Acta Neurologica Belgica (2021) 121:113–118
https://doi.org/10.1007/s13760-019-01261-w

ORIGINAL ARTICLE

The effect of EMG biofeedback on lower extremity functions in hemiplegic patients

Gülseren Dost Sürücü[1] · Özge Tezen[1]

Received: 11 October 2019 / Accepted: 11 December 2019 / Published online: 2 January 2020

Abstract
The aim of this study was to investigate the efficacy of electromyography biofeedback (EMG BF) therapy in the treatment of ankle dorsiflexion which complicates ambulation in patients who developed hemiplegia after a cerebrovascular accident (CVA). A total of 40 patients attending the inpatient rehabilitation programme who developed hemiplegia after CVA were included in this randomized controlled study. The patients were randomly divided into two groups. In the 20 patients included in the EMG BF group, a visual and auditory EMG BF therapy was applied to tibialis anterior muscles, the extensor of the ankle, 5 days a week for 3 weeks in addition to conventional physiotherapy. The other 20 patients in the control group were only treated with conventional physiotherapy applications. All patients were evaluated for spasticity, ankle range of movement (ROM) scores, the Modified Motor Assessment Scale (MMAS) scores, Brunnstrom's neurophysiological assessment and EMG BF electrical muscle activity before and after treatment. There were significant improvements in the posttreatment ROM, Brunnstrom and MMAS values in both groups, whereas the levels of significance were mostly higher in the EMG BF group than in the control group. In addition, there were no significant changes in spasticity and electrical activity of tibialis anterior muscles in the control group while the EMG BF group demonstrated significant changes. This study showed that the clinical and functional parameters were improved by the use of EMG BF therapy for lower extremities, in addition to conventional rehabilitation programs, in hemiplegic patients with walking difficulty due to insufficient ankle dorsiflexion.

Keywords EMG biofeedback · Stroke · Rehabilitation · Exercise

Introduction

The cerebrovascular accident (CVA) is a non-traumatic brain injury characterized by neurological deficits such as loss of motor function, sensory changes, cognitive dysfunction, speech disorder or coma resulting from occlusion or rupture of blood vessels in the brain [1, 2].

Majority of CVA, an ischemic or hemorrhagic brain injury, is characterized by acute focal neurological deficits and is referred to as stroke [3]. The goal of rehabilitation of hemiplegia after CVA is to rapidly retrieve the patient's maximal functional capacity, particularly physical capacity, and help the patient acquire as much independence and productivity as possible. Therefore, acquiring postural control, functionalizing upper extremities and providing ambulation training in the early treatment in a short time will facilitate the patient's independence in the activities of daily living [4]. The main focus in most of the post-stroke rehabilitation is on the recovery of motor function and walking ability. Various approaches are used for motor recovery, but the effectiveness and superiority of these applications are controversial. Until today, corrective exercises based on orthopedic principles, neurophysiological exercises and motor learning techniques have been widely used [5].

EMG biofeedback (EMG BF) is one of the techniques supporting motor learning techniques and has been used in rehabilitation for over 40 years [6]. EMG BF therapy is based on the enhancement of myoelectric signals obtained from the muscles, which then were converted into visual and auditory signals with the aim to inform the individual about the activity of muscles [7]. Some meta-analyses revealed some evidence that the use of EMG BF was helpful in

✉ Gülseren Dost Sürücü
gulserendost@hotmail.com

Özge Tezen
ozgetezen77@gmail.com

[1] Department of Physical Medicine and Rehabilitation, Faculty of Medicine, Adıyaman University Education and Research Hospital, Adıyaman, Turkey

combination with standard physiotherapy techniques and that randomized clinical trials were needed for further confirmation [8].

The aim of this study was to investigate the clinical and functional effects of EMG BF on the lower extremities of patients developing hemiplegia after CVA.

