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Heating Plates Placement Structure for Optimal Muscle Stress Relief with Low Power Consumption

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Abstract: A rapid contraction of the calf muscles, which can leave an hour of discomfort and soreness. Imagine that it happens to elderly people who live alone and bare their suffering helplessly. The goal of this research is to develop a device to automatically alleviate the pain of a cramp. This paper describes the ongoing development of the device focusing on how to minimize power consumption (heat plate placement structure) but providing optimal performance to relax the stressed muscle. To suggest the structure, the TRIZ technique for solving problems is used. The suggested placement structure was tested on 20 participants and the results revealed that the power consumption could be decreased by up to 66%, hence, enabling the future product to be able to use the battery as a power source and operate for longer hours in a single use of battery.

Keywords: Automatic cramp relief device, heat plate, TRIZ, inventive principles

1. Introduction

33.33 % of adults and 50 % of adults over 60 years of age have an annual leg cramp, usually at night [1]. Muscle strains cause pain or mild to extreme discomfort and tension in the leg [2]. Nocturnal leg muscle stress can lead to other complications, such as sleep interruption and a human sleep period that can make people feel exhausted or lethargic on the following day. Leg muscle stress can make it very difficult to fall asleep, and this can lead to problems such as insomnia over time [2]. The length of the muscle stress varies, with cramps lasting a few seconds to a few minutes. It can be reduced when the stress arises by applying a rub, stretching gently, or applying some heat to the targeted muscle [3]. Often, for elderly people, a helping hand is needed to apply the suggested former mentioned treatments and to make matters worse, no one is there, and these vulnerable veterans are left alone in agony.

The main goal of this study is to design a mechanism for the automatic relief of muscle stress pain in order to help elderly people, especially those who live alone. There are several therapies that can be used to relieve muscles stress. The use of ice in cold therapy on a stressed muscle decreases blood flow. Its acts as a topical anesthetic, numbing painful tissues and slowing the transmission of pain signals to the brain [4]. However, the use of ice or watery elements in an automatic device is not possible due to the difficulty to provide cold temperature instantly compared to hot temperature. Heat also can be used to ease muscle stress. Heat can help to regenerate muscles and increase the rate of glycogen refilling [4], [5]. Heat can also increase muscle endurance and the energy rate of muscle contraction reduces [6]. As the proposed device uses electricity to produce heat and must be in standby mode for 24 hours (muscle stress will occur at any time), this may lead to high energy consumption. 48% of the electricity is consumed for cooling and heating equipment [7]. This paper describes the preliminary outcome of the ongoing development of an automated cramp relief device. This

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paper reflects on how to reduce power demand but deliver maximum performance to relax the stressed muscle by examining the configuration of heating plates placement on the target area.

The Theory of Inventive Problem Solving (TRIZ) introduced by the Soviet Union is used as a method for inventive ideas to minimize power yet to create a large heating region (in this paper the targeted muscle stress study is at the leg calf). TRIZ is able to suggest a variety of concepts that resolve a contrasting issue [8],[9]. The details of the TRIZ technique and the feasibility test of the proposed will be covered in the next section. In the final section, the results will be presented with the discussion of the findings

2. Materials and Methods

2.1 Heat plate

Heat will help to relieve the pain of muscle stress. This is because heat is able to extend the muscle and strengthen the soft tissue. Studies have shown that heat improves muscle endurance and decreases accidents [4],[5],[6]. Therefore, in order to have a positive effect on the muscle, heat must be applied below the temperature of the human body for a few minutes or up to an hour [4]. Moreover, the skin temperature for the arms and legs is typically around 31 degrees Celsius [10] [4]. Besides being suitable for rising blood circulation, heat is commonly used before exercise because it can offer multiple advantages, such as increased tissue metabolism, glycogen resynthesis, and even good muscle recovery [11]. There are two types of the heating plate, i.e. dry heating plate and wet heating plate. Wet heating plate uses liquid to move heat or an external gel. A wet heat therapy is recorded to alleviate pain faster than dry heat, but maintenance would be messier and be shorter than dry heat [10]. Dry heating plate heats easily [10], [12], rendering dry heating plate a decent option for automated systems and low power consumption. However, as the energy is proportional to the area, see equation (1), the heat plate of the plate needs to be as small as possible to provide an optimal heating treatment.

$$\text{Energy} = kA(T1-T2)/d, \text{ where} \qquad (1)$$

T1 and T2 temperatures of the corresponding side of the plate and surface region A and the thickness d of the pad. The thermal conductivity value of the disk used is k.

