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Overflow using proprioceptive neuromuscular facilitation in post-stroke hemiplegics: A preliminary study

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ABSTRACT

Hemiplegia is the classic condition resulting from a stroke. To assist in recovery, the overflow method can be employed to stimulate the affected limb, using the healthy contralateral lower limb (LL) to activate the plegic upper limb (UL) musculature. The aim of this study was to evaluate the immediate effect of overflow using the PNF method on the plegic upper limb muscles of post-stroke individuals in the acute and chronic stages, as well as on the muscles of healthy individuals. A total of 22 individuals participated in the work, comprising 8 healthy individuals (control group), 6 post-stroke acute stage individuals (acute group), and 8 post-stroke chronic stage individuals (chronic group). The participants were assessed using a questionnaire with sections for personal and disease data and application of the ICF scale and the Fugl-Meyer index. The three groups were submitted to electromyographic evaluation, using the posterior deltoid (PD), anterior deltoid (AD), pectoralis major (PM), and external oblique (EO) muscles in four different positions: P1 (resting the UL, with the LL contralateral to the affected limb positioned in diagonal); P2 (resting the UL, with manual resistance in the contralateral LL); P3 (affected UL positioned in diagonal, with manual resistance in the contralateral LL) e P4 (affected UL positioned in diagonal, with fixed point and manual resistance in the contralateral LL). The electromyography results revealed no significant differences between most of the positions for the four muscles evaluated ($p > 0.05$). However, high clinical relevance ($d > 0.8$) was found for muscle activation in positions 2 and 4. It could be concluded that for post-stroke individuals in the acute and chronic stages, overflow using PNF effectively increased activation of the PD, AD, PM, and EO muscles in the P2, as well as position 4.

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1. Introduction

In terms of clinical motor activity manifestations, hemiplegia is the classic symptom resulting from a stroke (Cacho et al., 2004). It is characterized by the loss of voluntary movement on one side of the body, associated with muscular, sensory, and cognitive alterations (Benvegnu et al., 2008). Plegia in the upper limb affects 85% of stroke victims in the early stages and remains after six months in 55–75% of cases (Feys et al., 1998; Olsen, 1990; Parker et al., 1986; Wade et al., 1983).

Proprioceptive neuromuscular facilitation (PNF) is one of the various rehabilitation techniques that can be used to minimize the clinical manifestations of a stroke. It employs different sensori-motor combinations to promote motor learning, establishing a balance between agonist and antagonist muscles by means of reciprocal innervation (Teixeira, 2008). The PNF approach employs a range of principles and procedures that assist the therapist in achieving functional improvement. One of these procedures is overflow, also known as cross-training, in which application of stimulus to one limb causes muscle contraction in the contralateral extremity, hence activating weak muscles by stimulating strong ones (Morales et al., 2003; Voss et al., 1987; Partridge, 1954). The

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stimulus is applied during an active movement of the individual against an appropriate resistance (Cruz-Machado et al., 2006).

There are two lines of thought concerning the mechanisms underlying the effects of overflow. Some authors favor neural mechanisms, whereby voluntary muscular contraction causes activation in the corresponding cortex and increases excitation in the motor centers and the CNS pathways, especially in the synapses of the anterior horn cells of the medulla. This is the location of a large part of the interneurons that communicate with afferent neurons that deliver signals to the brain, for both the limb that performs voluntary contraction and the contralateral limb (Kabat and Knott, 1953; Munn et al., 2004; Lent, 2005). Recent studies describe effects that extend beyond the contralateral side and highlight that overflow, by means of neural mechanisms, can have positive effects in the homologous muscles as well as in any other part of the body (Adamson et al., 2008; Sande de Souza et al., 2014). Other authors favor biomechanical mechanisms, suggesting that activation of the contralateral musculature is due to the application of resistance in the limb, leading to postural adjustment and causing the opposite side to contract in order to stabilize the movement (Pink, 1981).

Overflow can be used clinically as part of a PNF procedure or in isolation, but there have been few studies of such techniques (Podivinskv, 1964; Hellebrandt and Waterland, 1962; Gregg et al., 1957). In a recent study by Sande de Souza et al. (2014), greater activation was found using specific positioning during the overflow procedure in healthy subjects, using the lower limb to stimulate the upper limb. However, information remains scarce concerning application of the technique in the case of clinically demanding diseases (Meningroni et al., 2009; Cabral et al., 2005).