Subjects and methods

This study was approved by the local ethics committee of our hospital. In this study, 40 adequate patients were included after obtaining their informed consent, out of a total of 339 patients who developed hemiplegia after CVE and were admitted to the inpatient rehabilitation program. The patients' age, gender, educational background, etiology, hemiplegic sides, duration of hemiplegia and systemic diseases, if any, were recorded. The adequate patients who were cooperative, motivated and willing to work, had no vision-hearing problems and sensorial aphasia, good sitting balance, no ankle dorsiflexion (Brunnstrom stage 3) and had no serious systemic disease were included in the study. The patients who were uncooperative had vision and hearing problems, no sitting balance, severe systemic diseases, peripheral vascular diseases in the lower extremity, those other than the Brunnstrom lower extremity stage 3 and those with ankle contracture were excluded from the study. They were divided into two groups as the control group and the study group. Twenty patients in the control group were rehabilitated with the conventional methods such as ankle range of motion (ROM) exercises, stretching exercises and Brunnstrom exercises (It is based on the specific synergies being clarified through various cutaneous and proprioceptive stimuli and central facilitation) [9], whereas 20 patients in the study group underwent EMG BG therapy for 3 weeks, 5 days a week, 20 min each session equalling to a total of 15 sessions, in addition to the conventional methods.

Neuromuscular examination and functional evaluations

The Modified Ashworth Scale (MAS) was used to evaluate spasticity. (0) no increase in muscle tone; (1) slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the range motion (ROM) when the affected part(s) is/are moved in flexion or extension; (2) slight increase in muscle tone, manifested by a catch in the middle range and resistance throughout the remainder of the ROM, but affected part(s) moved easily; (3) significant increase in muscle tone through most of the ROM, but affected parts moved easily; (4) considerable increase in muscle tone, passive movement difficult; 5: affected part(s) rigid in flexion or extension [10].

The ankle ROM on the hemiplegic side lower extremities was measured and recorded with a goniometer in supine position before and after the treatment.

Muscle strength of the patients was evaluated with Brunnstrom's neurophysiological assessment and recorded before and after treatment. This test describes six stages of the stroke recovery process in hemiplegic patients. According to this staging model, the lowest stage was determined as stage I (flaccid, no voluntary movement), whereas the highest stage was determined as stage VI (isolated joint movement). Upper extremity, lower extremity and hands are evaluated separately [11].

The sitting to standing and walking sub-scales in the Modified Motor Assessment Scale (MMAS) were used to evaluate the functional status of participants before and after treatment. *Sitting to standing*; 0: not able (1) gets to standing with help from therapist (2) may need help (uneven weight distribution, uses hands for support) (3) gets to standing without using hands (4) gets to standing in 5 s. Extension of hips and knees (5) sitting and standing with no help. Full extension of hips and knees (6) sitting and standing with no help three times in 10 s. *Walking;* (0) not able (1) stands on the affected leg and steps forward with other leg. (2) walks with stand-by help from one person. (3) walks 3 m alone or uses any aid. (4) walks 5 m with no aid in 15 s. (5) walks 10 m with no aid, turns around, picks up a small sandbag from floor and walks back in 25 s. (6) walks up and down 4 steps with or without aid three times in 35 s [12].

EMG BF therapy

Electronica Pagani Italy Modular Biofeedback™ device was used for EMG BF therapy. The device consisted of computers and modular units. The modular device was operated on a 9-v alkaline battery and connected to the computer with a fiber-optic cable. The modular device had four channels, each of which allowed the use of three superficial electrodes. During the EMG BF therapy, the patient was placed in a quiet room and seated on a chair with hemiplegic lower extremity knee and ankle in 90^0 flexion. After the surface electrodes were cleaned with alcohol cotton, they were placed in the motor point of the tibialis anterior muscle for optimum activity. The modular EMG BF device was operated and all the EMG signals acquired from the muscles were transmitted into the computer via a fiber-optic cable. The voltage–time graph was displayed and the peak values were measured in microvolts (μV) and recorded. Patient muscle activity was monitored on the computer screen in the form of visual and auditory signals. The upper and lower limits were determined in microvolts on which the muscle activity of the patient was desired to be kept on a bar graph (column graph) displaying the increase–decrease in parallel to muscle activity. When the muscle activity exceeded this limit, the device sent an audible warning and the patient tried to maintain the muscle activity within the desired range where the sound could be heard. The patients were taught to surpass the red–black line on the bar graph and maintain muscle activity beyond the isoelectric line. In addition, we monitored the motor unit potentials on a line graph at the right of the column graph and provided the patient with verbal feedback from time to time.

