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## Original article

# Effects of neuromuscular training and electrical stimulation on ankle stability and muscle strength of peroneus longus in rock climbers

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**Background:** Ankle sprains during rock climbing are caused by several factors, such as landing on the ground and footing while climbing. Additionally, ankle sprains involved with the footing are often due to rock climbing shoes. These shoes are often restricting the motion of the feet, resulting in the shortening of the toe and ankle muscles in supination, which leads to a higher risk for an ankle sprain. Investigating neuromuscular training and electrical stimulation are necessary for the development of an effective training of the ankles to prevent injury.

**Objectives:** To study the effects of neuromuscular training and electrical stimulation on ankle stability and muscle strength of the peroneus longus (PL) in rock climbers.

**Methods:** Sixteen rock climber volunteers of 18 - 30 years old were tested for the isometric muscle strength of their PL muscle and ankle stability while moving. The subjects were divided into two groups of eight people: Group 1 performed functional ankle training on a wobble board (WB) (n = 8), and Group 2 did similar but with additional neuromuscular electrical stimulation (NMES) (n = 8). The groups were trained 3 days a week for 4 weeks.

**Results:** The results showed that within the WB and WB+NMES groups after 4 weeks training, there was a significant increase in the PL muscle strength and the stability of the ankle while moving ( $P < 0.05$ ). However, there was no significant difference between the groups themselves.

**Conclusion:** This study concluded that the training program for both groups could increase the PL muscle strength and the stability of the ankle while moving.

**Keywords:** Ankle stability, electrical stimulation, muscle strength, neuromuscular training, peroneus longus.

Rock climbing is a challenging and famous sport all over the world. It was selected as one of the sports programs in the upcoming 2020 Summer Olympics.<sup>(1)</sup> According to various studies that focused on rock climbing injuries, the findings showed that particularly the upper and lower extremities had a high risk of injury. Even so, these studies had contradictory results. Many of them were only case studies or only focused on general hand injuries.<sup>(2)</sup> Nevertheless, most rock climbing injuries are actually foot injuries, particularly ankle sprains.<sup>(2)</sup> These foot injuries occur due to several factors: the landing on the ground after jumping

down from an elevated location,<sup>(3)</sup> the footing while climbing, the numerous types of footing due to different stones,<sup>(4)</sup> and wearing rock climbing shoes.<sup>(2, 5)</sup> The shoes are often too small, resulting in the shortening of the toes and ankle muscles in supination, which leads to a high risk of ankle sprains. The key muscle to prevent ankle sprains and to reduce their severity is the peroneus longus (PL) and the peroneus brevis (PB).<sup>(5, 6)</sup> Ankle sprains could repeatedly occur to the same side of the ankle, which could lead to chronic ankle instability.<sup>(7)</sup>

According to a relevant study, balance training is mostly suggested to those with an ankle instability—for example, standing on one leg or on a device with little stability (such as a wobble board [WB]).<sup>(8)</sup> The study also stated that balance training is useful for reducing the incidents of ankle sprains. This reduction is not caused due to the increase of nervous and muscle system control but rather due to the increased strength

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of the muscle and ankle tendons.<sup>(8)</sup> In addition, several studies have also suggested that neuromuscular electrical stimulation (NMES) in healthy people and athletes is useful to increase the function of muscles as well as the nervous and muscle systems, especially when conducting voluntary muscle contraction stimulation.<sup>(9)</sup>

Muscle strength and ankle stability might relate to balance while standing on unstable surfaces. In this case, the effect of muscle nerves from balance training, using a stability training device, is necessary for the improvement of training efficiency. Here, NMES is an effective approach that can increase muscle function and the nervous and muscle system control.<sup>(10)</sup> In this study, we examined the effects of neuromuscular training and electrical stimulation on the ankle stability and muscle strength of the PL in rock climbers. The results from this study have been translated into guidelines that can increase muscle strength and ankle stability in order to reduce the possible risk of instability, and thus, causing ankle injuries during rock climbing.

