Scientific Research Publishing

Open Journal of Therapy and Rehabilitation, 2022, 10, 257-269
https://www.scirp.org/journal/ojtr
ISSN Online: 2332-1830
ISSN Print: 2332-1822

Comparison of Electromyography Responses in Spinal Cord Injury Patients Using an Operant Conditional Protocol Treatment

Christiane Pereira Cavalcante de Abreu*, Lucia Helena Storer Ribeiro, Maria Eugenia Mayr de Biase, Tarcisio Eloy de Pessoa Barros Filho

Institute of Orthopedics and Traumatology, Clinical Hospital, School of Medicine, University of São Paulo, São Paulo, Brazil
Email: *chrisabreu@gmail.com

How to cite this paper: de Abreu, C.P.C., Ribeiro, L.H.S., de Biase, M.E.M. and de Pessoa Barros Filho, T.E. (2022) Comparison of Electromyography Responses in Spinal Cord Injury Patients Using an Operant Conditional Protocol Treatment. *Open Journal of Therapy and Rehabilitation*, **10**, 257-269.
https://doi.org/10.4236/ojtr.2022.104018

Received: October 11, 2022
Accepted: November 21, 2022
Published: November 24, 2022

Abstract

Background Electromyography (EMG) biofeedback has been used in spinal cord injury rehabilitation, but optimal indication and treatment protocols still need to be identified. **Objectives** To use an operant conditioning learning paradigm to compare the EMG responses in subjects with spinal cord injury for optimal indication of EMG biofeedback treatment. **Participants** Thirty rehabilitation outpatients with incomplete cervical spinal cord injury. The subjects were divided into three groups based on their scores on the ASIA scale (ASIA B, ASIA C and ASIA D groups), with ten patients in each group. **Methods** Repeated-measure trials were conducted to compare patients' EMG responses between pre-initial and post-biofeedback treatment. In the sessions, visual feedback of EMG activity of the triceps brachii muscle was provided to the patient in accordance with the treatment protocol. **Results** One-way ANOVA and the Kruskal-Wallis test were used to examine the differences in the measures between groups. The initial EMG and final EMG measures were not significantly different between the ASIA C and D groups, but these measures were different between the ASIA B group and the ASIA C and D groups. In the ASIA B group, the EMG responses started out lower than those in the other groups and varied less, especially in comparison to the ASIA C group. **Conclusion:** These results reveal that the patients classified as ASIA C and D achieved better responses of the operant conditional learning protocol and optimal indication for the biofeedback treatment.

Keywords

Spinal Cord Injury, Biofeedback, Electromyography, Learning, Neuroplasticity

1. Introduction

Spinal cord injury (SCI) results from direct trauma to the tissue and is associated with loss of motor, sensory, and autonomic functions caudal to the site of injury [1], leading to a loss of independence. [2] The global incidence of SCI varies from 8.0 to 246.0 cases per million inhabitants per year. [3] In Brazil, the incidence of SCI is 40 new cases/year/million inhabitants. [4] SCI affects not only a patient's physical and psychological health but also the patient's family, the broader community and the economy. [5]

The goals of rehabilitation are mainly to improve quality of life through functional independence, social inclusion, and community reintegration [6] [7]. Patients have indicated that walking and standing are highly desirable goals. [8] To compensate for functional loss and to use parts of the sensory motor system that are still intact, professionals in the area use FES, locomotor training, [9] functional activities, muscle strength, electromyography (EMG) biofeedback [10] and home exercise. [11]

Biofeedback is an operant conditioning technique used to establish learned voluntary control of specific physiological responses. [10] A patient's biological information is measured, and feedback is provided to the patient to increase awareness and control over the biological process, [12] thereby providing visual and auditory information regarding muscle contraction and movements in real time. [13] SCI patients could increase the EMG responses of muscles below the level of injury after receiving EMG biofeedback, [10] and the subjected who used this technique could reduce their stretch reflex. [14] As observed in the literature, EMG biofeedback has been used in SCI, but studies regarding the optimal indication and protocols are necessary.

Therefore, this study aims to use an operant conditioning learning paradigm to compare the EMG responses in subjects with spinal cord injury for optimal indication of EMG biofeedback treatment. This study also describes future research directions.

2. Method

2.1. Subjects

The subjects were 30 individuals with quadriplegia resulting from incomplete cervical SCI, at level C6, C5 and C4, who presented for EMG biofeedback sessions and treatment at the University of Sant'Anna Rehabilitation Center, São Paulo and at the University of Miami Biofeedback Rehabilitation Center. At the time of the EMG testing and biofeedback sessions, all subjects had reached a plateau in their functional recovery and had already gone through physical therapy interventions. Individuals with other neurological disorders (e.g., brain injury, stroke, cognition disorders) were excluded. Subjects' clinical characteristics are listed in **Table 1**.