Both the study and the control groups were told what they were expected to do. In the control group, the patients underwent some clinical scales for the evaluation of ambulation and functional status before and after the treatment and the efficacy of conventional treatment was assessed by measuring the muscle activity in microvolts. In the study group, the patients underwent EMG BF therapy, in addition to the conventional treatment, after measuring pre-treatment muscle activity in microvolt and applying relevant scales to determine the status of ambulation and functions. After 15 sessions of therapy, we repeated and recorded the EMG BF muscle activity measurement in microvolts and relevant clinical scales for ambulation and functional status. After 15 sessions of therapy, we repeated the EMG BF muscle activity measurement in microvolts and relevant clinical scales for ambulation and functional status.

The patients in both groups were evaluated for MAS, ankle active ROM measurement, Brunnstrom's neurophysiological assessment, MMAS scores and EMG BF electrical muscle activity measurement before and after treatment.

Both groups were statistically evaluated using the 'Statistical Package for Social Sciences' (SPSS) programme for Windows. Categorical variables were presented as percentage, and continuous variables were presented as mean ± standard deviation (minimum–maximum). In the study, student's t test, Chi-square test, Wilcoxon signed Ranks test, Mann–Whitney U test and the Spearman's correlation test were used for the evaluation. The significance level was accepted as $p < 0.05$ in all statistical analyses.

Results

Of the hemiplegic 20 patients in the EMG BF group, 13 were female and 7 were male; of 20 patients included in the control group, 12 were female and 8 were male. The mean duration of hemiplegia was 117 + 22.6 (min:30, max:352) days in the study group and 110 + 20.6 (min:34, max:297) days in the control group. There was no statistically significant difference in age, gender, hemiplegic side, hemiplegia etiology, duration of hemiplegia and systemic diseases between the groups (Table 1, $p > 0.05$).

Table 1 Demographic and clinical characteristics of the groups

	The EMG BF group (n = 20) (mean ± SD)	The control group (n = 20) (mean ± SD)	PA[a,b]
Age	60.55 ± 2.45	65.30 ± 1.40	> 0.05
Gender		12 (60%)	
Female	13 (65%)	8 (40%)	> 0.05
Male	7 (35%)		> 0.05
Side			
Right hemiplegia	11 (55%)	12 (60%)	>0.05
Left hemiplegia	9 (45%)	8 (40%)	>0.05
Etiology			
Thromboemboli	16 (80%)	18 (90%)	> 0.05
Haemorrhage	4 (20%)	2 (10%)	> 0.05
Duration of hemiplegia (day)	117 ± 22.6	110 ± 20.6	> 0.05
Systemic disease	17 (85%)	19 (95%)	> 0.05

[a,b] t test and Chi-square test for independent variables

In both groups, the Ashworth Scale (AS) for the assessment of spasticity in lower extremities revealed no significant difference in pre-treatment and post-treatment spasticity ($p > 0.05$); whereas there was a significant difference between the admission and discharge values in the study group ($p < 0.05$) and there was no difference between the admission and discharge values in the control group ($p > 0.05$). (Table 2)

There was no significant difference in the pre-treatment values of active ankle dorsiflexion range of motion between the study and control groups ($p > 0.05$). No statistically significant difference was found in the post-treatment values of active ankle dorsiflexion range of motion between the study and control groups ($p > 0.05$). The difference was in favor of the EMG BF group. Comparison of the values before and after treatment in both groups revealed that there was an increase in the post-treatment values compared to the pre-treatment values, which was more significant in the BF group (Table 3).

There was no significant difference in the pre-treatment of Brunnstrom-lower extremity values between the study and control groups ($p > 0.05$). However, there was a significant difference in the post-treatment Brunnstrom-lower extremity values between the study and control groups ($p < 0.01$). The post-treatment Brunnstrom-lower extremity values were found higher in the EMG BF group (Table 4).