Table 1 - An example of a table

An example of a column heading	Column A (*t*)	Column B (*t*)
And an entry	1	2
And another entry	3	4
And another entry	5	6

2.2 The Cause and Effect of the Chain Analysis

The proposed cramp relief device is programmed to be able to sense cramping as it occurs, to heal the pain easily, to work automatically, to conserve power and to be easy to use. However, the proposed solution will result in high power usage as it would be ON all the time, more heat energy and many systems are required to make it run automatically. Fig. 1 of the Cause and Effect Chain Analysis shows this [8]. Based on Fig.1, three factors could give rise to high-power consumption in its architecture. Firstly, that may be attributable to an Electromyography (EMG) muscle transmitter that must be active all the time to detect muscle stress. Secondly, in order to relieve the discomfort efficiently and uniformly, the heating plate must be built to cover the whole goal area, in this case, the calf. Finally, the system has to be moveable so that it can reach the target area. This will bring another system to the unit, which means more power is required.

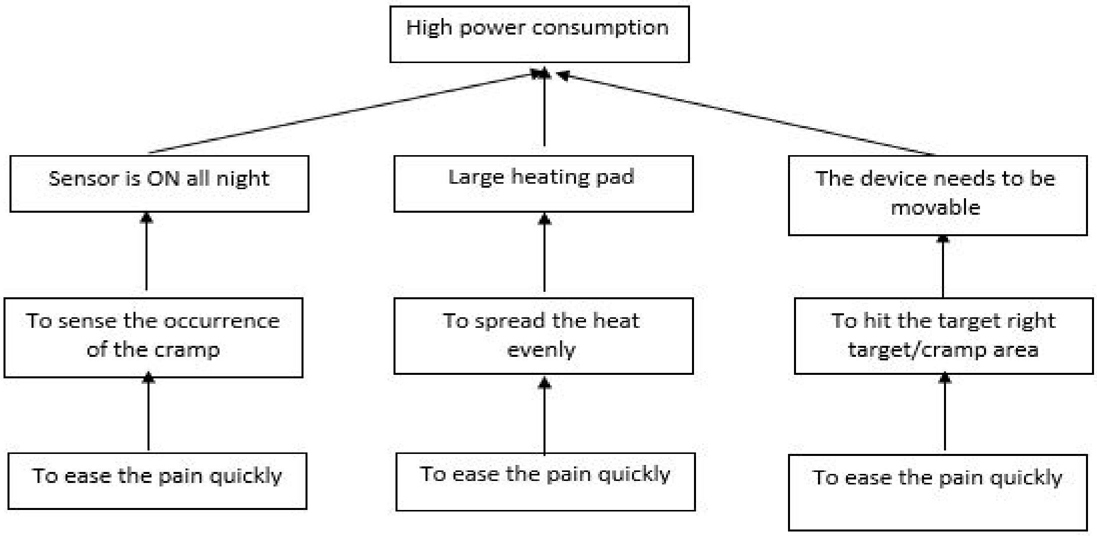


Fig. 1 - Cause and effect chain analysis to derive the possible root cause of the power consumption problems

Two contradictions can be inferred from Cause and Effect Chain Analysis: first, the sensor has to be ON all the time to sense the cramping case, but it will cause high power consumption, and secondly, in order to relieve muscle stiffness more rapidly, the heat needs to distribute evenly across the muscle. Around the same time, though, heat isolation will lead to one or more broad measurements of the heating plate being mounted on the calf, which will lead to high power consumption. In the next chapter, all contradictions will be analyzed by using the TRIZ tool and several solutions will be suggested

2.3 Engineering Contradiction Analysis

Engineering Contradiction (EC) is one of the tools of TRIZ to solve a problem faced by an attempt to improve one of the characteristics of the system which results in the degradation of another characteristic [8]. The mixture of better and worsening parameters would indicate a few solutions as seen in the contradiction matrix [8], [9].