## Materials and methods

### Populations

The population for examination included 16 rock climbing volunteers from the Thammasat University, Rangsit Campus, including seven males and nine females, aged 18 - 30 years. The volunteers were chosen based on their medical records. Only those without any previous ankle sprains, ankle instability,<sup>(7,11)</sup> or pain from stroking around the anterior talofibular ligament and the calcaneofibular ligament were chosen.<sup>(12)</sup> Additionally, they never had received ankle training,<sup>(7)</sup> never had a restricted range of ankle motion, never had ankle surgery, or had any bone fracture of the ankles or other lower extremities.<sup>(11)</sup> Volunteers also never had any other illnesses or conditions that affected balance, such as otitis, Meniere's disease, vertigo, head injury, or drug-induced balance disruption due to side effects. Plus, the volunteers should have never received any ankle treatments. Finally, they were required to understand the instructions and explanations and willing to participate in the study. The volunteers were educated about the objectives and details of the study and also signed the agreement document for their participation.

### Data collection

#### Isometric muscle strength measurement

The isometric muscle strength of the PL muscle was measured (intraclass correlation coefficient;

ICC = 0.99). The volunteers were instructed to lie down with their face up. Both toes of the volunteers were in a relaxing state. The researcher then arranged the posture and position of the volunteers so that their heels parted about 10 cm. The volunteers were requested to exert their PL muscle by contracting it for a moment in the posture of plantarflexion with eversion.<sup>(7)</sup> The muscle strength was measured during the movement by using a wireless muscle strength tester (tracker™ version 5, JTECH medical industries, Inc., USA). Before recording, the volunteers were instructed to try lower levels than the maximum for familiarity.<sup>(13)</sup> Each time before performing a test, the volunteers had to start from the default posture. As for the test itself, after the instruction "Get ready. 1, 2, 3, exert," the volunteer had to try to push against the resistance of the researcher as hard as possible. The wireless muscle strength tester started its timing after the word "exert" and stopped the time after 5 seconds of exertion. After each test, while preparing for the next one, the volunteers had a 30-second break. The measurement was repeated twice, followed by a 1-minute break. Then, the measurement switched to the other leg, three times per leg. The maximum values were recorded in kilograms.<sup>(13)</sup>

#### Ankle stability measurement while moving

A single leg hexagon hop was performed to measure the ankle stability while moving (ICC = 0.98). The volunteers were instructed to stand only on the leg of which they were most capable with. Both hands were touching the waist at the beginning. The volunteers had to stand at the center of the circle inside a hexagon, of which each side was 60 cm long, and the distance to the circle 40 cm. Then, the volunteers were instructed to hop to the outside of each side of the hexagon and then hop back again into the circle where they started. The volunteers had to turn their face away clockwise from the direction they hopped to without touching the hexagon line. They hopped as far as possible while still being able to hop back and touch the line inside the hexagon. The researcher counted the number of times the volunteers completed their action in all directions and counted the time in seconds while testing. The test was conducted twice with a 1-second break in between, and the mean values were recorded.<sup>(14)</sup> In case the volunteers lost their balance, and their elevated foot fell down to the ground, the test was considered a failure, and the timing was then stopped.<sup>(11)</sup>

**Training program**

The volunteers participated in the training program for 3 days per week (Monday, Wednesday, and Friday) and 4 weeks in total. As for the training, the volunteers were divided into Group 1 and Group 2. Herein, Group 1 performed the functional ankle training on a WB with various postures:

- Posture 1: The volunteers stood only on the leg they were most familiar with on the WB. They had to bent the knee of the standing leg to an angle of approximately 75 degrees.
- Posture 2: The volunteers stood on both legs on the WB.
- Posture 3: The volunteers stood on both legs on the WB with half-bent knees.