The subjects were evaluated according to the American Spinal Injury Association (ASIA) Impairment Scale [15] and divided into 3 groups (ASIA B, ASIA C and ASIA D) with 10 subjects per group. Each group presented the same level of recovery. Patients with gradation ASIA A and E were excluded. The subjects were outpatients at the University of Sant'Anna Rehabilitation Center, São Paulo and at the University of Miami Bio-Feedback Rehabilitation Center in august of 2002 for the period of one month treatment.

Subjects then signed a Participation Consent Form, previously authorized by the Committee of Ethics in Research of the Medical School of the University of São Paulo—USP. All the subjects consented to the use of their data for this study.

2.2. Material

EMG measurements were obtained with disposable surface electrodes (Ag/AgCl 3M®) connected to the Neuroeducator (Therapeutic Alliances, Inc). EMG was calculated by analysing the root mean square voltage with an integral noise level of less than 0.2 μV, a bandwidth of 10 to l000 Hz, and a common mode rejection better than 140 dB, with a sampling frequency of 1 kHz. EMG signals were integrated over 0.l sec, calibrated in μV sec, and displayed on the 20" colour monitor in the form of a continuous line updated every tenth of 1 sec for sweeps of 20 sec duration, [10] and visual feedback of the muscle was provided to the subject.

Table 1. Clinical characteristics of subjects—Q1 = 1st quartile; Q3 = 3rd quartile; SD = Standard Deviation; CV = Coefficient of variation; SW = Shapiro-Wilk test; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

Clinical Characteristics	General (n = 30)	ASIA B (n = 10)	ASIA C (n = 10)	ASIA D (n = 10)	p value
NEUROLOGICAL LEVEL (30)					
C4	9 (30%)	5 (50%)	4 (40%)	0 (0%)	0.072b
C5	16 (53.33%)	4 (40%)	4 (40%)	8 (80%)	
C6	5 (16.67%)	1 (10%)	2 (20%)	2 (20%)	
YEARS SINCE INJURY (30)					
Min-Max	1 - 7	1 - 7	1 - 6	1 - 7	0.722f ($\eta^2 = 0.05$)
Q1-Q3	2 - 4	2 - 4.75	1.25 - 3.75	2 - 4	
Median	2	3	2	2.5	
Mean	3.07	3.5	2.7	3	
SD	1.93	2.27	1.77	1.83	
CV	62.89%	64.94%	65.44%	60.86%	
SW	0.001**	0.120	0.106	0.137	
AGE IN YEARS (30)					
Min-Max	20 - 48	20 - 48	20 - 34	21 - 39	0.051f ($\eta^2 = 0.15$)
Q1-Q3	22.25 - 33.75	27.75 - 38.25	21 - 28	23.25 - 34	
Median	28	31.5	22	27	
Mean	29.1	33.6	24.8	28.9	
SD	7.95	9.3	5.29	6.81	
CV	27.33%	27.68%	21.32%	23.55%	
SW	0.009**	0.560	0.014*	0.140	

3. Procedures

3.1. EMG

The 3 disposable surface electrodes were positioned in the triceps brachii muscle. Two electrodes used to measure the electrical signal were positioned between the motor point and tendon insertion. The third electrode, which was positioned between the other two electrodes, was used as a reference and acted as the ground. The electrodes were connected to the Neuroeducator (Therapeutic Alliances, Inc).

For the initial EMG (EMGi) measurement, the patient was in the sitting position in a wheelchair in front of the 20” monitor, the shoulder was held in 90˚ flexion, and the elbow was held at a starting point of 90˚ flexion. The therapist instructed the patient to extend the right elbow and then the left elbow. The EMGi measure was obtained from the highest voluntary EMG response from the triceps brachii during elbow extension or the attempt of the movement.

3.2. Biofeedback Sessions

In the same position as the initial measures, the therapist held their own arm and provided instruction to the patients on how to perform an elbow extension; when possible, the therapist provided resistance. A criterion line was placed on the monitor in the upper standard deviation of the subject’s integrated EMG response. The subjects were advised that the moving line that they were about to see on the monitor was a reflection of the EMG signal of the triceps. The subjects were then informed that their task was to increase the magnitude of the moving line to a level higher than the criterion line. The subjects were given 20 seconds to complete the task and were verbally reinforced when the amplitude of the EMG was higher than the criterion line. After the 20-second trial was completed, the EMG data were analysed. If the magnitude of the voluntary EMG response was higher, then the set criterion line was raised to the upper standard deviation of the new larger EMG response. The procedure was repeated until the magnitude of the EMG reached a plateau. It was repeated as many times as the patient could do, and the right and left sides were alternated in the session with rest times in between. If the patient reached 640 microvolts in the EMG responses, they no longer needed to try because this was the value considered normal in the protocol.