The first contradiction about the use of the sensor is analyzed as follows:

IF the sensor is ON all the time,
THEN the event of the cramp is detected quickly, (improve parameter)
BUT the use of power is high. (worsening parameter)

From the 39 parameters [8], parameters involved in this system are
Improve parameter = Loss of Information (#24)
Worsening parameter= Power (#21)

The second contradiction with respect to the heating plate area of target is analyzed in the following:

IF the surface of the heating pad is large or many
THEN, the heat will be dissipated faster and in a wide area, (improve parameter)
BUT, the power consumption is high. (improve parameter)

From the 39 parameters [8], the parameters involved in this system are
Improve parameter =
1) Area of stationary object (#6)
2) Speed (#9)
3) Duration of action by stationary object (#16)
4) Temperature (#17)

Worsening parameter = Power (#21)

In TRIZ, all possible Inventive Principles (IP) based on identified engineering contradiction (improving and worsening parameters) can be obtained from the contradiction matrix table. IP are generic solutions that can be used to solve the contradictive problem [8]. Table 1 shows the obtained recommended IP from the contradiction matrix table [8]. TRIZ only suggests the possible solutions based on previous successful implementation of identical contradiction problems. Therefore, from Table 1, 11 recommend IPs are suggested. All suggestions were considered and analyzed based on practicability and feasibility. For example, number 19 (Periodic action), this IP can be executed by putting the device in ON and OFF mode periodically. This method could reduce the power consumption, but it could reduce the effectiveness of relieve cramps as well. However, it could be a suitable solution for the first contradiction as mentioned above where the system can be put under idle mode when all the time and only ON when the cramp happens. This part of the solution will be studied further in future development.

In this paper, the results of the combination of recommended IP number 14 (Curvature) and 16 (partially of excessive action) are reported. IP curvature suggested the heating plate is shaped to a curvy form to fit the surface of the calf leg. It makes sense as our leg surface is not flat while the plate is flat and inflexible, hence the heat is not dissipated fully and effectively. The latter IP could suggest that the heat plate should focus on the main area which are gastrocnemius muscles and the Achilles tendon only as these parts of the anatomy are affected when the cramp happens.

Table 1 - The recommended IPs for both contradictions from the contradiction matrix table [8]

Parameter to be improved	Parameter that worsen	Recommended IP
24	21	#10 Preliminary action #19 Periodic action
6,9,16,17	21	#2 Taking part #14 Curvature #16 Partial of excessive action #17 Another dimension #25 Self service #19 Periodic action #32 Color action #35 Parameter change #38 Strong oxygen

2.4 Potential Solution and Design

The calf muscle is made up of two muscles on the back of the lower leg. The gastrocnemius is the largest calf muscle and is responsible for the apparent bulge beneath the skin. The gastrocnemius contains two "heads" that work together to form a diamond shape. The soleus muscle, which sits beneath the gastrocnemius, is a tiny, flat muscle. At the base of the calf muscle, the gastrocnemius and soleus muscles taper and join. The Achilles tendon and tough connective tissue near the bottom of the calf muscle combine. The Achilles tendon connects the heel bone to the toes (calcaneus). The calf muscle lifts the heel to facilitate forward movement whether walking, running, or jumping [2]. When this muscle is stressed, ideally, for fast relief, the heat plate should cover the whole back of the lower leg as shown in Fig.2 (left leg). In this paper, the heating plate is made from a piece of 1 mm thick copper with 2.0 cm x 1.0 cm dimension. In the control experiment (will be further explained in the experimental paradigm), 9 pieces of heating plate (connected parallelly to 5 V of DC supply) were used to give a maximum cover on the calf. The plates were arranged inside a heat resistance cloth to form a pad. The design of the heating plate is fixed in shape as normally found commercially.