Post-stroke individuals with hemiplegia, who are likely to suffer from substantial functional decline and the presence of comorbidities (Teixeira-Salmela et al., 2000), can benefit from the overflow procedure and the associated increase in immediate muscle activation in the plegic upper limb. Therefore, the aim of this study was to evaluate the immediate effect of PNF overflow treatment on the muscles of the plegic upper limbs of post-stroke individuals in the acute and chronic stages, as well as on the muscles of healthy individuals. The hypothesis adopted was that activation in the upper limb would be increased following the use of overflow in the three groups investigated.

2. Methodology

This research is transversal and explanatory, adopting an experimental and quantitative approach. The project was approved by the Research Ethics Committee of the Federal University of Triângulo Mineiro (UFTM) under protocol nº 1647 (2013).

A total of 22 participants were divided into three groups: healthy control group (CG, 8 individuals); acute stage post-stroke group (AG, 6 individuals); and chronic stage post-stroke group (CAG, 8 individuals). The average ages (years) were 56.65 ± 10.12 (CG), 57.16 ± 10.98 (AG), and 54.13 ± 8.26 (CAG). The subjects were selected for convenience, due to the specific hemiplegia characteristics required in the post-stroke groups, such as being plegic in the upper limbs, but with good lower limb mobility to enable locomotion. The small number was also due to the initiation of the thrombolysis procedure, which resulted in lower motor impairment and decreased hemiplegia in most of the post-stroke individuals. In the post-stroke groups, diagnosis of stroke was confirmed by imaging examination, and the individuals had no previous episodes of brain injury with alteration of cognitive or motor functions.

The AG and CAG group participants were patients at the Neurology Section of the UFTM Clinical Hospital and/or the Dr. Fausto da Cunha Oliveira Rehabilitation Center. All patients were under medical supervision, with personalized drug treatments, and only individuals who met the inclusion criteria participated in the study.

The inclusion criteria used for the post-stroke acute stage individuals were as follows: age between 40 and 80 years, diagnosis of stroke with acute stage hemiplegia (duration less than 6 months) (Kraft et al., 1992), and without rehabilitation during 15 days prior to the evaluation. For post-stroke chronic stage individuals, the inclusion criteria were as follows: age between 40 and 80 years, diagnosis of stroke with chronic stage hemiplegia (duration longer than 6 months) (Kraft et al., 1992), without rehabilitation during 15 days prior to the evaluation. All the participants adhered to the established medical procedures during the course of this research.

In the healthy group, suitable individuals were selected and were paired in terms of age with the individuals in the post-stroke groups. The side of the body used for comparison with the chronic and acute post-stroke groups was divided equally between the upper right and upper left limbs. In addition, the healthy individuals were required to have no previous history of neurological or orthopedic diseases.

For all three groups, the subjects were required to have a sufficient cognitive level to be able to understand the procedures and guidelines. After reading the terms of agreement, all the subjects signed free and informed consent documents for participation in the study.

Individuals were excluded from the post-stroke groups if, on the day scheduled for evaluation, they showed improvement in the plegia, being characterized as hemiparetic, and/or presented high blood pressure, which prevented the evaluation. The characteristics of the three groups are provided in Table 1.

The participants were assessed on a single occasion, with the assessment lasting an average time of around 60 min. Firstly, an interview was conducted to obtain personal information and anamnesis and vital signs data (mainly evaluating blood pressure), focusing on the upper limb. This was followed by application of the modified Ashworth scale for tonus evaluation, with scores from 0 to 4 (Bohannon and Smith, 1987).

The ICF core set (Riberto, 2011) for stroke was used to characterize the AG and CAG individuals. The items used were those for body function and activities and participations, with items related to body structures and environmental factors being excluded. Each item was classified according to the ICF recommendations.

The Fugl-Meyer index (Cacho et al., 2004) was also used to characterize the AG and CAG individuals. In the present work, the Fugl-Meyer items concerning the lower limb were not used. For the upper limb, the questions used were those related to evaluation of the motor function of shoulder, elbow, wrist, and hand (synergy, reflexes, grip, stability, and coordination), totaling 66 points. Additional questions, totaling 48 points, concerned the amplitude of movement (AOM) and joint pain in the following movements: shoulder flexion, 90° abduction, external rotation, and internal rotation; elbow flexion and extension; wrist flexion and extension; flexion and extension of the fingers; and pronation and supination of the forearm. For each item, the score ranged from 0 to 2 points.