Each patient had an individual file, and the highest EMG response of each session was collected. The highest EMG response in microvolts from all the sessions was used as the final EMG (EMGf) response.

4. Statistical Analysis

The homogeneity of the groups was tested using Fisher’s exact test for neurological level, and the equality of distribution of years since injury and age between ASIA groups was tested using the Kruskal-Wallis test. A p-value > 0.05 indicated that we should not reject the association or the equality of distributions.

The EMGi and EMGf on the right and left triceps and the variation between the initial and final measurements were analysed using one-way ANOVA. The Kruskal-Wallis test (nonparametric equivalent) was used to verify the differences between the groups Paired comparisons were made using Dunn's post-hoc test for the Kruskall Wallis test and Tukey's test for ANOVA. (Table 2)

Table 2. Triceps brachii EMG initial (EMGi) and final (EMGf) response—Q1 = 1st quartile; Q3 = 3rd quartile; SD = standard deviation; CV = coefficient of variation; SW = Shapiro-Wilk test; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

Characteristics	General (n = 30)	ASIA B (n = 10)	ASIA C (n = 10)	ASIA D (n = 10)	p value
Right triceps brachii - EMGi Mv (30)					
Min-Max	2 - 799	2 - 74	118 - 390	205 - 799	<0.001***f (η^2 = 0.78)
Q1-Q3	25.75 - 301	5.75 - 23	132.5 - 221	265 - 619.5	
Median	139.5	13.5	139.5	340	
Mean	213	19.5	189	430.5	
SD	214.77	21.43	93.19	211.38	
CV	100.83%	109.89%	49.31%	49.1%	
SW	<0.001***	0.006**	0.006**	0.121	
Right Triceps brachii - EMGf Mv (30)					
Min-Max	3 - 800	3 - 85	251 - 661	320 - 800	<0.001***e (η^2 = 0.69)
Q1-Q3	57.25 - 624.5	15.25 - 53	367.75 - 619.75	488.5 - 793.5	
Median	397.5	33	430.5	609	
Mean	370.07	34.5	465	610.7	
SD	281.91	26.53	152.61	180.61	
CV	76.18%	76.89%	32.82%	29.57%	
SW	0.008**	0.566	0.229	0.174	
Right side variation (30)					
Min-Max	0 - 497	1 - 38	112 - 423	0 - 497	<0.001***f (η^2 = 0.52)
Q1-Q3	17.25 - 260	5.75 - 20.25	242 - 331.75	122 - 239.75	
Median	146.5	14.5	272	156	
Mean	157.07	15	276	180.2	
SD	144.57	11.6	88.86	143.43	
CV	92.04%	77.3%	32.2%	79.6%	
SW	0.007**	0.617	0.965	0.250	
Left triceps brachii - EMGi Mv (30)					
Min-Max	1 - 649	1 - 83	119 - 620	190 - 649	<0.001***f (η^2 = 0.77)
Q1-Q3	33.75 - 308	6.5 - 26.25	131.5 - 238	292.25 - 628	
Median	157.5	17	157.5	490	
Mean	232.3	23.6	222	451.3	

Continued

SD	224.99	25.59	152.87	193.11	
CV	96.86%	108.42%	68.86%	42.79%	
SW	<0.001***	0.026*	<0.001***	0.029*	
Left triceps brachii - EMGf Mv (30)					
Min-Max	3 - 800	3 - 179	325 - 800	395 - 800	<0.001***f (η^2 = 0.69)
Q1-Q3	101.75 - 697.25	16.5 - 80	405.75 - 689.5	640.75 - 798.75	
Median	498	52.5	585	716	
Mean	436.7	64.7	558.1	687.3	
SD	301.45	62.8	176.98	132.81	
CV	69.03%	97.06%	31.71%	19.32%	
SW	0.002**	0.084	0.368	0.043*	
Left side variation (30)					
Min-Max	1 - 519	1 - 128	166 - 519	84 - 410	<0.001***e (η^2 = 0.68)
Q1-Q3	63 - 347	9 - 57	208.25 - 454	148.75 - 350	
Median	172	35	336	191.5	
Mean	204.4	41.1	336.1	236	
SD	161.41	41.15	136.17	117.05	
CV	78.97%	100.12%	40.51%	49.6%	
SW	0.027*	0.105	0.197	0.157	

5. Results

When comparing EMGi responses before biofeedback and EMGf responses after biofeedback, we found differences in the distributions or means for all measures between the groups. (Figure 1 and Figure 2) The scores did not differ between the ASIA C and D groups, but these scores did differ between the ASIA B group and the ASIA C and ASIA D groups.