With respect to the proposed heat plates placement structure, from section 2.3, suggested IP numbers 14 (curvature) and 16 (partial of excessive action) were chosen. Therefore, the copper plate is bent to form a curve so it will fit on the calf surface. Only 3 plates (connected parallelly to 5 V of DC supply) were inside the heat resistance cloth pad. 2 plates were placed on the gastrocnemius and 1 on the Achilles tendon. This heat plates placement structure is shown in Fig.2 (right leg).

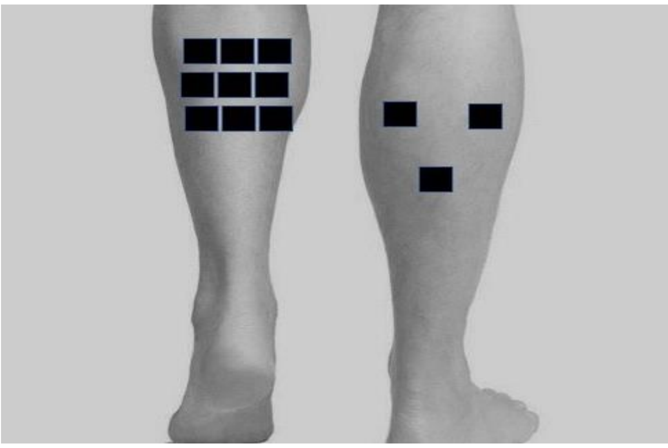


Fig. 2 - The placement of the heating plates on the calf. On the right leg is the proposed heating plates placement structure and on the left leg is the control heating plates placement structure

2.5 Experimental Paradigm

2.5.1 Participant(s)

All 20 participants (female only to prevent any inter-gender impact on the outcome) who are volunteers for this study are from 20 and 25 years of age with a weight of 45 to 55 kg.

2.5.2 Electromyography (EMG) electrodes

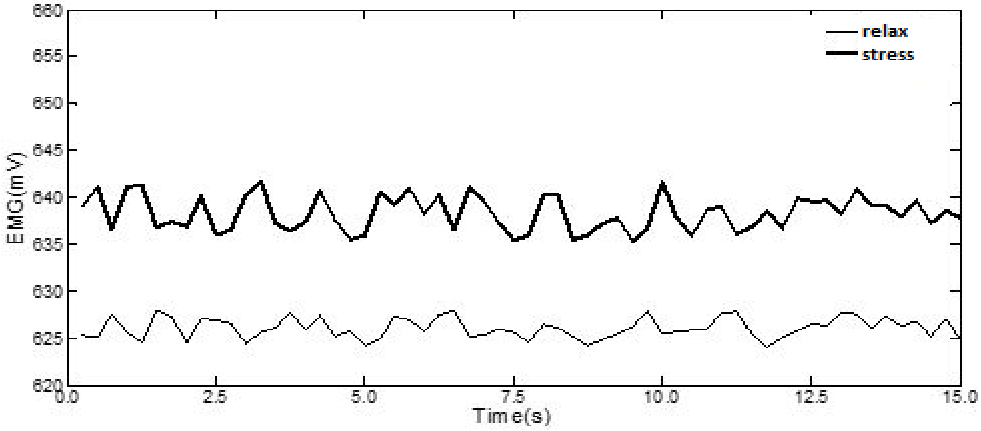
Mostly, the leg muscle that is affected when cramps occur is the calf muscle [13] [2]. Therefore, 3 surface EMG electrodes; the middle muscle electrode, the end muscle electrode and the reference muscle electrode were placed on the gastrocnemius muscle of the participants. Before placing the electrodes, extra precaution was made to ensure there is no dirt or dust on the muscle as it can affect the reading of the EMG muscles sensor.