Two four-channel Miotool 400 USB (Miotec) devices were used, with differential active sensors consisting of 1 cm diameter Ag/AgCl disk electrodes (MAXICOR) separated by a center-to-center distance of 3 cm. The operating parameters of the equipment were a channel gain of 1000x, a 14-bit A/D converter, acquisition rate of 2000 Hz per channel, 110 dB common-mode rejection ratio, noise level <2 LSB (least significant bit), and input impedance of 10^{10} Ohm//2 pF.

The electromyographic analysis was performed with the following muscles: posterior deltoid (PD), anterior deltoid (AD),

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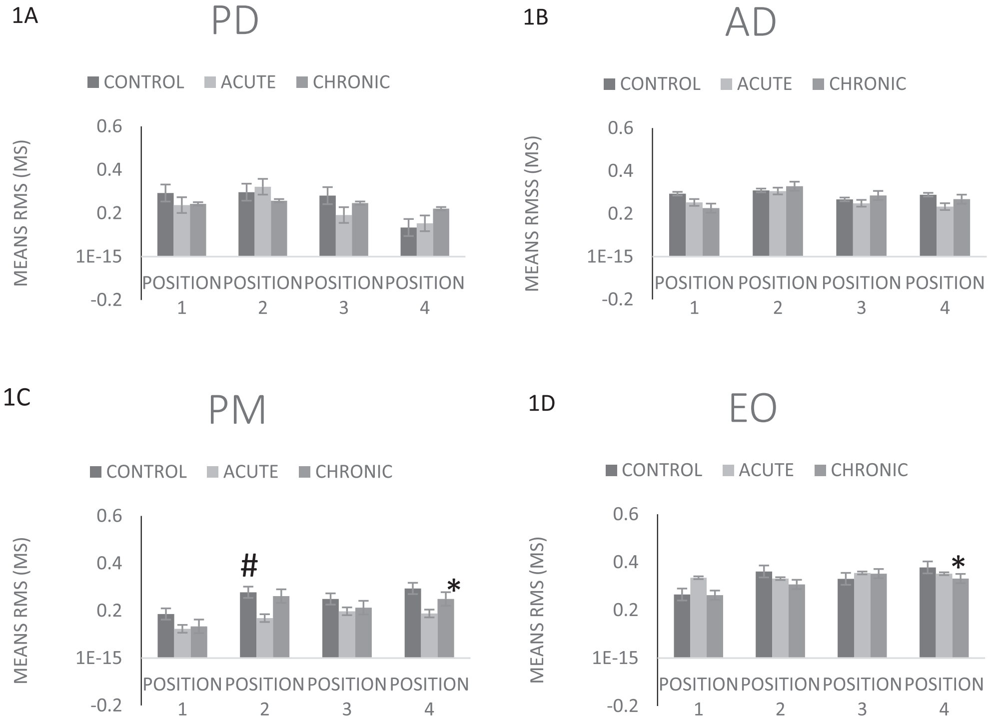

Fig. 1. Means and standard deviations of the normalized RMS values of the muscles for each position, in the control, acute, and chronic groups: (A) posterior deltoid (PD), (B) anterior deltoid (AD), (C) pectoralis major (PM), (D) external oblique (EO). *p < 0.05 vs. position 1, control group; #p < 0.05 vs. position 1, chronic group.

pectoralis major (PM), and external oblique (EO). The preparation and positioning of the electrodes followed the SENIAM protocol (Surface Electromyography for the Non-Invasive Assessment of Muscles) (Hermes et al., 2000), which stipulates that in order to decrease the impedance, trichotomy of the location should be performed, followed by degreasing using alcohol, abrasion of the skin with fine sandpaper, and final cleaning with alcohol. After these procedures, the electrodes can be attached to the skin.

On the PD muscle, the center of the electrode was placed about two fingers distance below the acromial angle, in the posterior region. On the AD, the electrode was placed one finger width distal and anterior to the acromion (Hermes et al., 2000). The SENIAM guidelines were also followed for the PM muscle, with localization of the motor point and positioning of the electrode between the innervation zone and the tendon insertion, midway between the belly and the lateral border of the muscle (Hermes et al., 2000). The positioning of the electrode on the EO muscle was at the midpoint between the iliac crest and the lower point of the dorsal edge (at the height of the third lumbar vertebra) (Ng et al., 2002).

