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Original Research

Thermography related to electromyography in runners with functional equinus condition after running

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ABSTRACT

Objectives: To assess how skin temperature could be related with gastrocnemius muscle activation and thus detect association between the extensibility of the triceps-surae and the skin temperature pattern.
Design: A Cross Sectional Study. Secondary level of care.
Setting: Recreational runners from an athletic club.
Participants: 57 healthy male subjects with functional equinus condition were recruited (age 42.82 ± 6.97 years, height 173.68 ± 9.79 cm, weight 73.19 ± 8.13 kg, body mass index 20.41 ± 2.48).
Main outcome measures: Skin temperature and electromyography of the gastrocnemius muscle before and after running exercise.
Results: Skin thermal assessment value for Gastrocnemius muscles were assessed in 57 participants before and after running. We found a significant increase of skin temperature after running deeply related with electromyography values (Confidence interval 95%). The temperature of Gastrocnemius was increased in runners after activity.
Conclusions: Thermal imaging is deeply related with muscle pattern activation for lower limb. Based on our findings, we propose that infrared thermography assessment of the gastrocnemius is adequate to check Gastrocnemius muscle activity condition in runners.

1. Strenghts

- Use of a non-invasive tool for clinical assessment
- Thermography and electromyography Method applied
- Runners population

2. Limitations

- Sample size was obtained from an only runners club.
- All the participants developed the same sport activity

3. Introduction

Gastrocnemius-soleus equinus (GSE) is defined as the condition which appears ``the inability of the ankle joint to dorsiflex beyond a neutral position with the knee extended or with the knee flexed (after excluding osseous pathology)`` (Digiovanni et al., 2002; Downey & Banks, 1989). Thus GSE seems to be an asymptomatic condition could be related with an alteration in the Achilles tendon (AT) and Triceps Surae complex (TS). By the other hand, GSE is related with different plantar pressures patterns with a modification for low limb muscle activity (Lamm, Paley, & Herzenberg, 2005; SilfverskiöLD, 1924; Downey et al., 1992; Root, Orien, & Weed, 1977).

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Modifications in the lower limb muscle pattern contraction are related to GSE and could be related with a different electromyography (EMG) activity for the lumbo-pelvic control musculature (transversus-abdominus) and lower limb muscles (TS). GSE condition has been deeply evaluated with force platform devices, EMG, balance test analysis (Blustein & D'amico, 1985; Mahar, Kirby, & Mcleod, 1985; Bhave, Paley, & Herzemberg, 1999; Blake & Ferguson, 1992; Vink & Huson, 1987; Gurney, Mermier, Robergs, Gibson, & Rivero, 2001; Balestra, Frasinelli, Knaflitz, & Molinari, 2001). GSE get a deep association with dynamic, stabylometric and static muscle activity (Bhave et al., 1999; Blake & Ferguson, 1992). In addition, some scientific publications have showed how muscle contraction may reach a heat transfer promoting a rise for the skin thermal values (Ammer & Damiano, 2016; Formenti et al., 2017; Gomes Moreira, Costello, Brito, & Quintana, 2017; Zontak, Sideman, Verbitsky, & Beyar, 1998).

Gait and posture are associated with a continuous contraction of anti-gravitational muscles. Modifications for thermal skin values could be associated with postural patterns, abnormal plantar pressures and a different range of movements of ankle/knee. High thermal infrared (IR) assessment could non-invasively test these skin thermal patterns (Gomes Moreira et al., 2017).

The main purpose was to assess how a thermal-IR camera could test thermal skin pattern in runners and its relationship between the extensibility and EMG of the gastrocnemius muscle. The aim of the study was to check skin thermal differences in gastrocnemius before activity and after activity and its relationship with EMG.

4. Methods

We recruited a consecutive sample of 57 runners with six training hours per week (age 42.82 ± 6.97 years, height 173.68 ± 9.79 cm, weight 73.19 ± 8.13 kg, body mass index 20.41 ± 2.48 (Quetelet's equation BMI = weight (kg)/height (m) x height (m))). The exclusion criteria (Formenti et al., 2017; Gomes Moreira et al., 2017; Zontak et al., 1998)were a) lumbopelvic pain b) foot injuries c) musculoskeletal pain d) chronic ankle instability, e)previous foot/ankle surgery f) fractures g) drugs treatment and h) lower limb length discrepancy.