2.5.3 Procedures

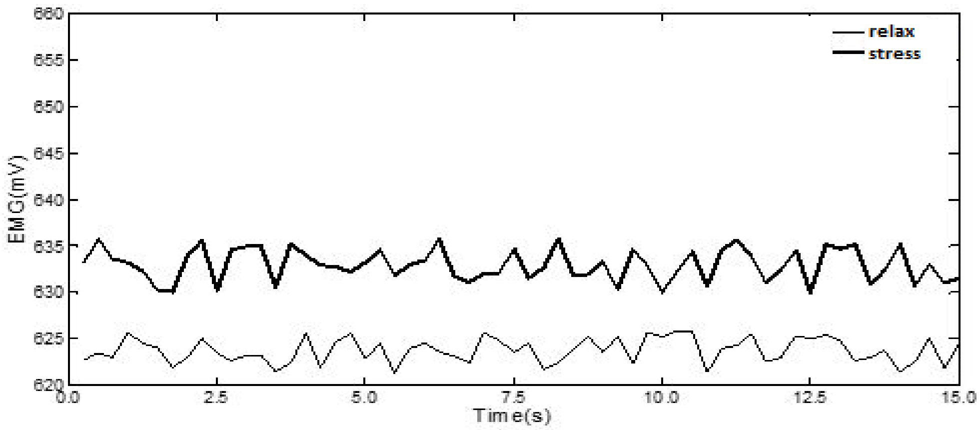
1. Relaxed muscle reading for all participants was taken with the EMG muscle sensor for 15 seconds.
2. Participants were asked to walk 500 meters before ascending the four-story stairs for two rounds.
3. After the drills were finished, the EMG recording was taken for 15 seconds.
4. Then the heating plates were placed:
   Right leg - The proposed heat plates placement structure. 3 plates on both gastrocnemius muscles and the Achilles tendon, respectively. This proposed placement of heat plates is denoted as proposed therapy onwards.
   Left leg - For control data. The design of the heating plate is fixed in shape as normally found commercially. This heat plates placement structure is denoted as control therapy onwards.
5. The readings of surface EMG signal for the whole experiment were recorded.

3. Results and Discussion

As a result of the physical activities, the muscles contain lactic acid and as it builds up, the pH of the blood around the muscles decreases [14]. This drop-in pH steadily prevents the muscles from contracting further. You need to pause at this stage so that the lactic acid can be metabolized. In order to simulate a stressed muscle for research purposes, the participants were given a couple of the physical exercises that concentrated on the muscles of the leg. Different muscle reading (right leg) can be seen in Fig.3, before and after the exercise. Fig. 3 displays the outcomes of 2 participants (randomly selected) for examples. The thick line denotes a stressed reading of the muscle, and the thin line denotes a relaxed reading of the muscle. Stressed muscle reading reveals and increases amplitude relative to muscle relaxation. The trend can be seen in all participants as seen in Fig. 4. This figure demonstrates the average EMG reading of each calming and stressed muscle participant.



(a)



(b)

Fig. 3 - This figure shows the example of individual results. (a) Participant A and (b) Participant B. These are the results of EMG reading of the muscle during relaxation and after the physical activities

There is no significant difference in the EMG reading between the left and right legs. Using the Wilcoxon test (p-value=0.05), 18 of the 20 participants did not display a major difference between the stressed muscles of the right and left leg, see Fig. 5. This indicates that both legs have equal stress during physical exercise. The aim of this study is to ensure that both legs have comparable stress such that the distinction between the use of 3 heating plates and 9 heating plates is unquestionable. Fig. 5 displays the p-value of the relevance test for all participants.

Fig. 6 gives two examples of the results of both therapy i.e. relaxing, proposed therapy (right leg) and control therapy (left leg). The relaxed and stressed muscle measurements are shown in an average value of 15 seconds. The graphs of stressed and relaxed muscles are regardless of the time axis. They were included in the graph as a reference of the before and after the physical exercises. Based on the observation, both therapies repaired the stressed muscle. With regards to recovery time, there is no substantial difference between the two therapies. 18 other participants have shown similar findings, see Fig. 7. Table 2 shows the transition of the EMG reading at the beginning of therapy (Start) to the end of treatment (End) and relaxation (Relax) for comparison. EMG readings are the average of the first 1 minute EMG reading (Start) and the last 1 minute EMG reading for both End and Relax situations. Table 2 indicates that both procedures healed the stressed muscle in the same duration.

