the difference in respiratory process while speaking between the examined groups and the significance of the difference between the afore mentioned types of utterances. The mean values of \( \Delta \text{ETCO}_2 \), \( \Delta \text{SCO}_2 \) and \( \Delta \text{ECO}_2 \) did not have any bearing in detecting any differences. This may be attributed to the mixed, tonic-clonic character of the errors connected with stuttering. Although repetitions, prolongations and blockades were dominant in the utterances of stutterers, there was also a certain number of sounds, syllables, words or phrases insertions as well as respiratory insertions.

The indicators of breath ergonomics while speaking (FE) obtained for utterances of stutterers (58%) were significantly lower \( (p < 0.001) \) than those for fluent speakers’ (75%). Besides, the values of FE obtained (for all persons) while speaking without VF
B. STANKIEWICZ et al.

(57%) were significantly lower \((p < 0.0005)\) than during speaking with visual feedback (76%). The values of FE obtained for stutterers during speaking with VF (69%) were significantly higher \((p < 0.005)\) than while speaking without VF (46%). Additionally, stuttering intensity decreased from 10±5% while speaking to 6±4% while speaking with VF. The FE values obtained by stutterers while speaking with VF did not differ statistically from those obtained by fluent speakers while speaking as well as speaking with VF. Figure 2 shows FE values obtained by two groups of people during two types of speaking.

![Figure 2. Mean values of the FE indicator obtained for stutterers and fluent speakers while speaking and speaking with CO\(_2\) based visual feedback to control breathing.](image)

As shown in Fig. 2, the FE values for speaking with visual feedback were higher than those for speaking without VF both in stutterers and in fluent speakers. Both groups reacted similarly to the change of speaking conditions – the \(GROUP \times CONDITION\) interaction was not significant (see Table 1).

Based on the values of ETCO\(_2\), SCO\(_2\), and ECO\(_2\) parameters received for individual CO\(_2\) peaks of capnographic curves of the stutterers’ utterances and mean values of the parameters obtained for rest respiration, the values of \(\DeltaETCO_2\), \(\DeltaSCO_2\), and \(\DeltaECO_2\) were determined. Afterwards a 1-way MANOVA analysis was carried out to compare the phrases containing tonic errors (repetitions, prolongations, and blockades) with the fluent phrases in the stutterers’ utterances. The \(PHRASES\) factor occurred on two levels, i.e. 1 – non-fluent phrases, 2 – fluent phrases. The analysis showed that the difference between the values of \(\DeltaETCO_2\), \(\DeltaSCO_2\), and \(\DeltaECO_2\) parameters obtained for non-fluent and fluent phrases was highly significant (Wilks’ lambda = 0.71; RRao(3, 96) = 13.1; \(p < 0.000001\)).

The results of post-hoc Tuckey tests indicated that all three parameters (i.e. \(\DeltaETCO_2\), \(\DeltaSCO_2\), and \(\DeltaECO_2\)) had an effect on the significance of the difference between non-fluent and fluent phrases; for each parameter \(p < 0.0005\). The results are shown in Figs. 3–5.

The mean value of \(\DeltaETCO_2\) received for CO\(_2\) peaks connected with non-fluent phrases containing tonic errors totaled approximately 0.5%, and for CO\(_2\) peaks connected with fluent phrases of stutterers’ utterances it stood ar \(-0.3\%\). The difference was significant at the level of \(p < 0.0005\) (Fig. 3). The mean value of \(\DeltaSCO_2\) received
VISUAL FEEDBACK BASED ON EXPIRED CO\textsubscript{2} AS A THERAPY METHOD ...

**Fig. 3.** Mean values of end-tidal CO\textsubscript{2} changes while speaking in relation to rest respiration, standard deviation (SD) and standard error (SDER) for non-fluent phrases containing tonic errors and fluent phrases of the stutterers’ utterances.

**Fig. 4.** Mean values of the change of the area under CO\textsubscript{2}/time curve while speaking in relation to rest respiration, standard deviation (SD) and standard error (SDER) obtained for non-fluent phrases containing tonic errors and fluent phrases of the stutterers’ utterances.

**Fig. 5.** Mean values of the change of average CO\textsubscript{2} emission while speaking in relation to rest respiration, standard deviation (SD) and standard error (SDER) obtained for non-fluent phrases containing tonic errors and fluent phrases of the stutterers’ utterances.

for CO\textsubscript{2} peaks connected with non-fluent phrases amounted to approximately 9\%*s, and for the CO\textsubscript{2} peaks connected with fluent phrases amounted \(-4\% *s; p < 0.0005\) (Fig. 4). The mean value of \Delta ECO\textsubscript{2} received for CO\textsubscript{2} peaks connected with phrases...
containing tonic errors was close to zero, while for fluent phrases of stutters' utterances amounted to $-0.7\%$; $p < 0.0005$ (Fig. 5).

4. Conclusions

The MANOVA comparative analysis of $\Delta \text{ETCO}_2$, $\Delta \text{SCO}_2$, and $\Delta \text{ECO}_2$ of CO$_2$ peaks connected with the non-fluent phrases containing tonic errors and CO$_2$ peaks connected with fluent phrases of the stutters’ utterances showed that the former had significantly higher values of all these parameters. It follows that tonic errors which were dominant while stuttering caused lung ventilation decrease aiming to hypventilation.

The MANOVA analysis proved that the stutters’ utterances had significantly lower breathing ergonomics indicators (FE) than the utterances made by fluent speakers. The values of breath ergonomics while speaking with visual feedback significantly increased and stuttering intensity decreased with respect to speaking without VF. Besides, there was no statistical difference in the FE values obtained for stutters while speaking with VF and those obtained for fluent speakers while normal speaking and while speaking with VF.

In view of the above, the CO$_2$-based visual feedback seems to be promising therapy method of respiratory disturbances in stuttering.

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