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ORIGINAL ARTICLE

MUSCLES INVOLVED IN THE PRONE LEG LENGTH INEQUALITY TEST IN HEALTHY SUBJECTS.

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SUMMARY

Introduction: The leg length inequality test (LLI) is used within the evaluative procedures of various chiropractic methods; however, no research has been conducted that seeks to determine which muscle groups are involved in this evaluative procedure.

Objective: To identify which muscles, when stimulated with a transcutaneous neuromuscular electric current, generate changes in the length of the lower extremities.

Methodology: 25 participants, aged 20 to 30 years, were recruited to participate in this two-stage study. In the first stage, participants received a chiropractic evaluation and adjustments. If after the intervention, the participants presented equality in the length of their legs, they were included in the second stage (20). This consisted of neuromuscular stimulation of 24 muscles with a transcutaneous electrical current to determine if this stimulation generated a change in the LLI test.

Results: Electrical stimulation of the following muscles generated a change in the length of the lower extremity: a) Muscles that generated a decrease in the length of the lower extremity with a significance $p < 0.01$ were: quadratus lumborum bilaterally, thoracic paraspinals bilaterally. b) Muscles that generated an increase in the length of the lower extremity with a significance $p < 0.01$: gluteus maximus bilaterally, gluteus medius bilaterally and quadriceps bilaterally.

Conclusions: This study reveals a significant change in the apparent length of the lower extremities upon neuromuscular stimulation of certain muscle groups covered in this investigation.

Keywords: Leg length inequality; Chiropractic; Physical examination.

INTRODUCTION

Various health disciplines, including chiropractic, consider the measurement of leg length inequality (LLI) as an assessment test with different purposes, meanings and validity [1]. The LLI test is included within the evaluative procedures of various chiropractic analysis and adjustment methods[2], showing good inter-rater reliability [3-5].

The LLI is generally categorized as anatomical or functional. Anatomically based LLI is the result of congenital or acquired deformities and represents an actual bony asymmetry that exists somewhere between the femoral head and the calcaneus [6].

Functional LLI is a more complex phenomenon in which there is no structural change in the lower extremity that decreases the length of the lower extremity, but an apparent change in length is still observed by the evaluator. The observed length change is believed to be the result of various physiological and/or biomechanical adaptations due to abnormalities along the kinetic chain, such as the presence of vertebral misalignment or vertebral subluxations [1,5,7-9].

There is evidence demonstrating the existence of functional inequality in the length of the lower extremity[10] , yet there are questions associated with the neurological and biomechanical processes behind this phenomenon. In the 1984 Thompson method manual, Dr. J. Clay Thompson describes theoretically what possibly occurs at the neurological level in patients with functional leg length inequality[11]: “This denotes the neuropathological relationship seen in many patients. The term contracted leg emphasizes the origin of a neurological imbalance, which appears as an innervational overload to the extensor muscles, causing unilateral spastic contraction and unequal extremities”. These early theories refer to a change in muscle tone generated by the central nervous system (CNS) as a neurological explanation for the functional inequality in the length of the lower extremities. He adds: “These systems constantly react to proprioceptive inputs to the cerebral cortex, cerebellum and brain stem to maintain postural balance”. He then analyzes how structural imbalances (joint subluxation or fixation) alter the proprioceptive inputs, which generates a response by the CNS altering postural muscle tone. Similarly, there are other neurological models that associate the change in muscle tone as a response to joint dysfunction[12].

These altered CNS responses are included in the operational models of vertebral subluxation[13]. The intervertebral segments possess a large number of mechanoreceptors that inform the CNS what is occurring at each level of the spine [14-18]. Vertebral subluxations generate altered mechanical/nociceptive inputs, resulting in an altered or out-of-normal response from the nervous system, which is called dysafferentation. Similarly, responses associated with a reversible change in muscle tone by the CNS are referred to as dysponesis [19].