The electromyography was performed placing the subjects in four different positions:

POSITION 1 (P1): In supine, resting the upper limbs, with the lower limb (LL) contralateral to the affected limb positioned with 90° angles of hip and knee, 10° external hip rotation, and adduction for 5 s.

POSITION 2 (P2): In supine, resting the upper limbs, with manual resistance in the contralateral lower limb, maintaining 5 s isometry in diagonal flexion-adduction-external rotation.

POSITION 3 (P3): In supine, with the affected upper limb positioned in diagonal external flexion-abduction-rotation of the shoulder and elbow extension, with manual resistance in the contralateral lower limb, maintaining 5 s isometry in diagonal flexion-adduction-external rotation.

POSITION 4 (P4): Supine, with the affected upper limb positioned in diagonal flexion-abduction-external rotation of the shoulder and extension of the elbow, with the wrist fixed on a support (using non-elastic Velcro) to maintain the position of the upper limb during 5 s of isometric contraction of the contralateral lower limb in diagonal flexion-adduction-external rotation (Sande de Souza et al., 2014).

In groups AG and CAG, the electromyographic data were collected for the affected and contralateral upper limbs, with only the affected arm being positioned in the diagonals. In the case of the control group (CG), the measurements were performed for both arms, with the arm evaluated (the one that performed the diagonals) being the arm previously selected for comparison with the AG or CAG individual.

Finally, the RMS (root mean square) values were obtained for each muscle during performance of the diagonals in the different upper limb positions. The data were normalized according to the highest activation of each muscle in each position.

The means and standard deviations were calculated for the different variables and the Kolmogorov-Smirnov test was used to evaluate normality. For normal data, the paired *t*-test for intragroup analysis was applied. When the sample data did not obey normality, the nonparametric Mann-Whitney test was applied. One-way ANOVA followed by Tukey's post-hoc test was used for intra-group evaluation of the different overflow conditions. In all cases, a significance level of $p < 0.05$ was adopted. The Cohen's d effect size test for dependent samples was also employed, considering the various positions used for the acute and chronic groups, in order to identify the existence of clinical relevance.

3. Results

The ICF results in the case of the AG group, 36 items out of the total of 56 items of the core set on body function were cited. The items that were mentioned with greatest frequency by over 60% of the individuals and were classified as moderate (2) to severe (3) were the following functions: sleep (b134), psychomotor (b147),

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Table 1
Characterization of the individuals evaluated.

Group	CG (n = 8)	AG (n = 6)	CAG (n = 8)
Age (years)	56.65 ± 10.12	57.16 ± 10.98	54.13 ± 8.26
Sex	37.5%M, 62.5%F	50%M, 50%F	62.5%M, 37.5%F
Dominance	100%R	100%R	75%R, 25%L
Stroke type	–	100%I	87.5%I; 12.5%H
Plegic side/side evaluated	50%R, 50%L	50%R, 50%L	62.5%R, 37.5%L
Time post-stroke	–	46 ± 25.29 days	24 ± 11.01 months
Use of upper limb orthesis	–	No use	5 yes/3 no
Associated diseases	–	SAH, diabetes, smoking	SAH, diabetes, alcoholism, smoking
Ashworth scale	–	100%- 0	87.5%- 3, 12.5%- 1
Average Fugl-Meyer score (motor function/AOM and pain)	–	15.33/43.83	12.62/40

F - feminine; M - masculine; I - ischemic; H - hemorrhagic; R - right; L-left; AOM - amplitude of movement; SAH - systemic arterial hypertension. $p > 0.05$ in relation to age.

emotional (b152), proprioceptive (b260), weight maintenance (b530), joint mobility (b710), joint stability (b715), muscular strength (b730), muscular resistance (b740), motor reflex (b750), control of voluntary movements (b760), and the gait pattern (b770). Out of the 58 items concerning activity and participations, 42 items were mentioned and those that could be highlighted in terms of frequency and classification as moderate to severe were as follows: performing a single task (d210), performing multiple tasks (d220), performing the daily routine (d230), changing the basic position of the body (d410), shifting position (d420), lifting and carrying objects (d430), fine use of the hand (d440), use of the hand and arm (d445), walking (d450), moving (d455), moving through different locations (d460), using certain equipment (d465), using transport (d470), driving (d475), washing (d510), caring for parts of the body (d520), dressing (d540), preparing meals (d630), performing domestic tasks (d640), and performing basic economic transactions (d860).