For the variation measures, we found that for the right arm, the variance in the ASIA B group was statistically smaller than that in the ASIA C group but not the ASIA D group. Difference between group B and group C ($p < 0.001$***), difference between group B and group D ($p = 0.054$), difference between group C and group D ($p = 0.085$). In the left arm, the variance was statistically smaller in the ASIA B group than in the ASIA C and ASIA D groups. Difference between group B and group C ($p < 0.001$), difference between group B and group D ($p < 0.001$), difference between group D and group C ($p = 0.108$).

The EMGi and EMGf did not significantly differ between the ASIA C and D groups, but these measures did differ between the ASIA B group and the ASIA C and D groups. (Figures 3-6)

This finding indicates that the measures in the ASIA B group start off lower and vary less than those of the other groups, especially in comparison to the ASIA C group measures.

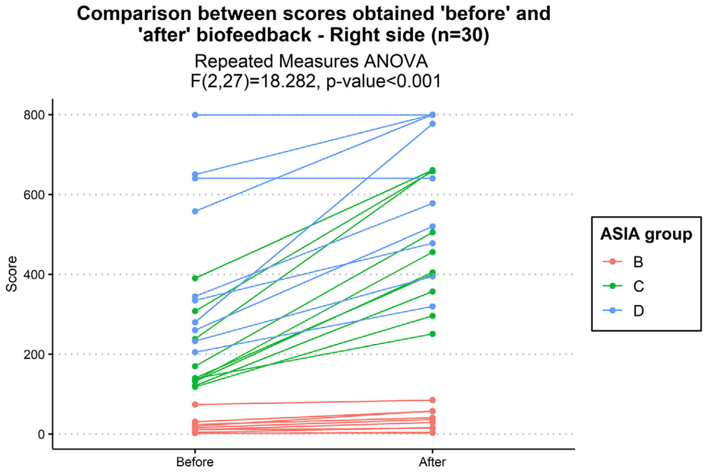

Figure 1. Comparison between scores obtained before and after biofeedback-right side (n = 30).

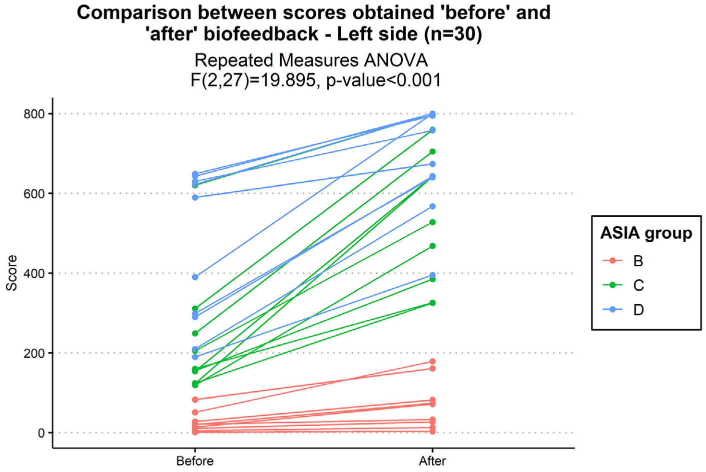

Figure 2. Comparison between scores obtained before and after biofeedback-left side (n = 30).

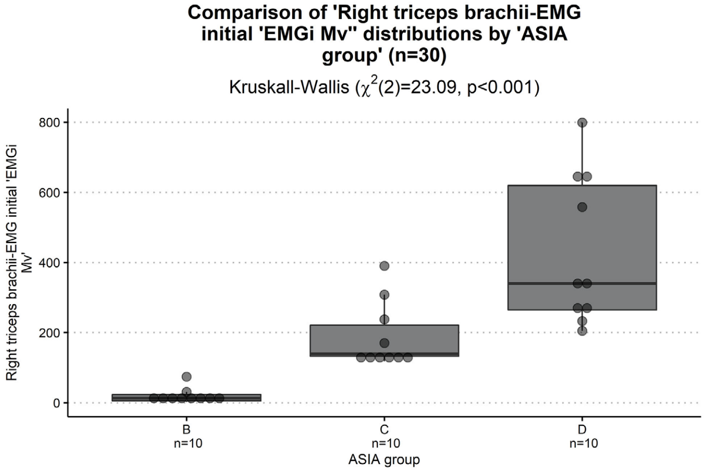

Figure 3. Comparison of right triceps brachii-EMG initial—EMGi Mv distribution by ASIA group (n = 30).