Researchers at the New Zealand College of Chiropractic research center have followed the research line of relating the effects of chiropractic and central integration of somatosensory inputs [20-22], including its effects on cortical motor activation and neuromuscular function [23-28].

This study seeks to determine the muscle groups that, when electrically stimulated, generate a change in leg length. The results obtained may help to better understand the neurological mechanisms related to the changes in postural muscle tone observed in the LLI test.

METHODOLOGY

The research was conducted in a laboratory room administered by the Department of Basic Sciences from St. Sebastian University in Valdivia, Chile.

Participants

Twenty-five students were recruited from St. Sebastian University in Valdivia, Chile. To be included, participants had to: 1. be over 18 years of age; 2. be able to be in prone position during the evaluation process; 3. agree to the experimental procedure; 4. sign the informed consent form. The exclusion criteria were; 1. Consumption of drugs that could affect muscle tone; 2. Diseases of the central or peripheral nervous system; 3. Structural or anatomical leg length inequality. After the induction about the details of this research and the signature of the informed consent, the experimentation was started.

Procedure

This study is divided into two stages. In the **first stage**, a chiropractic evaluation was performed in search of the presence of subluxations present in the axial skeleton of the participants and that, consequently, had a current or potential influence on the LLI test, after which the chiropractic adjustments corresponding to this evaluation were performed.

To be included in the second stage of the research, participants had to have no lower limb length inequality when performing the LLI test or that the lower limb length varied when performing head turns or applying pressure on the axial skeleton. This criterion was confirmed by a collaborator who recorded the findings and performed a lower extremity length measurement with a digital "meter foot".

The five participants who failed to regulate the lower limb length inequality following the first stage procedure were excluded from the second stage.

The **second stage** aimed to electrically stimulate different muscle groups and determine whether the activity of these muscles influenced the length of the lower limbs when performing the LLI test. For this, the participant had to be positioned in prone position, with the torso naked, on a stretcher with a facial hole and with both ankles arranged inferiorly to the caudal edge of the stretcher to avoid any influence of the stretcher rubbing against the position of the ankle-foot complex.

Subsequently, 52 electrodes were arranged on 24 muscles of the participant's body, these electrodes were arranged on the proximal and distal contractile tissue of each muscle.

Table 1. Musculature activated electrically

Cervical paraspinals muscles	Thoracic paraspinals muscles
Latissimus dorsi muscles	Lumbar paraspinal muscles
Lumbars quadratus muscle	Gluteus maximus muscles
Gluteus medius muscles	Adductors muscles
Quadriceps muscles	Hamstrings muscles
Triceps Suralis muscles	Tibialis Anterior muscle

All the above-mentioned muscles were activated bilaterally.

Stimulation of each muscle was performed with a transcutaneous neuromuscular electric current with the following parameters: 1. 50 Hz frequency; 2. 250 us phase duration; 3. variable intensity necessary to detect a minimal palpable muscle contraction.

These parameters aim to reproduce a sustained muscular contraction. For this stimulation, an Enraf Nonius model Tensmed S82 electro-stimulator with adaptable stimulation parameters was used. This electro-stimulator was operated by a kinesiologist with clinical and teaching experience in electrotherapy.

For each electrically activated muscle, the LLI assessment was performed by the examiner and by the collaborator, who used a digital meter foot to corroborate the examiner's findings. To confirm the result obtained, the examiner and the collaborator performed 3 measurements of the LLI; if the same result was obtained in all three measurements, the collaborator recorded on the recording sheet (Table 2) one of the following options; 1. If a change in the length of the lower extremity was observed during electrical stimulation, an X was marked in the "positive" column corresponding to the stimulated muscle; 2. If no change in the length of the lower extremity was observed during electrical stimulation, an X was marked in the "negative" column corresponding to the stimulated muscle. If the result was positive, the collaborator should record in the "observations" column one of the following options; 1. If a decrease in the length of the lower extremity was observed, on the same side of the muscle stimulation, an X was marked in the "shorten" section; 2. If an increase in the length of the lower extremity was observed, on the same side of the muscle stimulation, an X was marked in the "lengthen" section. The lengthen option was included in this study after pilot tests were carried out, which accounted for this variable.