For the core set applied to the CAG group, 48 out of the total of 56 items on body function were cited, with the functions mentioned most frequently and classified as moderate (2) to severe (3) being as follows: temperament and personality (b126), psychomotor (b147), emotional (b152), vision (b210), speech (b310), fluency and rhythm of speech (b330), joint mobility (b710), joint stability (b715), muscular strength b730), and muscular resistance (b740). Out of the 58 items concerning activity and participations, 52 items were mentioned, with those that could be highlighted in terms of frequency and classification of moderate to severe being as follows: lifting and carrying objects (d430), fine hand use (d440), use of the hand and arm (d445), walking (d450), moving (d455), moving through different locations (d460), using certain equipment (d465), using transport (d470), driving (d475), and preparation of meals (d630).

The Fugl-Meyer results for the AG group, the average score for the motor function items was 15.33 (±3.55). For the items concerning AOM and pain, the average score was 43.83 (±5.1). For the CAG group, the average motor function score was 12.62 (±14.7), while an average score of 40 (±5.5) was obtained for the AOM and pain items (See Table 1).

The electromyography results for the PD muscle (Fig. 1A), in LL diagonal, there were no significant differences ($p > 0.05$) among the positions for any of the groups (CG, AG, and CAG). The same was observed for the AD muscle (Fig. 1B). However, in the case of the PM muscle, there were significant differences between P1 and P4 ($p = 0.044$) for CG and between P1 and P2 ($p = 0.035$) for CAG, with no significant differences among the remaining positions and groups (Fig. 1C). In the case of the EO muscle, there was a significant difference between P1 and P4 ($p = 0.032$) for CG, and no significant differences among the remaining positions and groups (Fig. 1D). (See Fig. 1).

The results of the Cohen's d test revealed substantial differences in the acute group (AG), with clinical relevance ($d > 0.8$) in the following situations: the PD muscle was more active in position 2, while the PM muscle was more active in positions 3 and 4. The AD and EO muscles showed no relevant differences among the positions. In the chronic group (CAG), there were clinically relevant differences for the AD muscle in position 2 and the PM and EO muscles in position 4. The PD muscles showed no differences among the positions. The values obtained using Cohen's d test are provided in Table 2 (See Table 2).

4. Discussion

The objective of this work was to evaluate the immediate effect of overflow according to the FNP method on the muscles of the plegic upper limbs of post-stroke individuals in the acute and chronic phases, as well as healthy individuals. The use of the overflow method was considered because post-stroke hemiplegic individuals in the acute and chronic stages do not present active movements in the affected limbs. The overflow could act to initiate a muscular response, which could then be further stimulated using other techniques. In the literature, few studies have explored such an approach in a population characterized by pronounced physical limitations and disabilities (Meningroni et al., 2009; Cabral et al., 2005; Mills and Quintana, 1985). In the most recent work related to the overflow technique, Sande de Souza et al. (2014) provided valuable information in terms of the methodology and the possible different positions that could be used for muscle activation in post-stroke individuals.

Different positions were therefore used, because in accordance with the PNF concept, a variable pattern of positions can provide a range of muscle activations, with the position adopted altering the order of neural discharges and improving the efficiency of movement of the joint (Shimura and Kasai, 2002). Limb restraint was also used, because overflow can be more efficient when the limb being treated is fixed in position (Sande de Souza et al., 2014).

Based on the data obtained for the different positions, the hypothesis that greater activation of the upper limb would be achieved with overflow was partially proven, since there were no significant differences, except between P1 and P2 for the PM muscle in the CAG group. However, the results obtained using the Cohen's d test revealed high clinical relevance of some differences in muscle activation. In general, the greatest activations were obtained in position 2, which is the classical overflow position, and position 4, which used a fixed point. Position 2 resulted in greater activation of the AD muscle in the chronic group and the PD muscle in the acute group. Position 4 facilitated activation of the PM and EO muscles in the chronic group and the PM muscle in the acute group. These results were similar to those found for a group of healthy

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Table 2
Values obtained in Cohen's d test.