In addition, the motor assessment of both groups demonstrated that there was no significant difference between the pre-treatment values of the MMAS scale in sitting to standing and walking sub-scales ($p > 0.05$), whereas the comparison of post-treatment values revealed a statistically

Table 2 Number of patients and comparisons by lower extremity spasticity in the groups

Degree of spasticity (ASH)	Pre-treatment				Post-treatment					p^b
	0	1	2	4	0	1	2	3	4	
The EMG BF group	7	7	5	1	8	11	0	0	1	*p < 0.05*
The control group	8	7	5	0	8	10	1	1	0	$p > 0.05$
p^a	$p > 0.05$				*p < 0.05*					

[a]The Mann–whitney test

[b]Wilcoxon signed ranks test, statistically significant values are shown in italic font

Table 3 Values of active ankle dorsiflexion range of motion (°) in the groups

	Pre-treatment	Post-treatment	p^b
The EMG BF Group	6.50 ± 1.08	18.26 ± 2.45	**< 0.001**
The control group	7.27 ± 1.30	11.62 ± 2.14	**< 0.01**
p^a	$p > 0.05$	p **< 0.05**	

[a]Student's t test

[b]Wilcoxon Signed Ranks test; statistically significant values are shown in italics

Table 4 Results of the Brunnstrom (Bs) assessment for lower extremity in the study and control groups

Brunnstrom (Bs)	Pre-treatment	Post-treatment			p^b
	Stage 3	Stage 3	Stage 4	Stage 5	
The EMG BF group	20 (100%)	6 (30%)	10 (50%)	4 (20%)	*< 0.01*
The control group	20 (100%)	14 (70%)	6 (30%)	0 (0%)	*< 0.05*
p^a	$p > 0.05$	*p < 0.01*			

[a]The Mann–whitney test

[b]Wilcoxon signed ranks test, statistically significant values are shown in italic font

significant difference in sitting to standing and walking subscales in favor of the control group ($p < 0.01$) (Table 5).

The evaluation of the EMG BF activities in tibialis anterior muscles acquired by surface electrodes in both groups revealed that there was no significant difference in pre-treatment EMG BF values ($p > 0.05$). However, there was a significant difference in post-treatment values ($p < 0.05$). There was a significant difference between the pre and post-treatment values in the study group ($p < 0.01$). There was no significant difference between the pre and post-treatment values in the control group ($p > 0.05$) Table 6).

It was noted that EMG BF therapy was significantly correlated with Brunnstrom's neurophysiological assessment at discharge ($r = 0.517$), ankle ROM at discharge($r = 0.501$), the MMAS sitting to standing ($r = 0.453$) and walking scores at discharge ($r = 0.409$) and spasticity at discharge ($r = 0.447$).

Discussion

The goal of rehabilitation of hemiplegia after CVA is to rapidly retrieve the patient's maximal functional capacity, particularly physical capacity, and help the patient acquire as much independence and productivity as possible. Therefore, the acquisition of postural control, functionalization of upper extremities and ambulation training in the early period will improve patients' independence level in activities of daily living. In patients developing hemiplegia after CVA, walking ability is a major factor in determining whether the individual can completely regain productivity or not.

Our study results showed that the improvements in ROM, muscle strength, muscle tone and functions were much higher in the hemiplegic patients who were rehabilitated with lower extremity EMG BF combined with conventional physiotherapy compared to those who were only treated with conventional physiotherapy.

EMG BF has been investigated as a treatment modality for neuromuscular education of neurological diseases since

Table 5 Pre-treatment and post-treatment Modified Motor Assessment Scale (MMAS) scores in the study and control group

	Pre-treatment		Post-treatment		p^b
	Sitting to standing	Walking	Sitting to standing	Walking	
The EMG BF Group	1.80 ± 0.99	1.55 ± 0.94	2.65 ± 1.07	2.65 ± 0.89	*< 0.001*
The control group	1.80 ± 0.52	1.75 ± 0.68	2.60 ± 0.84	2.70 ± 0.83	*< 0.01*
p^a	$p > 0.05$		*p < 0.05*		

