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VISUAL FEEDBACK BASED ON EXPIRED CO_2 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 CO_2-based visual feedback therapy method (VF) for respiratory disturbances in stuttering was preliminarily assessed. Sound and expired CO_2 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 CO_2 ($ETCO_2$), the area under CO_2/a time curve (SCO_2), and the average emission of CO_2 ($ECO_2 = SCO_2/t_{\mathrm{breath\_cycle}}$) for the CO_2 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 CO_2 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 spirometric 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 capnoraphic 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 ($ECO_2 = SCO_2/t_{\text{breathing\_cycle}}$), and 4) the factor of breath ergonomics while speaking (FE) were determined (Fig. 1). In addition to that, the intensity of stuttering for stutter-

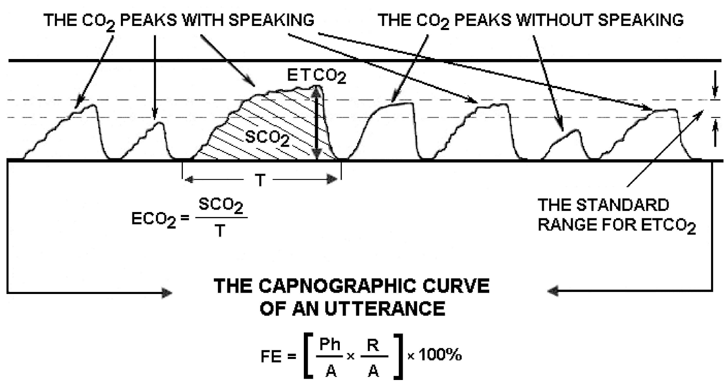

Fig. 1. Determining of the parameters of $ETCO_2$, SCO_2, ECO_2, and FE. Ph – the number of the CO_2 peaks connected with speaking, R – the number of the CO_2 peaks within the standard range for $ETCO_2$, A – the number of all the peaks of the capnographic curve [7].

ers' utterances was calculated for each speaker. On the basis of rest respiration before speaking, the standard range for end-tidal CO_2 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 CO_2 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) $\Delta ETCO_2 = ETCO_2$ (the utterance) $-$ $ETCO_2$ (rest respiration),
2) $\Delta SCO_2 = SCO_2$ (the utterance) $-$ SCO_2 (rest respiration),
3) $\Delta ECO_2 = ECO_2$ (the utterance) $-$ ECO_2 (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 1. The MANOVA analysis results – comparison of $\Delta ETCO_2$, ΔSCO_2, ΔECO_2 and FE values obtained for stutterers and fluent speakers while speaking and speaking with visual feedback. The GROUP factor at the level of 1 – stutterers, and 2 – fluent speakers. The CONDITION factor at the level of 1 – speaking, and 2 – speaking with VF.

Factor:	Wilks' lambda	R Rao	df 1	df 2	p
GROUP	0.736	3.68	4	41	$< 0.05*$
CONDITION	0.641	5.75	4	41	$< 0.001*$
GROUP $\times$ CONDITION	0.888	1.30	4	41	NS

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 $\Delta ETCO_2$, ΔSCO_2 and ΔECO_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

(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.

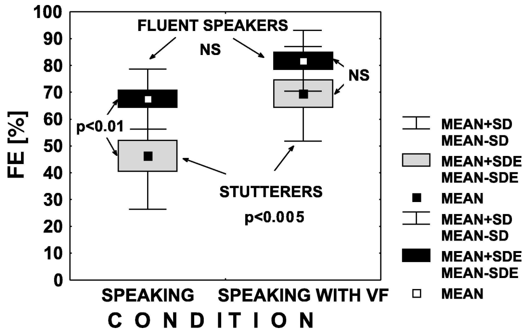

Fig. 2. Mean values of the FE indicator obtained for stutterers and fluent speakers while speaking and speaking with CO_2 based visual feedback to control breathing.