The volunteers did each posture for 5 seconds, with a 15-second break in between. During the training for each posture, the volunteers had to open and close their eyes five times in total. The entire training took 10 minutes. The volunteers tried to keep their balance on the WB, and the researcher adjusted and selected the postures from the training program on the WB based on previous studies.<sup>(15 - 18)</sup>

Group 2 performed the functional ankle training on a WB+NMES. The training procedures and postures were the same as those in Group 1, except for the addition of electrical stimulation. The use of electrical muscle stimulation was an adjusted approach based on the study by Canning A. *et al.*<sup>(10)</sup> Briefly, a faradic current was applied to stimulate the PL muscle (using the bipolar technique with the electrodes placed on the PL muscle). The ratio of stimulation per break was 5: 10 sec. The intensity used for the stimulation was within the tolerance of the volunteers. During the training for each posture, the volunteers from Group 2 also opened and closed their eyes for 5 times in total. This entire training took 10 min similar to Group 1.<sup>(10)</sup>

**Statistical analysis**

Physical characteristics included age, weight, height, body mass index (BMI), and isometric muscle strength of the PL muscle. These values were displayed as the mean with the standard deviation (SD).

As for the comparison of the results, the before and after results (after 4 weeks of training) within each group were compared using a paired *t* - test. As for the comparison between groups after 4 weeks of training, an unpaired *t* - test was used. The statistical significance was set at *P* < 0.05.

**Results**

**Physical characteristics**

The average physical characteristics of all volunteers were determined, which included an age of 21.19 ± 1.83 years, a height of 164.69 ± 7.56 cm, a weight of 59.13 ± 13.07 kg, a BMI of 21.60 ± 3.52 kg/m<sup>2</sup>, and an isometric PL muscle strength of 13.23 ± 1.99 kg (Table 1).

**Comparison of isometric muscle strength of PL muscle**

The measurement results showed that the before and after training isometric muscle strength of the PL muscle in the WB group and the WB+NMES group in week 4 was significantly increased (*P* < 0.05), as shown in Table 2. However, the strength between the two groups was not significantly different (*P* > 0.05), as shown in Table 3.

**Comparison of ankle stability while moving**

The measurement results showed that the ankle stability while moving before and after training in the WB group and the WB+NMES group in week 4 was significantly increased (*P* < 0.05), as displayed in Table 2. However, the stability between groups was not significantly different (*P* > 0.05), as illustrated in Table 3.

**Table 1.** Physical characteristics.

| Physical characteristics                        | Total (n = 16) | WB (n = 8)    | WB+NMES (n = 8) | P - value |
|---|----------------|---------------|-----------------|-----------|
| Age (yr)  | 21.19 ± 1.83   | 21.63 ± 2.32  | 20.75 ± 1.16    | 0.36      |
| Height (cm)                                     | 164.69 ± 7.56  | 163.38 ± 7.72 | 166.00 ± 7.69   | 0.51      |
| Weight (kg)                                     | 59.13 ± 13.07  | 56.88 ± 15.62 | 61.38 ± 10.52   | 0.51      |
| BMI (kg/m <sup>2</sup> )                        | 21.60 ± 3.52   | 21.03 ± 4.24  | 22.17 ± 2.78    | 0.54      |
| Isometric muscle strength of the PL muscle (kg) | 13.23 ± 1.99   | 13.30 ± 1.67  | 13.17 ± 2.38    | 0.90      |

BMI = body mass index; PL = peroneus longus

**Table 2.** Comparison of isometric muscle strength of the PL muscle before and after the training in week 4 in the WB group and the WB+NMES group.

| Parameters                                      | Before<br>(Mean ± SD) | Week 4<br>(Mean ± SD) | (95% CI)               | P - value |
|---|-----------------------|-----------------------|------------------------|-----------|
| <b>WB</b>                                       |                       |                       |                        |           |
| Isometric muscle strength of the PL muscle (kg) | 13.30 ± 1.67          | 18.56 ± 3.29          | -5.26 (-7.10 to -3.42) | 0.000*    |
| Ankle stability while moving (sec)              | 11.14 ± 4.23          | 5.34 ± 1.01           | 5.80 (2.89 to 8.17)    | 0.002*    |
| <b>WB+NMES</b>                                  |                       |                       |                        |           |
| Isometric muscle strength of the PL muscle (kg) | 13.17 ± 2.38          | 18.36 ± 1.66          | -5.19 (-7.71 to -2.65) | 0.002*    |
| Ankle stability while moving (sec)              | 11.81 ± 4.53          | 5.68 ± 0.83           | 6.13 (2.72 to 9.53)    | 0.004*    |