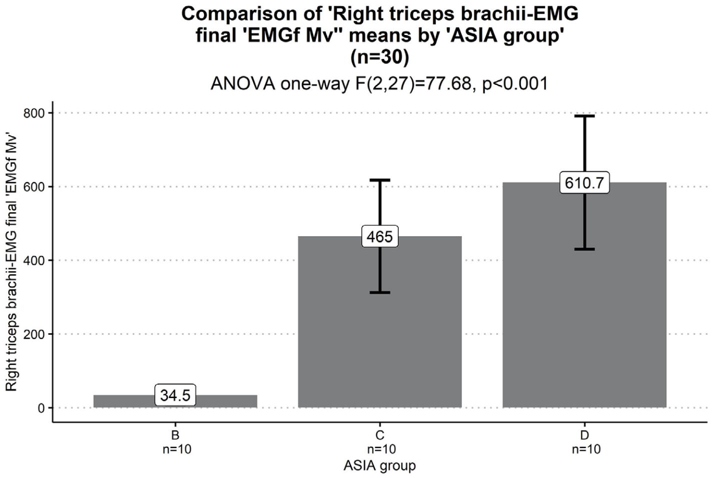

Figure 4. Comparison of right triceps brachii-EMG final—EMGf Mv means by ASIA group (n = 30).

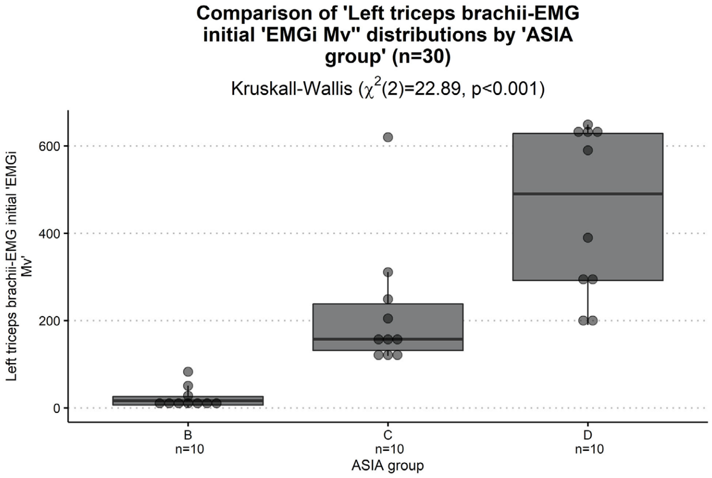

Figure 5. Comparison of left triceps brachii-EMG initial—EMGi Mv distributions by ASIA group (n = 30).

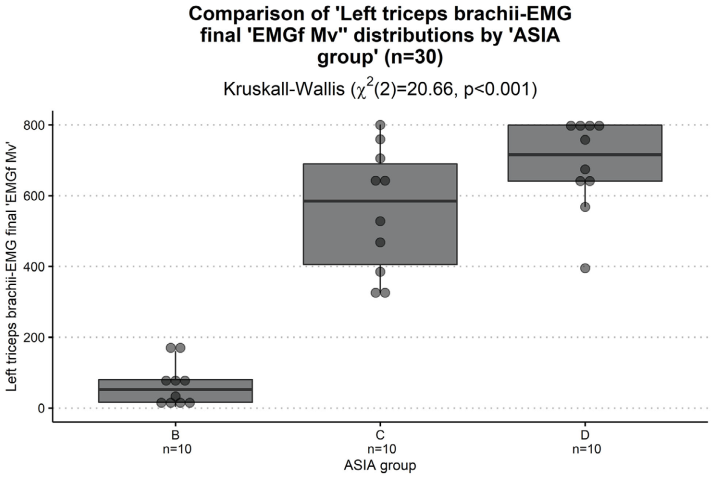

Figure 6. Comparison of left triceps brachii-EMG final—EMGf Mv distributions by ASIA group (n = 30).

6. Discussion

In recent years, the use of biofeedback has been growing in many areas and has been shown to be effective in fibromyalgia [16], chronic low back pain [17], urinary incontinence [18] [19] and motor recovery after stroke [20].

The efficacy of biofeedback in SCI rehabilitation is still unclear, as optimal treatment protocols or indications have been identified, resulting in poor outcomes and mixed success.

In 1996, Kohlmeyer *et al.* [21] studied a group of cervical spinal injury patients and concluded that biofeedback protocols did not increase the level of recovery of wrist extension function more significantly than traditional treatment.

The results of this study revealed that it is possible to increase the EMG responses below the level of the injury after spinal cord injury with biofeedback sessions, as was concluded by Brucker and Buleva [10], but this increase is related to the motor recovery level that the patient presents, requiring a minimum of neuromotor activity return in the muscle that will be treated and an operant conditioning paradigm protocol treatment.