Table 2. Registration sheet used by the collaborator.

Participant				
Age				
Muscle Activated Electrically	**Length Change**		**Observations**	
Cervical Erectors	**Positive**	**Negative**	**Shorten**	**Lengthen**
Right				
	Positive	**Negative**	**Shorten**	**Lengthen**
Left				
	Positive	**Negative**	**Shorten**	**Lengthen**
Paraspinal Thoracic	**Positive**	**Negative**	**Shorten**	**Lengthen**
Right				
	Positive	**Negative**	**Shorten**	**Lengthen**
Left				
	Positive	**Negative**	**Shorten**	**Lengthen**
Latissimus dorsi	**Positive**	**Negative**	**Shorten**	**Lengthen**
Right				
	Positive	**Negative**	**Shorten**	**Lengthen**
Left				
	Positive	**Negative**	**Shorten**	**Lengthen**
Paraspinal Lumbar	**Positive**	**Negative**	**Shorten**	**Lengthen**
Right				
	Positive	**Negative**	**Shorten**	**Lengthen**
Left				
	Positive	**Negative**	**Shorten**	**Lengthen**
Quadratus Lumborum	**Positive**	**Negative**	**Shorten**	**Lengthen**
Right				
	Positive	**Negative**	**Shorten**	**Lengthen**
Left				
	Positive	**Negative**	**Shorten**	**Lengthen**
Gluteus Maximus	**Positive**	**Negative**	**Shorten**	**Lengthen**
Right				
	Positive	**Negative**	**Shorten**	**Lengthen**
Left				
	Positive	**Negative**	**Shorten**	**Lengthen**
Gluteus Medius	**Positive**	**Negative**	**Shorten**	**Lengthen**
Right				
	Positive	**Negative**	**Shorten**	**Lengthen**
Left				
	Positive	**Negative**	**Shorten**	**Lengthen**
Hamstrings	**Positive**	**Negative**	**Shorten**	**Lengthen**
Right				
	Positive	**Negative**	**Shorten**	**Lengthen**
Left				
	Positive	**Negative**	**Shorten**	**Lengthen**

Triceps Surails	Positive	Negative	Shorten	Lengthen
Right				
	Positive	Negative	Shorten	Lengthen
Left				
	Positive	Negative	Shorten	Lengthen

Quadriceps	Positive	Negative	Shorten	Lengthen
Right				
	Positive	Negative	Shorten	Lengthen
Left				
	Positive	Negative	Shorten	Lengthen

Adductors	Positive	Negative	Shorten	Lengthen
Right				
	Positive	Negative	Shorten	Lengthen
Left				
	Positive	Negative	Shorten	Lengthen

Tibialis anterior	Positive	Negative	Shorten	Lengthen
Right				
	Positive	Negative	Shorten	Lengthen
Left				
	Positive	Negative	Shorten	Lengthen

Table 2: Registration sheet

RESULTS

To establish the significance between the change in lower extremity length associated with electrical muscle stimulation, a biostatistician independent of the study applied McNemar's test [29].

The following is a description (Table 3) of the findings for each muscle stimulated, the frequency and percentage of the event, plus the significance level with McNemar's test in the 20 participating subjects:

Table 3. Results obtained.