Temperature and EMG were the studied variables of the study. The examination procedure consisted of thermal imaging and EMG measuring on the start and on the end of exercise. An infrared ThermaCam was chosen to assess the temperature values for the gastrocnemius. To conduct EMG measurement in muscle the four channel Noraxon MyoTrace 400 device was used.

Ethical Research Committee of the "Hospital de La Princesa" (Spain) approved the study. All participants completed preciously informed consent. The Declaration of Helsinki with the ethical standards normative for human experimentation was respected. We applied the Strobe (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines. A convenience sample method was developed for the sample size.

A detailed checklist for the assessment of skin temperature using infrared thermography settings entitled "Thermo-graphic Imaging in Sports and Exercise Medicine" (TISEM) was carried out. The consensus statement attempts to standardize the collection and analysis of skin temperature data recorded using infrared thermography[14]. At the previous week to the clinical assessment all the participants were inquired not to use drugs or physical therapy treatments. In addition, on the thermal assessment, heavy meals and vasomotor substances (caffeine) were banned.

All measurements were developed in an examination room with no direct ventilation-flow towards participants and a humidity of 45% ± 10% and a temperature of 24.1 ± 1 C°.

At the beginning, participants lay in a relaxed supine position on a clinical gurney for examination; the ankle dorsal flexion range of movement was tested with a goniometer. The evaluation was carried with the Silverskiold's test in order to assess equinus (Lamm et al., 2005; SilfverskioLD, 1924). Equinus examination was carried out by a single rater, a Podiatry-Doctor (R.B.B.V, 20 years aged-experienced) in order to enforce the reliability of the clinical assessment.

The thermal image capture (thermograms) began with the participant standing up in a relaxed position. Five IR-Shots were registered for gastrocnemius region. Subjects then ran for 15-min on a treadmill at a speed of 8 km/h and the thermal imaging capture was repeated after that.

Thermal image was captured with an FLIR/SC3000/QWIP Thermacan-infrared thermal device with an 8–9 μm spectral range and 0.02-K temperature-sensitivity (NETD at 30 °C). IR-imaging capture process was developed by the same Podiatry-Doctor (DRS, 15 years aged-experienced) using a fixed tripod at the same distance for all participants (Fig. 1).

To conduct EMG measurement Noraxon MyoTrace 400 device was used. Further, signal processing was provided in MyoResearch software and MATLAB environment. Dual EMG disposable electrodes were placed according to the SENIAM recommendations (-Surface ElectroMyoGraph, 2018) on the gastrocnemius. A neutral electrode was placed on the *malleolus medialis.* All electrodes and cables were secured with adhesive, medical tape (Micropore 3M, USA), to reduce movements artefacts.

Just before and immediately after running, thermal images and emg were collected.

5. Statistical analysis

Statistical package for social sciences, version 22.0 for Windows (IMB SPSS Statistics for Windows; NY: IBM Corp.) was used for the analysis data. An α error of 0.05 (95% confidence interval) and a desired power of 80% (β error of 0.2) were used for all statistical tests.

The Kolmogorov Smirnov test was selected to check data normality. All collected data get a normal distribution. The descriptive analysis of the variables was showed through mean and

Fig. 1. Infrared thermography imaging.

standard deviation. A Paired Student's t-tests were used in order to check differences between different moments (before vs. after running activity). Pearson's test were carried out to check the correlation between EMG and thermography mean value, before and after running.

6. Results

The descriptive values for subject age, height, and weight or body mass index were shown in Table 1.

However, after exercise, the temperature was significantly warmer for participants in all variables (minimum, maximum, mean) for gastrocnemius muscle (Table 2). The EMG achieved values are showed in Table 3.

Between the thermal values and EMG factors of *gastrocnemius medialis* results there exists the one statistically significant good relationship between Δ Median and Mean Freq and Mean thermal value ($r = 0{,}76$, $r = 0{,}58$, $p = 0{,}01$).

By the other hand the thermal and frequency factors of *gastrocnemius lateralis* results there exists the one statistically significant good relationship between Δ Median Freq and Mean and Mean thermal value ($r = 0{,}78$, $r = 0{,}56$, $p = 0{,}01$).