[a]The Mann–Whitney test

[b]Wilcoxon Signed Ranks test, statistically significant values are shown in italic font

Table 6 Pre-treatment and post-treatment EMG BF activities in Tibialis anterior muscles in the study and control group (μV)

	Pre-treatment	Post-treatment	p^b
The EMG BF group	288.83 ± 6.44	314.21 ± 6.93	*< 0.01*
The control group	290.62 ± 5.98	289.05 ± 8.50	> 0.05
p^a	$p > 0.05$	*p < 0.05*	

[a]Student's t test

[b]Wilcoxon Signed Ranks test; statistically significant values are shown in italic font

1960. Several studies have been published supporting the favorability of EMG BF since 1973 [13]. Although EMG BF has been used for many years, the effectiveness of this technique is still under debate. In a meta-analysis of 8 randomized controlled trials published in 1998, it was reported that EMG BF was superior to the conventional therapies in strengthening the ankle DF in stroke patients [14]. On the other hand, another meta-analysis of 13 randomized controlled trials noted that EMG BF was no superior to standard physiotherapy [8]. These meta-analyses evaluated muscle strength, ROM, walking and functional parameters, but they did not include muscle tone.

In our study, we obtained statistically significant improvements in Brunnstrom values in the EMG BF group. Isolated muscle strength cannot be assessed objectively as synergy patterns are dominant in hemiplegic patients. However, the majority of the relevant studies evaluated isolated muscle strength, whereas we used Brunnstrom's neurophysiological assessment in our study.

Several studies reported that the motor assessment in hemiplegic patients could be safely performed using the MMAS [15]. In our study, the patients' motor functions were also assessed by the MMAS sitting to standing and walking subscales and Brunnstrom's neurophysiological assessment in the EMG BF and the control group. There was no significant difference in the pre-treatment values between the groups, whereas the post-treatment scale assessment revealed a significant difference between the groups, in favor of the EMG BF group. Cozean et al. carried out a study in which they aimed to improve gait in patients with post-stroke hemiplegia and found out that EMG BF combined with Functional Electric Stimulation (FES) was useful in the recovery of knee and ankle as well as walking speed and returning to everyday life [16]. Arpa et al. carried out a study including 34 patients, in which they designed randomized controlled groups as EMG BF + exercise and sham EMG BF + exercise, they observed significant improvements in the values of ROM, muscle strength, Barthel index and 10 m walking test, except for spasticity, in both groups, but they reported no statistically significant difference between the groups [17]. The fact that there was no difference between both groups was attributed to the short disease duration. The evaluation of these studies mainly indicates that EMG BF is useful for improving motor functions and walking speed as well as increasing ROM and muscle activation. However, there are also studies revealing negative results on the efficacy of EMG BG therapy [18]. These contradicting results can be mostly attributed to the limited number of patients, different study designs, different disease duration and limited number and duration of EMG BF sessions.

EMG BF is based on the principle of acquiring a conscious awareness of movements that are usually made unconsciously, thus helping patients gain control over their movements. Individuals cannot be aware of muscle activity without the sense or sight of muscle contraction. Early-stage stroke patients may experience unfelt or unseen minimal contractions which can be displayed electrically and usually transmitted to patients in the auditory form. The visual feedback of such early-stage voluntary contraction encourages the patient and helps gain control over muscles. The device will flash a warning light in undesired muscle contractions and so the patient learns to suppress synergistic movements [19]. The efficiency of feedback for drop-foot in hemiplegia results from the activation of neuromotor pathways. There are 2 theories as to how this happens. The first one supports that new pathways are formed or previous cerebral and spinal pathways and networks are activated by the stimulation with feedback. The second one supports that the remaining proprioceptive senses are regulated by visual and acoustic warnings. The latter is more widely accepted [20]. Various researchers noted that motivation was a critical factor in achieving maximum success [21]. We also provided our patients with "verbal feedback" to motive them and help them concentrate.