Electrical Muscle Stimulation	Frequency of the event		% of the event		Significance level McNemar's Test
	Event	**Fr**	**Event**	**%**	
Right Cervical Erectors	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Left Cervical Erectors	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Paraspinal Thoracic Right	LL SL NC	0/20 18/20 2/20	LL SL NC	0 90 10	**p= 0,0002**

Paraspinal Thoracic Left	LL SL NC	0/20 16/20 4/20	LL SL NC	0 80 20	**p= 0,00006**
Latissimus dorsi Right	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Latissimus dorsi Left	LL SL NC	0/20 1/20 20/20	ALE ACE SC	0 5 95	**p = 1**
Paraspinals Lumbar Right	LL SL NC	0/20 5/20 15/20	LL SL NC	0 25 75	**p= 0,1336**
Paraspinals Lumbar Left	LL SL NC	0/20 6/20 14/20	LL SL NC	0 30 70	**p= 0,0233**
Right Quadratus Lumborum	LL SL NC	0/20 20/20 0/20	LL SL NC	0 100 0	**p= 0,00002**
Left Quadratus Lumborum	LL SL NC	0/20 20/20 0/20	LL SL NC	0 100 0	**p= 0,00002**
Right Gluteus Maximus	LL SL NC	20/20 0/20 0/20	LL SL NC	100 0 0	**p= 0,00002**
Left Gluteus Maximus	LL SL NC	20/20 0/20 0/20	LL SL NC	100 0 0	**p= 0,00004**
Right Gluteus Medius	LL SL NC	20/20 0/20 0/20	LL SL NC	100 0 0	**p= 0,00002**
Left Gluteus Medius	LL SL NC	20/20 0/20 0/20	LL SL NC	100 0 0	**p= 0,00002**
Right Hamstring	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Left Hamstring	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Right Triceps Suralis	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Left Triceps Suralis	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Right Quadriceps	LL SL NC	20/20 0/20 0/20	LL SL NC	100 0 0	**p= 0,00002**

Left Quadriceps	LL SL NC	20/20 0/20 0/20	LL SL NC	100 0 0	**p= 0,00002**
Right Adductors	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Left Adductors	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Right Anterior Tibialis	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Left Anterior Tibialis	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated

Being: LL: Lengthen limb; SL: Shorten limb; NC: No change.

The statistical results show a significant change in the variation of lower extremity length observed with the LLI test during neuromuscular electrical stimulation in some of the muscles selected in this study. These muscles, when electrically stimulated, generate a decrease or increase in the length of the lower extremity on the same side of the stimulation. The muscles that generate a decrease or "shortening" in the length of the lower extremity on the same side of the stimulation with a significance of $p<0.01$ are: 1. Quadratus lumborum bilaterally; 2. Paraspinal thoracic bilaterally.
The musculatures that generate an increase or "lengthening"; of the lower extremity on the same side of the stimulation with a significance $p<0.01$ are: gluteus maximus bilaterally, gluteus medius bilaterally and quadriceps bilaterally.

DISCUSSION

In this study, the variation in lower limb length observable through the LLI test during electrical stimulation indicates that the activation of certain muscle groups has a significant relationship in the apparent leg length inequality. These results provide a broader view of the origin of functional LLI, comparing it with theories of biomechanical origin only, which have been losing validity with technological advances in the analysis of biomechanics [30-32].

Several studies conclude a relationship between chiropractic care or adjustments to the spine of individuals with significant changes in cortical motor activity, muscle tone and strength. In a systematic review and meta-analysis, Chi Ngai Lo et al. suggest that chiropractic adjustments generate an increase in isometric strength in healthy people[25] . Haavik, determined that following chiropractic care generated a significant increase in the bite force in healthy subjects[28] . Niazi et al. (2015), indicates that spinal adjustments induce significant changes in the low-threshold motor unit excitability network, increased electromyographic signals and maximal muscle contraction strength in the study subjects, associated with an increase in descending control and/or modulation of afferent pathways, reducing muscle fatigue[23] .

Christiansen concluded that a single session of adjustments increases muscle strength and cortical excitability in ankle muscles in athletes [26]. Similar results have been found in two studies indicating that a single session of chiropractic adjustments in stroke survivors generates an increase in cortical motor excitability, improving the function and efficacy of muscle strength [24,27].