Operant conditioning, which depends on the stimulus of an answer and is also known as trial-and-error learning [22], is directly related to the success of EMG biofeedback treatment. [10]

Based on the operant paradigm protocol, the patients were well aware of the goals of the sessions, the instructions for the movement and the explanation of the work they were supposed to do, and verbal motivation and rewards were given in all tries.

We believe that the learning paradigm was a key factor for increasing EMG amplitudes, as the subjects had a chance with this protocol to use the capacity of the spinal cord to learn “spinal learning” [23] [24] [25] through active-dependent plasticity [23]. Edgerton *et al.* [26] related that one of the ways that altered EMG ratios might occur is via a conscious reeducation of the motor system. After central nervous system injury, the EMG biofeedback session is one of the ways to visualize the EMG signal, and through this visualization, patients can try to better access the circuits that still have not been used through the repetition of movement of a certain muscle. [27]

We suggest that the differences in EMG responses between each group of patients were directly related to the motor response return level of the subjects. For some contraction or small movements, it is necessary to allow the equipment to measure the electrical signal in the muscle that represents the effort of a better use of the spinal cord in each try. We suggest that this is the reason why patients in groups ASIA C and ASIA D could increase their EMG responses. Other observation is that, during the sessions the therapist was able to provide resistance to the elbow extension movement to the patients in groups ASIA C and ASIA D. With this strategy the patients could increase the EMG responses. The subjects in group ASIA B could not visualize the effort of the trials in the monitor, as their muscle score was 0 with no palpable or visible contraction at the triceps brachii, with no possibilities to use the same strategy used with patients in groups ASIA C and ASIA D. As the subjects of the present study had incomplete SCI with different levels of muscle strength, one subject in group C had a high EMGi response in the left side comparing to the others in the group (**Figure 5**) and one subject in group D had a low EMGf in the left side comparing to others in the group. (**Figure 6**) In this study, it was observed that even within the same level of injury, there were differences in responses. Other studies that investigated the use of EMG biofeedback in spinal cord injury did not evaluate the recovery level but only the injury level. [28] [29]

In 2001, Wolpaw and Tennissen [30] explained that the operant conditioning protocol in humans and animals can produce changes in reflexes that are associated with functional and structural plasticity, including changes in motor neuron firing threshold, axonal conduction velocity and synaptic terminals on motor neurons. Additionally, compartmental changes produced by practice or after a lesion reflect the combination of multiple supraspinal plasticity, and induction and orientation of the activity-dependent plasticity in the cord are essential components in new therapeutic techniques with the goal of maximizing functions after spinal cord injury or recovery functions in a spinal cord that has regeneration.

There have been significant advances in research on spinal plasticity [24] [31] [32] [33]. These advances may be applied for the treatment of spinal cord injury. Functional recovery after an injury depends in part on the reorganization of undamaged neural circuits using activity-dependent plasticity, where the spinal circuitry is capable of significant reorganization through neuronal plasticity. [33] A recent study [34] reported that the key factor in recovery is the largely activity-dependent plasticity of spinal and supraspinal networks.

Rehabilitation methods using neuroplasticity can yield better results after SCI, and EMG biofeedback can be applied to increase electrical signals below the level of injury. Using EMG biofeedback with correct indications and the use of an operant conditioning paradigm can orient and induce spinal plasticity, thereby integrating rehabilitation treatments after SCI. The combination of therapies can offer better results and lead to a level of functional recovery that would not be expected, thus contributing to better quality of life.

Future research should examine whether the increase of the EMG responses after the treatment results in functional and motor improvement among subjects undergoing the treatment who maintain the achieved EMG levels. Future research should also include a control group without EMG biofeedback treatment for comparisons.

7. Limitations

The present study did not include a control group to measure and quantify changes in the variables. This study did not evaluate the patients using the same scale (ASIA) after the biofeedback treatment, to compare and observe gains in motor control or functional abilities. For this reason, was not possible to affirm if the EMG treatment contributing to better quality of life.

8. Conclusion

These results reveal that the patients classified as ASIA C and D achieved better responses of the operant conditional learning protocol and optimal indication for the biofeedback treatment

Acknowledgements

We express our gratitude for the patients, for Centro Universitário Sant'Anna and EMG biofeedback laboratories at the University of Miami for permission to use the EMG biofeedback laboratories for this study and Dr. Bernard S. Brucker, PhD (in memoriam) for the support, initiation and kindness with staff and patients.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] O'Shea, T.M., Burda, J.E. and Sofroniew, M.V. (2017) Cell Biology of Spinal Cord Injury and Repair. *Journal of Clinical Investigation*, **127**, 3259-3270. https://doi.org/10.1172/JCI90608

[2] Budh, C.N. and Österåker, A.L. (2007) Life Satisfaction in Individuals with a Spinal Cord Injury and Pain. *Clinical Rehabilitation*, **21**, 89-96. https://doi.org/10.1177/0269215506070313