\* $P < 0.05$ **Table 3.** Comparison of isometric muscle strength of the PL muscle before and after the training in week 4 between the WB group and the WB+NMES group.

| Parameters                                      | WB<br>(Mean ± SD) | WB+NMES<br>(Mean ± SD) | (95% CI)              | P - value |
|---|-------------------|------------------------|-----------------------|-----------|
| Isometric muscle strength of the PL muscle (kg) | 18.56 ± 3.29      | 18.36 ± 1.66           | 0.20 (-2.69 to 3.09)  | 0.88      |
| Ankle stability while moving (sec)              | 5.34 ± 1.01       | 5.68 ± 0.83            | -0.34 (-1.34 to 0.65) | 0.47      |

## Discussion

This study aimed to examine the effects of neuromuscular training and electrical stimulation on ankle stability and muscle strength of the PL in rock climbers. The volunteers were divided into the WB group (Group 1: performed functional ankle training on a WB) and the WB+NMES group (Group 2: performed functional ankle training on a WB+NMES).

Herein, according to our results, the isometric muscle strength of the PL muscle and ankle stability while moving before and after the training in the WB group and in the WB+NMES group in week 4 were significantly increased ( $P < 0.05$ ). In contrast, the strength and stability between the two groups were not significantly different ( $P > 0.05$ ). Thus, we found that the isometric muscle strength of the PL muscle in both the WB and WB+NMES training groups increased.

Both group training approaches were based on neuromuscular principles. In regards to the WB group, the increased muscle strength can be described by two principles. The first is called overload, which it involves the basis of the strength promotion process. To clarify, when the body undergoes an unfamiliar load (for example, training overload), it adapts itself

to endure that load through a physiological change or a nervous system adaptation. As a consequence, the body is able to respond to the overload more efficiently. This is because normal muscles tend to contract (mostly concentric contraction) when they are stimulated. The second principle is called active muscle function. Herein, a great number of studies have indicated that voluntary muscle contraction training improves the motor system more efficiently than passive muscle function or involuntary muscle contraction. In perspective of our obtained results, the increased muscle strength in the WB+NMES group is most likely an effect of these principles. Herein, the first argument includes overload, which is in line with the voluntary muscle contraction principle: the harder the contraction is, the more strength the muscle will gain, rather than training for less contraction. Normally, muscles become strong because of their function, which motivates the maximum contraction of those muscles. What also happens during the maximum contraction is the maximum muscle tension. Thus, if NMES generates a maximum muscle contraction, it can also result in an increase of muscle strength.<sup>(10)</sup> The second argument regarding the role of above-mentioned principles is that NMES initiates

the recruitment of large nerves before small ones. In turn, this affects the stimulation of fast-twitch (type II) muscle fiber, of which its contraction force is stronger than the slow-twitch (type I) one. Based on this reasoning, NMES generates the recruitment of the motor unit.

According to the study of Bax L, *et al.*<sup>(19)</sup> NMES is an effective approach for strengthening the quadriceps femoris in healthy people and patients, both without exercise. Nonetheless, several studies have concluded that NMES does not significantly affect the increase of strength when comparing those with and without exercise. These contradictions might be due to experimental conditions—for example, there are various types of muscle contraction and various intensities of NMES. The WB+NMES group in this study underwent common peroneal stimulation by using a faradic current, which stimulates the dorsal motor and primary motor cortex and pushes their performance. This implies that common peroneal stimulation caused the PL muscle to increase its activity.<sup>(20)</sup> These results are in agreement with the study of Vrbova G, *et al.*<sup>(21)</sup> who showed that electrical stimulation can replace the motor nerves in case of nervous system injuries and can increase medical treatment efficiency.