Therefore, 3 heating plates give the same results as by using 9 heating plates. The adjustable curve of the plate suits the leg and allows the maximum heat and the same transition from the pad to the flesh. As the 3 heating plates are adequate to heal muscle stress, there is no need to cover the whole calf surface to obtain optimal performance. This indicates that the power demand will be decreased by up to 66%.

With respect to the design of the automatic cramp relief device, the suggested heating plate can be used to solve the power consumption of the device which allows the device to just use the battery as a power source and have a longer life span.

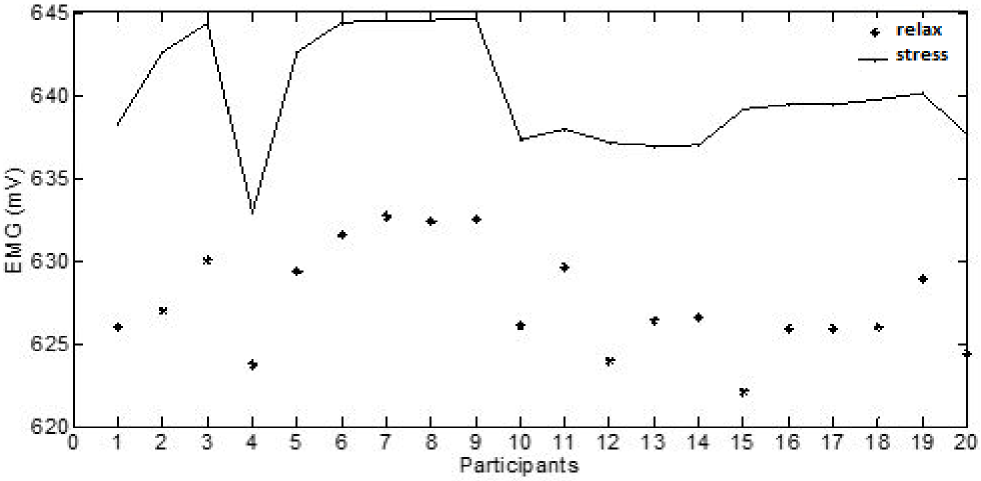


Fig. 4 - This figure shows the average EMG reading of each participant for relaxed and stressed muscle