	ACUTE				CHRONIC			
	PD	AD	PM	EO	PD	AD	PM	EO
P1 x P2	−0.71	−0.46	**−1.2**	0	0	**−1.5**	0	0
P2 x P3	**1.25**	0.58	−0.55	−0.23	0	0	0	0.3
P3 x P4	0.53	0	0	0	0.3	0	−0.53	0.34
P1 x P4	**1.08**	0.6	**−0.96**	−0.34	0	**1.2**	**−1.47**	−0.76
P2 x P4	**1.77**	0.69	−0.28	−0.27	0.47	**1.2**	0	−0.25
P1 x P3	0.55	0	**−1.74**	−0.28	0	−0.57	**−1.37**	**−1.2**

Values exceeding 0.8 indicate large differences with clinical relevance, described in bold in the table. Values between 0.5 and 0.79 indicate moderate differences. Values between 0.2 and 0.49 indicate small differences. Values below 0.2 indicate no difference (shown here only as 0).

individuals by Sande de Souza et al. (2014), who observed greater activation of these muscles using the same positions adopted here, as well as a greater effect of the overflow procedure when restraint was used.

The findings suggested that overflow may have a small effect when applied to post-stroke individuals suffering from hemiplegia. It is possible that cases exhibiting hemiparesis could benefit more from the overflow procedure, indicating the need for further studies.

These findings can also be compared with other studies of overflow involving homologous musculatures of ipsilateral or contralateral limbs. Reznik et al. (2015) found greater activation in homologous muscles of healthy young subjects submitted to classical overflow according to the PNF method. The same was found by Gupta et al. (2015) in a study involving 220 healthy adults. These previous studies did not identify any great activation in the contralateral muscles of different limbs, as in the present work. According to the authors, the findings could be linked to cross-training and homologous connections of the CNS and PNS.

In previous work using overflow with post-stroke individuals, but not based on the PNF method, Hwang et al. (2006) employed overflow to the compromised side, while the healthy side was being worked, which resulted in a response similar to that found for healthy individuals. Chang et al. (2013) observed an asymmetrical effect of overflow, considering the healthy and compromised limbs, which could be attributed to greater participation of the undamaged hemisphere in the activity of the muscles in the compromised limb. It was suggested that in addition to inter-hemispheric inhibition, other ipsilateral corticospinal projections could act as adaptive mechanisms in stroke patients.

The studies cited above did not evaluate either different positions or the muscles investigated here. Therefore, despite the lack of statistical significance, the Cohen's d test results reflected the novelty of the present study in terms of the following findings: 1) there was overflow to the plegic upper limb muscles from diagonals performed with the uncompromised lower limb; 2) positions 2 and 4 resulted in greater activation, albeit at a low level since the limbs concerned were plegic. According to the theory of muscular chains, such overflow between lower limb and upper limb is made possible by the connection between the muscles of the different sides of the body. The theory of muscular chains was developed by the Belgian physiotherapist Godelieve Denys-Struyf (1995), based on the concepts of the Proprioceptive Neuromuscular Facilitation method, among others. The theory is based on muscular connectedness, considering the physiology of the muscular tissue, which should be understood as a functional entity composed of the indivisible combination of fibrous connective tissue and contractile tissue. This is in agreement with the biomechanical concept of overflow (Vieira, 1998), according to which contractions of isolated muscles do not occur, while instead there is a sequence of movements that propagate through the body, so that the whole body is used when treating a specific region, as partially observed in this study. Clinically, this indicates that overflow could be used in cases of plegia employing opposite limbs, not only the homonymous limb, as widely reported in the literature. This increases the range of therapeutic options that could be used with stroke victims.

Limitations of this study included the small sample size and the selection of few muscles only in patients with hemiplegia. Further studies should be undertaken using this methodology, with investigation of overflow as a long-term rehabilitation method for use in this patient population, rather than only for immediate activation.

5. Conclusions

Application of the Cohen's d test showed that for plegic post-stroke individuals in the acute and chronic phases, the PNF overflow technique was effective in increasing activation of the PD, AD, PM, and EO muscles, employing the positions used in the classic procedure (position 2) and with a fixed point (position 4).

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