Few scientific studies have investigated the relationship of certain muscle groups to the LLI test. Knutson (2005) observed that the quadratus lumborum muscular endurance was significantly lower on the "shortened" lower limb side compared to a group that did not have a difference in lower limb length [33].

This study reveals that the primarily extensor musculature (gluteus maximus, gluteus medius and quadriceps) generate a lengthening or increase in the length of the lower extremity on the same side to activation. This is interesting, as normally chiropractic methods focus on determining which limb is "shortened". This information may provide a new look at the analysis of vertebral subluxations through the LLI test.

Regarding the muscles that shorten the limb, it was expected that the quadratus lumborum would generate an elevation of the pelvis on the same side of the muscle activation, therefore an apparent shortening of the lower limb would be observed. It is noteworthy that the thoracic paraspinal musculature generated this same effect with great significance and with less significance the lumbar paraspinal musculature, this could be related to the anatomical projection of these muscle groups with the iliac bone [34].

These results allow us to better relate the musculature, which when electrically activated generates a change in limb length, to the various descending motor neurological pathways that modulate the action of these same muscles.

The change in lower limb length during muscle activation performed in this study provides further support for the use of the LLI test by associating changes in limb length with changes in muscle tone in the presence of subluxations.

LIMITATIONS

Despite the specificity in the placement of the electrodes on the participant's skin, transcutaneous electrical stimulation can generate activation in musculature close to the target muscle, especially in the paraspinal sector, since many muscle groups have their origin or insertion in this sector. On the other hand, the electrical intensity applied to generate a minimal palpable contraction varied among participants when stimulating the same muscle. This is due to the differences in electrical resistance generated by the different biotypes of the participants. The use of percutaneous ultrasound-guided electrical stimulation is recommended for future research.

CONCLUSION

This study reveals that transcutaneous electrical stimulation on some muscle groups, generates a change in the apparent length of the lower extremities in a group of healthy subjects when performing the leg length inequality test.

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TABLES

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All the above-mentioned muscles were activated bilaterally.

Table 2. Registration sheet used by the collaborator.

Participant				
Age				
Muscle Activated Electrically	**Length Change**		**Observations**	
Cervical Erectors	**Positive**	**Negative**	**Shorten**	**Lengthen**
Right				
	Positive	**Negative**	**Shorten**	**Lengthen**
Left				
	Positive	**Negative**	**Shorten**	**Lengthen**
Paraspinal Thoracic	**Positive**	**Negative**	**Shorten**	**Lengthen**
Right				
	Positive	**Negative**	**Shorten**	**Lengthen**
Left				
	Positive	**Negative**	**Shorten**	**Lengthen**
Latissimus dorsi	**Positive**	**Negative**	**Shorten**	**Lengthen**
Right				
	Positive	**Negative**	**Shorten**	**Lengthen**
Left				
	Positive	**Negative**	**Shorten**	**Lengthen**

Paraspinal Lumbar	Positive	Negative	Shorten	Lengthen
Right				
	Positive	Negative	Shorten	Lengthen
Left				
	Positive	Negative	Shorten	Lengthen

Quadratus Lumborum	Positive	Negative	Shorten	Lengthen
Right				
	Positive	Negative	Shorten	Lengthen
Left				
	Positive	Negative	Shorten	Lengthen

Gluteus Maximus	Positive	Negative	Shorten	Lengthen
Right				
	Positive	Negative	Shorten	Lengthen
Left				
	Positive	Negative	Shorten	Lengthen

Gluteus Medius	Positive	Negative	Shorten	Lengthen
Right				
	Positive	Negative	Shorten	Lengthen
Left				
	Positive	Negative	Shorten	Lengthen

Hamstrings	Positive	Negative	Shorten	Lengthen
Right				
	Positive	Negative	Shorten	Lengthen
Left				
	Positive	Negative	Shorten	Lengthen