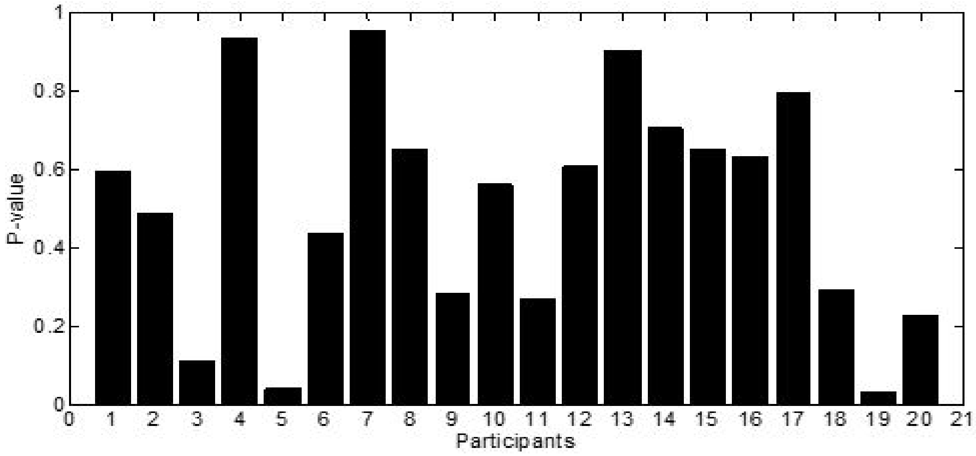
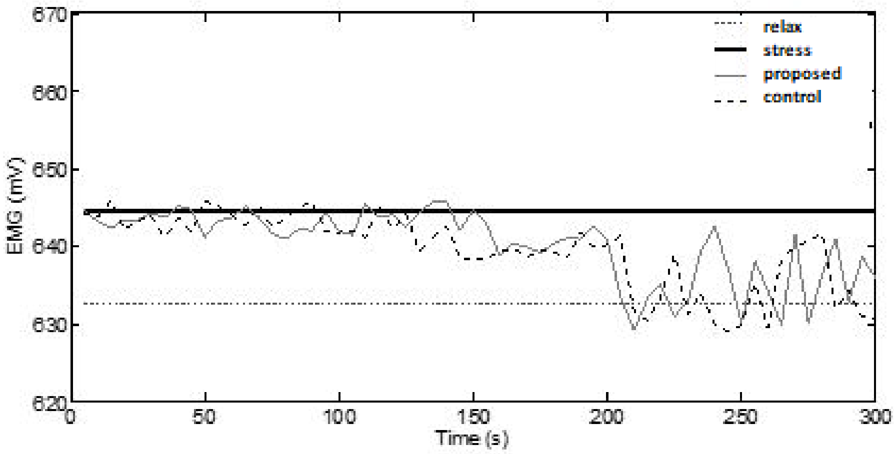
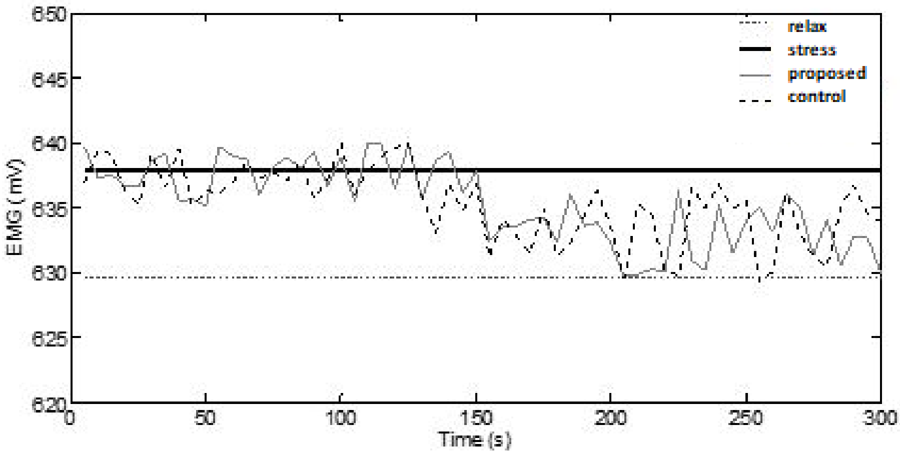


Fig. 5 - Wilcoxon significance test (P-value = 0.05) results of all participants



(a)



(b)

Fig. 6 - EMG reading of relax, stress, proposed therapy and control therapy of (a) Participant 9 and ; (b) Participant 11 as examples