[3] Furlan, J.C., Sakakibara, B.M., Miller, W.C. and Krassioukov, A.V. (2013) Global Incidence, and Prevalence of Traumatic Spinal Cord Injury. *Canadian Journal of Neurological Sciences*, **40**, 456-464. https://doi.org/10.1017/S0317167100014530

[4] De Campos, M.F., Ribeiro, A.T., Listik, S., *et al.* (2008) Epidemiology of Spine Injuries. *Journal of the Brazilian College of Surgeons*, **35**, 88-93. https://doi.org/10.1590/S0100-69912008000200005

[5] Ashammakhi, N., Kim, H.J., Ehsanipour, A., *et al.* (2019) Regenerative Therapies for Spinal Cord Injury. *Tissue Engineering Part B*: *Reviews*, **25**, 471-491. https://doi.org/10.1089/ten.teb.2019.0182

[6] Ministry of Health of Brazil (2013) Care Guidelines for the Person with Spinal Cord Injury. https://bvsms.saude.gov.br/bvs/publicacoes/diretrizes_atencao_pessoa_lesao_medular.pdf

[7] Roach, M. (2002) Community Social Structure as an Indicator of Social Integration and Its Effect on Quality of Life for Persons with a Spinal Cord Injury. *Topics in Spinal Cord Injury Rehabilitation*, **7**, 101-111. https://doi.org/10.1310/GV77-FV9X-XU19-A5TM

[8] Ditunno, P.L., Patrick, M., Stineman, M. and Ditunno, J.F. (2008) Who Wants to Walk? Preferences for Recovery after SCI: A Longitudinal and Cross-Sectional Study. *Spinal Cord*, **46**, 500-506. https://doi.org/10.1038/sj.sc.3102172

[9] Morawietz, C. and Moffat, F. (2013) Effects of Locomotor Training after Incomplete Spinal Cord Injury: A Systematic Review. *Archives of Physical Medicine and Rehabilitation*, **94**, 2297-2308. https://doi.org/10.1016/j.apmr.2013.06.023

[10] Brucker, B.S. and Bulaeva, N.V. (1996) Biofeedback Effect on Electromyography Responses in Patients with Spinal Cord Injury. *Archives of Physical Medicine and Rehabilitation*, **77**, 133-137. https://doi.org/10.1016/S0003-9993(96)90157-4

[11] Gómara-Toldrà, N., Sliwinski, M. and Dijkers, M.P. (2014) Physical Therapy after Spinal Cord Injury: A Systematic Review of Treatments Focused on Participation. *The Journal of Spinal Cord Medicine*, **37**, 371-379. https://doi.org/10.1179/2045772314Y.0000000194

[12] Neblett, R. (2016) Surface Electromyographic (SEMG) Biofeedback for Chronic Low Back Pain. *Healthcare*, **4**, Article No. 27. https://doi.org/10.3390/healthcare4020027

[13] Kim, J.H. (2017) The Effects of Training Using EMG Biofeedback on Stroke Patients Upper Extremity Functions. *Journal of Physical Therapy Science*, **29**, 1085-1088. https://doi.org/10.1589/jpts.29.1085

[14] Segal, R.L. and Wolf, S.L. (1994) Operant Conditioning of Spinal Stretch Reflexes in Patients with Spinal Cord Injuries. *Experimental Neurology*, **130**, 202-213. https://doi.org/10.1006/exnr.1994.1199

[15] American Spinal Injury Association (ASIA) (2002) International Standards for Neurological Classification of Spinal Cord Injury Worksheet. American Spinal Injury Association, Chicago.

[16] Sarnoch, H., Adler, F. and Scholz, O.B. (1997) Relevance of Muscular Sensitivity, Muscular Activity, and Cognitive Variables for Pain Reduction Associated with EMG Biofeedback in Fibromyalgia. *Perceptual and Motor Skills*, **84**, 1043-1050. https://doi.org/10.2466/pms.1997.84.3.1043

[17] Eichler, J., Rachinger-Adam, B., Kraft, E. and Azad, S.C. (2019) Efficacy of Biofeedback in Patients with Chronic Low Back Pain: Impact on Pain Intensity, Psychological Factors and Stress Markers. *Der Schmerz*, **33**, 539-548. https://doi.org/10.1007/s00482-019-0393-z

[18] Herderschee, R., Hay-Smith, E.J., Herbison, G.P., Roovers, J.P. and Heineman, M.J. (2011) Feedback or Biofeedback to Augment Pelvic Floor Muscle Training for Urinary Incontinence in Women. *Cochrane Database of Systematic Reviews*, No. 7, CD009252. https://doi.org/10.1002/14651858.CD009252