Besides the increased strength of the PL muscle thanks to the training postures in the WB group and the WB+NMES group—that is, standing only on the leg the volunteer was most familiar with, standing on both legs, and standing on both legs on the WB with half-bent knees—the postures also allowed the practice of the perception of joint positions and balance. In medical care, these postures are usually applied for ankle muscle rehabilitation for peroneus muscles, specifically to increase the lateral ankle joint while moving.<sup>(22)</sup> According to the study of Doherty C, *et al.*<sup>(23)</sup> they found that those who are rehabilitated from lateral ankle sprains will be confronted with reduced neuromuscular control at the ankles in the short term, which particularly involves the PL muscle. As a result, the used approach must be adjusted to maintain stability; that is, a hip strategy will be applied instead. This situation usually applies to people with functional ankle instability. In addition, when people suffer from ankle pain or muscle fatigue, they usually avoid loading any weight on their ankles. Instead, they use the gluteal muscles to provide balance stabilization and control. Muscle strength training, therefore, may rehabilitate ankle muscle balance and positioning to obtain a more stable position.<sup>(8)</sup>

Training to increase muscle strength does affect not only the muscle tissue but also the adaptation in the central nervous system. Motor learning stimulation through specific training is a consequence of balance activity that is associated with the activities we perform. The human body is a connecting mechanical system, so parts of the body and the supporting base are re-adjusted before muscle function to exert the strength. In this case, muscle strength can be improved after specific training, training postures, and the muscles that stop body motion and muscle contraction. Strength training might be initiated from the increase of the ability to stimulate motor cells during voluntary muscle contraction. However, the nervous system adaptation also represents the change in neuromuscular coordination; learning is a key factor that stimulates the improvement of neuromuscular recruitment. It also stimulates the involved muscle function during specific strength training.<sup>(24)</sup> Furthermore, the increase of muscle function might be a result of the increase of stimulation from supraspinal centers as the neuromuscular adapts in order to respond to the various types of training. This also affects the responsiveness of balance during balance training because the corticospinal is more stimulated, resulting in the stimulation of neural adaptations when learning is repeated in 1 week.<sup>(25)</sup> The study of Haruthai G, *et al.*<sup>(26)</sup> suggested that strength training changes the stimulation of motor cells and the nervous system coordination in spinal cords, while the command positions do not change. Their findings are in line with ours, in which they found that the two programs that stimulated the neuromuscular system resulted in its adaptation, bringing more isometric muscle strength to the PL muscle as a result.

The performed training on a WB by both groups (WB and WB+NMES) resulted in improved ankle stability while moving. The study of Sundaraganesh K, *et al.*<sup>(16)</sup> similarly found that a WB helps to improve the balance of athletes with functional ankle instability, both while they are standing still and while moving. A WB can help improve the perception of joints and balance through mechanoreceptors to create function of the muscles, tendons, and joints. The function basically starts through loading. Furthermore, in a study by Silva PdeB, *et al.*<sup>(27)</sup> they showed that when standing on a WB (compared to standing on stable ground), the PL muscle activity increased. This because the PL muscle is the core mechanism for keeping balance on a WB. The neuromuscular

connects ankle muscle function and is recruited more when using a WB surface for training where the sensation system helps the balance control (i.e., vestibular, visual, and somatosensory). Next, the study of Melnyk M, *et al.*<sup>(28)</sup> found that the long-term effects of WB training resulted in increased muscle strength and increased neuromuscular function in order to adjust for muscle spindle acuity. In their study, they assumed that the improvement of the incoming and outgoing of the sensorimotor is to control muscle contraction together. This may engender more efficient neuromuscular coordination, depending on the increased function of the motor unit. As a result, the sensorimotor unit may be recruited more, which is good for the balance.<sup>(29)</sup>

Overall, this study demonstrated that functional ankle training on a WB and functional ankle training on a WB+NMES could increase the isometric muscle strength of the PL muscle, leading to ankle stability while moving. Additionally, during the training on a WB and a WB+NMES, the PL muscle contraction was stimulated. The tendons under the feet contracted, and the joints were tightened. As a result, there was ankle stability while moving. Both groups showed improvement after the WB exercises.

Suggestions for further studies are as follows: 1) A digital device should be introduced for ankle stability evaluation, for example, the kinematic measurement system; 2) A device should be used that can evaluate the muscle function during the training or testing, for example, surface electromyography.

### Conclusions

The functional ankle training before and after training 4 weeks on a WB or WB+NMES increased the isometric muscle strength of the PL muscle and ankle stability while moving.

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### Conflict of interest

The authors, hereby, declare no conflict of interest.

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