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* × *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 stuttereres' utterances and mean values of the parameters obtained for rest respiration, the values of $\Delta ETCO_2$, ΔSCO_2, and ΔECO_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 stuttereres' 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 $\Delta ETCO_2$, ΔSCO_2, and ΔECO_2 parameters obtained for non-fluent and fluent phrases was highly significant (Wilks' $\mathrm{lambda} = 0.71$; $\mathrm{RRao}(3, 96) = 13.1$; $p < 0.000001$).

The results of post-hoc Tuckey tests indicated that all three parameters (i.e. $\Delta ETCO_2$, ΔSCO_2, and ΔECO_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 $\Delta ETCO_2$ 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 ΔSCO_2 received

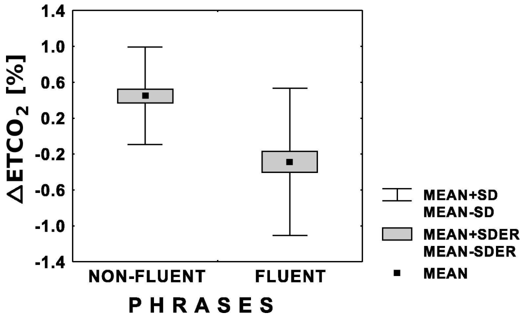

Fig. 3. Mean values of end-tidal CO_2 changes while speaking in relation to rest respiration, standard deviation (SD) and standard error (SDER) for non-fluent phrases containing tonic errors and fluent phrases of the stutterers' utterances.

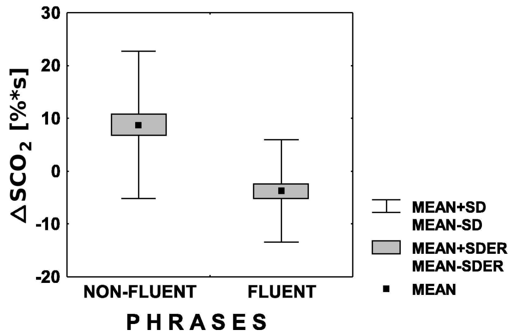

Fig. 4. Mean values of the change of the area under CO_2/time curve while speaking in relation to rest respiration, standard deviation (SD) and standard error (SDER) obtained for non-fluent phrases containing tonic errors and fluent phrases of the stutterers' utterances.

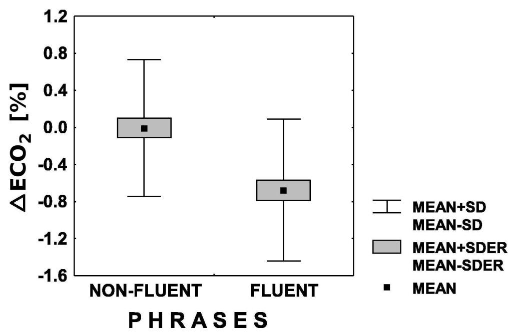

Fig. 5. Mean values of the change of average CO_2 emission while speaking in relation to rest respiration, standard deviation (SD) and standard error (SDER) obtained for non-fluent phrases containing tonic errors and fluent phrases of the stutterers' utterances.

for CO_2 peaks connected with non-fluent phrases amounted to approximately 9%*s, and for the CO_2 peaks connected with fluent phrases amounted -4%*s; $p < 0.0005$ (Fig. 4). The mean value of ΔECO_2 received for CO_2 peaks connected with phrases containing tonic errors was close to zero, while for fluent phrases of stutterers' utterances amounted to -0.7%; $p < 0.0005$ (Fig. 5).

4. Conclusions

The *MANOVA* comparative analysis of $\Delta ETCO_2$, ΔSCO_2, and ΔECO_2 of CO_2 peaks connected with the non-fluent phrases containing tonic errors and CO_2 peaks connected with fluent phrases of the stutterers' 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 hipoventilation.

The *MANOVA* analysis proved that the stutterers' 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 stutterers 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.

Acknowledgments

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