[19] Wu, X., Zheng, X., Yi, X., Lai, P. and Lan, Y. (2021) Electromyographic Biofeedback for Stress Urinary Incontinence or Pelvic Floor Dysfunction in Women: A Systematic Review and Meta-Analysis. *Advances in Therapy*, **38**, 4163-4177. https://doi.org/10.1007/s12325-021-01831-6

[20] Moreland, J.D., Thomson, M.A. and Fuoco, A.R. (1998) Electromyographic Biofeedback to Improve Lower Extremity Function after Stroke: A Meta-Analysis. *Archives of Physical Medicine and Rehabilitation*, **79**, 134-140. https://doi.org/10.1016/S0003-9993(98)90289-1

[21] Kohlmeyer, K.M., Hill, J.P., Yarkony, G.M. and Jaeger, R.J. (1996) Electrical Stimulation and Biofeedback Effect on Recovery of Tenodesis Grasp: A Controlled Study. *Archives of Physical Medicine and Rehabilitation*, **77**, 702-706. https://doi.org/10.1016/S0003-9993(96)90011-8

[22] Kandel, R.E., Scchwartz, J.H. and Jessell, T.M. (1995) Essentials of Neural Science and Behaviour. Appleton & Lange, New York.

[23] Rossignol, S. (2000) Locomotion and Its Recovery after Spinal Injury. *Current Opinion in Neurobiology*, **10**, 708-716. https://doi.org/10.1016/S0959-4388(00)00151-3

[24] Wirz, M., Colombo, G. and Dietz, V. (2001) Long Term Effects of Locomotor Training in Spinal Humans. *Journal of Neurology, Neurosurgery & Psychiatry*, **71**, 93-96. https://doi.org/10.1136/jnnp.71.1.93

[25] Grau, J.W. (2014) Learning from the Spinal Cord: How the Study of Spinal Cord Plasticity Informs Our View of Learning. *Neurobiology of Learning and Memory*, **108**, 155-171. https://doi.org/10.1016/j.nlm.2013.08.003

[26] Edgerton, V.R., Wolf, S.L., Levendowski, D.J. and Roy, R.R. (1996) Theoretical Basis for Patterning EMG Amplitudes to Assess Muscle Dysfunction. *Medicine & Science in Sports & Exercise*, **28**, 744-751. https://doi.org/10.1097/00005768-199606000-00013

[27] Basmajian, J.V. and De Luca, C.J. (1985) Muscles Alive: Their Function Revealed by Eletromyography. Williams& Wilkins, Baltimore.

[28] Klose, K.J., Needham, B.M., Schmidt, D., Broton, J.G. and Green, B.A. (1993) An Assessment of the Contribution of Electromyographic Biofeedback as an Adjunct Therapy in the Physical Training of Spinal Cord Injured Persons. *Archives of Physical Medicine and Rehabilitation*, **74**, 453-456. https://doi.org/10.1016/0003-9993(93)90103-H

[29] Stein, R.B., Brucker, B.S. and Ayyar, D.R. (1990) Motor Units in Incomplete Spinal Cord Injury: Electrical Activity, Contractile Properties and the Effects of Biofeedback. *Journal of Neurology, Neurosurgery & Psychiatry*, **53**, 880-885. https://doi.org/10.1136/jnnp.53.10.880

[30] Wolpaw, J.R. and Tennissen, A.M. (2001) Activity-Dependent Spinal Cord Plasticity in Health and Disease. *Annual Review of Neuroscience*, **24**, 807-843. https://doi.org/10.1146/annurev.neuro.24.1.807

[31] Burns, A.S. and Ditunno, J.F. (2001) Establishing Prognosis and Maximizing Functional Outcomes after Spinal Cord Injury: A Review of Current and Future Directions in Rehabilitation Management. *Spine*, **26**, S137-S145. https://doi.org/10.1097/00007632-200112151-00023

[32] Field-Fote, E.C. (2000) Spinal Cord Control of Movement: Implications for Locomotor Rehabilitation Following Spinal Cord Injury. *Physical Therapy*, **80**, 477-484. https://doi.org/10.1093/ptj/80.5.477

[33] Muir, G.D. and Steeves, J.D. (1997) Sensorimotor Stimulation to Improve Locomotor Recovery after Spinal Cord Injury. *Trends in Neurosciences*, **20**, 72-77. https://doi.org/10.1016/S0166-2236(96)10068-0

[34] Taccola, G., Sayenko, D., Gad, P., Gerasimenko, Y. and Edgerton, V.R. (2018) *And Yet It Moves*: Recovery of Volitional Control after Spinal Cord Injury. *Progress in Neurobiology*, **160**, 64-81. https://doi.org/10.1016/j.pneurobio.2017.10.004