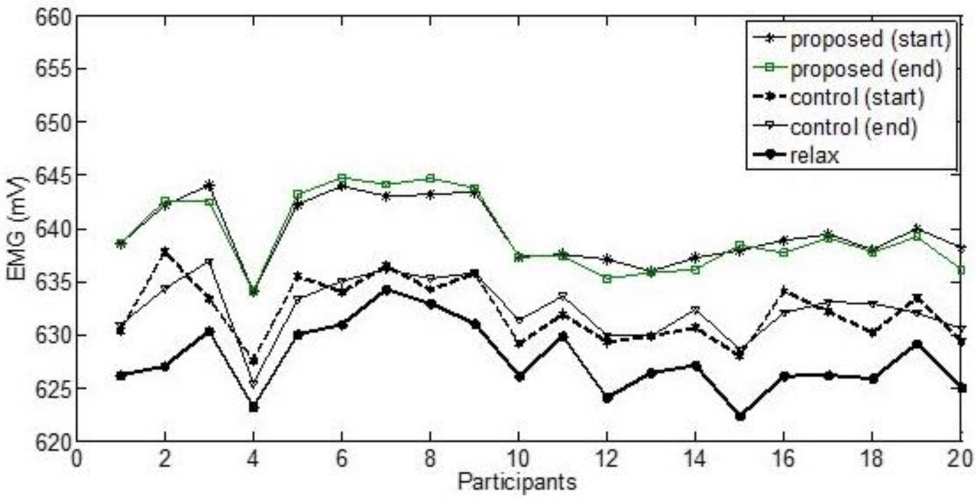


Fig. 7 - The average of the EMG reading at the first 1 minute at the beginning of the therapy (Start), the last 1 minute of the end therapy (End) and relaxed for comparison

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References

[1] Maisonneuve, H., Chambe, J., Delacour, C., Muller, J., Rougerie, F., Haller, D. & Leveque, M. (2016). Prevalence of cramps in patients over the age of 60 in primary care: A cross sectional study. BMC Family Practice, 17, 1-7. https://doi.org/10.1186/s12875-016-0509-9

[2] Johnson, J. (2019). What to know about leg cramps at night. 12 September 2019. [Online]. Available: https://www.medicalnewstoday.com/articles/326327. [Accessed 5 May 2020].

[3] Bentley, S. (1996). Exercise-induced muscle cramp. Proposed mechanismc and management. Sports Med. 21, 409-420. https://doi.org/10.2165/00007256-199621060-00003.

[4] Petrofsky, J.S., Laymon, M & Lee, H. (2013). Effect of heat and cold on tendon flexibilty and force to flex the human knee. Medical Science Monitor, 19, 661-667. https://doi.org/10.12659/MSM.889145.

[5] Naperalsky, M., Ruby, B. & Slivka, D. (2010). Environmental temperature and glycogen resynthesis. International Journal Sport Med, 31, 561-566. https://doi.org/10.1055/s-0030-1254083.

[6] Jarosch, R. (2008). Large-scale models reveal the two-component mechanics of striated muscle. Int. J. Mol Sci, 9, 2658-723. https://doi.org/10.3390/ijms9122658

[7] Thompson, B. (2019). 8 High energy-conduming appliance : learn how to save energy. 7 March 2019. [Online]. Available: https://www.greenprophet.com/2019/03/8-high-energy-consuming-appliances-learn-how-to-save-energy/. [Accessed 5 May 2020].

[8] Yeoh, T.S., Yeoh, T.J. & Song, C.L. (2009). TRIZ: Systematic innovation in manufacturing, Malaysia: First Fruits.

[9] Mann, D. (2019). The TRIZ journal, [Online]. Available: https://triz-journal.com/what-is-triz/. [Accessed 26 10 2020].

[10] Lowe, W. & Chaitow, L. (2009). Thermal modalities as treatment aids. In Orthopedic Massage, Mosby. 27-42.

[11] Petrofsky, J., Khowailed,I., Lee, H., Berk, L., Brains, G., Akerkar, S., Shah, J., Dabbak, F. & Laymon, M. (2015). Cold vs. heat after exercise-is there a clear winner for muscle soreness. J. Strength Cond Res. 29, 3245-52.https://doi.org/10.1519/JSC.0000000000001127

[12] Sandnes, B. (2008). The physics and the chemistry of the heat pad. American Journal of Physics. 76, 546. https://doi.org/10.1119/1.2830533.

[13] Allen, R.E., Kirby, K.A. & St. Mark's Family Medicine Residency. (2012). Nocturnal leg cramps. Am Fam Physician, 86, 350-355.

[14] Saeterbakken, A. H., Bårdstu, H. B., Brudeseth, A. & Andersen, V. (2018). Effects of strength training on muscle properties, physical function, and physical activity among frail older people: A pilot study. Journal of Aging Research, 1-11. https://doi.org/10.1155/2018/8916274

[15] Man, D. L. (2002). Hands-on systematic innovation, CREAX Press.