There were some limitations in this study. (1) We did not classify our patients according to the duration of disease as acute, subacute and chronic. (2) Only 15-session evaluation was included in the pre-treatment and post-treatment assessment of patients. Long-term post-treatment outcomes could not be assessed. (3) The total number of sessions was limited to 15. (4) We categorized the patients into two groups as the EMG BF group and the EMG BF + exercise group. A third sham EMG BF + Exercise group could have been created.

Conclusion

This study showed that the clinical and functional parameters were improved by the use of EMG BF therapy for lower extremities, in addition to conventional rehabilitation programs, in hemiplegic patients with walking difficulty due to insufficient ankle dorsiflexion.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

Ethical approval The study was performed in compliance with principles of Helsinki Declaration and approval of the local ethics committee was obtained.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Kim CM, Eng JJ (2003) The relationship of lower-extremity muscle torgue to locomotot performance in people with stroke. Phys Ther 83:49–57
2. Harris JE, Eng JJ, Marigold DS et al (2005) Relationship of balance and mobility to fall incidince in people with chronic stroke. Phys Ther 85:150–158
3. Yaltkaya K, Balkan S (1996) oğuz Y. Serebrovasküler hastalıklar 1196:179–215
4. Mc Dowell FH (1976) Rehabilitating patient with stoke. Postgrad Med 59:145–149
5. Pollock A, Baer G, Campbell P, Choo PL, Forster A, Morris J et al (2014) Physical rehabilitation approaches for the recovery of function and mobility following stroke. Cochrane Database Syst Rev 22:CD001920
6. Marinacci AA, Horande M (1960) Electromyogram in neuromuscular re-education. Bull Los Angel Neuro Soc 25:57–71
7. Glanz MKS, Chalmers T (1997) Biofeedback therapy in stroke rehabilitation: a review. J R soc Med 90:33–39
8. Woodford H, Price C (2007) EMG biofeedback for the recovery of motor function after stroke. Cochrane Database Syst Rev 18:CD004585
9. Swensen Jr (1984) Therapeutic exercise in hemiplegia. In: Basmajian JV (ed) Therapeutic exercise. Williams and Wilkins, Baltimore, p 557
10. Bohannon RW, Smith MB (1987) Interrater reliability of a modified Ashworth scale of muscle spasticity. Phys Ther 67:206–207
11. Sawner K, Lavigne J (1992) Brunnstrom's movement therapy in hemiplegia: a neurophysiological approach, 2nd edn. Lippincott, Philadelphia
12. Poole JL, Whitney SL (1988) Motor assessment scale for stroke patients; concurrent validity and interrater reliability. Arch Phys Med Rehabil 69:195–197
13. Rayegani SM, Raeissadat SA, Sedighipour L et al (2014) Effect of neurofeedback and electromyographic-biofeedback therapy on improving hand function in stroke patients. Top Stroke Rehal 21:137–157
14. Moreland JD, Thomson MA, Fuoco AR (1998) Electromyographic biofeedback to improve lower extremity function after stroke: a meta-analysis. Arch Phys Med Rehabil 79:134–140
15. Loewen SC, Anderson BA (1990) Predictors of stroke outcome using objective measurement scale. Stroke 21(1):78–81
16. Cozean CD (1988) Biofeedback and functional electric stimulation in stroke rehabilitation. Arch Phys Med Rehabil 69:401–405
17. Arpa S, Ozçakır S (2019) Does electromyographic biofeedback improve exercise effects in hemiplegic patients? J Rehabil Med 51:109–112
18. Peppen RP, van Kortsmit M, Lindeman E, Kwakkel G (2006) Effects of visual feedback therapy on postural control in bilateral standing after stroke: a systematic review. J Rehabil Med 38(1):3–9
19. Wade DT, Hever RV (1985) Recovery and rehabilitaion of physical loss, Stroke First edn. Champan and Hill Medicine, Durango, pp 235–260
20. Harvey RL (2010) Stroke syndromes. In: Braddom RL et al (eds) Physical medicine and rehabilitation, 4th edn. Elsevier, New York
21. Bogotaj V, Gross N (1989) Restoration of gait during two to 3 weeks of therapy with mutichannel electrical stimülation. Phys Ther 69(5):319–327