Triceps Surails	Positive	Negative	Shorten	Lengthen
Right				
	Positive	Negative	Shorten	Lengthen
Left				
	Positive	Negative	Shorten	Lengthen

Quadriceps	Positive	Negative	Shorten	Lengthen
Right				
	Positive	Negative	Shorten	Lengthen
Left				
	Positive	Negative	Shorten	Lengthen

Adductors	Positive	Negative	Shorten	Lengthen
Right				
	Positive	Negative	Shorten	Lengthen
Left				
	Positive	Negative	Shorten	Lengthen

Tibialis anterior	Positive	Negative	Shorten	Lengthen
Right				
	Positive	Negative	Shorten	Lengthen
Left				
	Positive	Negative	Shorten	Lengthen

Table 2: Registration sheet

Table 3. Results obtained.

Electrical Muscle Stimulation	Frequency of the event		% of the event		Significance level McNemar's Test
	Event	Fr	Event	%	
Right Cervical Erectors	LL	0/20	LL	0	Significance cannot be calculated
	SL	0/20	SL	0	
	NC	20/20	NC	100	
Left Cervical Erectors	LL	0/20	LL	0	Significance cannot be calculated
	SL	0/20	SL	0	
	NC	20/20	NC	100	
Paraspinal Thoracic Right	LL	0/20	LL	0	**p= 0,0002**
	SL	18/20	SL	90	
	NC	2/20	NC	10	
Paraspinal Thoracic Left	LL	0/20	LL	0	**p= 0,00006**
	SL	16/20	SL	80	
	NC	4/20	NC	20	
Latissimus dorsi Right	LL	0/20	LL	0	Significance cannot be calculated
	SL	0/20	SL	0	
	NC	20/20	NC	100	
Latissimus dorsi Left	LL	0/20	ALE	0	**p = 1**
	SL	1/20	ACE	5	
	NC	20/20	SC	95	
Paraspinals Lumbar Right	LL	0/20	LL	0	**p= 0,1336**
	SL	5/20	SL	25	
	NC	15/20	NC	75	
Paraspinals Lumbar Left	LL	0/20	LL	0	**p= 0,0233**
	SL	6/20	SL	30	
	NC	14/20	NC	70	
Right Quadratus Lumborum	LL	0/20	LL	0	**p= 0,00002**
	SL	20/20	SL	100	
	NC	0/20	NC	0	
Left Quadratus Lumborum	LL	0/20	LL	0	**p= 0,00002**
	SL	20/20	SL	100	
	NC	0/20	NC	0	
Right Gluteus Maximus	LL	20/20	LL	100	**p= 0,00002**
	SL	0/20	SL	0	
	NC	0/20	NC	0	
Left Gluteus Maximus	LL	20/20	LL	100	**p= 0,00004**
	SL	0/20	SL	0	
	NC	0/20	NC	0	
Right Gluteus Medius	LL	20/20	LL	100	**p= 0,00002**
	SL	0/20	SL	0	
	NC	0/20	NC	0	
Left Gluteus Medius	LL	20/20	LL	100	**p= 0,00002**
	SL	0/20	SL	0	
	NC	0/20	NC	0	

Right Hamstring	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Left Hamstring	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Right Triceps Suralis	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Left Triceps Suralis	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Right Quadriceps	LL SL NC	20/20 0/20 0/20	LL SL NC	100 0 0	**p= 0,00002**
Left Quadriceps	LL SL NC	20/20 0/20 0/20	LL SL NC	100 0 0	**p= 0,00002**
Right Adductors	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Left Adductors	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Right Anterior Tibialis	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated
Left Anterior Tibialis	LL SL NC	0/20 0/20 20/20	LL SL NC	0 0 100	Significance cannot be calculated

Being: LL: Lengthen limb; SL: Shorten limb; NC: No change.