7. Discussion

The gastrocnemius mean temperature was also higher after exercise than before for the selected participants and is deeply related with gastrocnemius muscle activity. This is the first descriptive analysis in order to assess the relationship between skin temperature and electromyography in runners with functional equinus.

The ankle dorsiflexion resistance was significant higher after running in GSE-subjects (Wrobel, Connolly, & Beach, 2004). The exercise may promote a stimulus to increase the thermal value in the gastrocnemius muscle. Our population was predominantly right-footed (52) versus left-footed (5) in a self-report analysis.

Several research have studied the physiological range of movement for ankle dorsiflexion (Digiovanni et al., 2002; Root et al., 1977). The higher range of dorsal flexion during the stance-phase of a normal gait appears exactly before the heel-lift phase with a knee extension. (Digiovanni et al., 2002). The minimum range of motion for normal gait is a)10°-dorsiflexion and b)20°-plantarflexion (Digiovanni et al., 2002; Downey & Banks, 1989; Root et al., 1977). The most noted range of movement for ankle dorsiflexion (static analysis) that the minimum range of movement for dorsiflexion-ankle for normal gait is 10° (Lamm et al., 2005; -Surface ElectroMyoGraph, 2018; Knutzen & Price, 1994; Nuber, 1988; Lavery, Armstrong, & Boulton, 2002; Wrobel et al., 2004; Winter 1984). Equinus promotes an increase for the plantar pressures and may promote foot and ankle biomechanical alterations (e.g, Sever's disease, Osgood-Schlatter disease, fasciitis plantar, Achilles tendon injury, pes planus, Hallux valgus) (Lamm et al., 2005). DiGiovanni et al. found equinus pattern in patients with ankle-foot pain (Digiovanni et al., 2002). However, equinus is also found in asymptomatic patients (Brodersen, Pedersen, & Reimers, 1993).

Further researchers will be needed to provide a deep knowledge about muscle activation and their clinical relationships between thermal values and their cutaneous muscle projection (Abate et al., 2010; Rodriguez-Sanz et al., 2017). After our findings, we propose that thermal images are related with emg activity and this analysis could be a reliable tool for the clinicians in patients with equinus condition.

8. Conclusions

Runners with functional equinus condition presented a higher temperature for gastrocnemius after a slight running activity and this increase of temperature was deeply related with EMG muscle

Table 1
Participant descriptive characteristics of the sample.

Variable	Runners values
Age (years)*	42.82 ± 6.97
Height (cm)*	173.68 ± 9.79
Weight (kg)*	73.19 ± 8.13
Body mass index*	20.41 ± 2.48

* Kolmogorov Smirnov test was carried out to check normality ($p \geq 0.05$).

Table 2
Temperature values (Degrees Celsius) for gastrocnemius participants before and after exercise.

Variable	Mean ± SD	P value
Gastrocnemius left minimum temperature before exercise	28.41 ± 1.57	,031†
Gastrocnemius left minimum temperature after exercise	29.38 ± 1.16	
Gastrocnemius left maximum temperature before exercise	30.85 ± 1.32	,035†
Gastrocnemius left maximum temperature after exercise	31.32 ± 1.22	
Gastrocnemius left mean temperature before exercise	29.92 ± 1.34	,006†
Gastrocnemius left mean temperature after exercise	30.44 ± 1.34	
Gastrocnemius right minimum temperature before exercise	28.35 ± 2.0	,024†
Gastrocnemius right minimum temperature after exercise	29.29 ± 0.97	
Gastrocnemius right maximum temperature before exercise	31.1 ± 1.14	,0135†
Gastrocnemius right maximum temperature after exercise	31.8 ± 0.98	
Gastrocnemius right minimum temperature before exercise	29.89 ± 1.14	,023†
Gastrocnemius right maximum temperature after exercise	30.55 ± 0.93	

† Statistically significant difference between groups ($P < 0.05$).

Table 3
Average Mean and Median Values differences between after and before running of gastrocnemius medialis and lateralis in comparison with thermal parameters.

EMG			TEMPERATURE		
	Δ Mean Freq [Hz]	Δ Median Freq [Hz]	Δ Min [°C]	Δ Max [°C]	Δ Med [°C]
Gastrocnemius Left	−0.69	−0.71	0.97	0.47	0.52
Gastrocnemius Right	−0.72	−0.75	0.94	0.7	0.66

values achieved. Infrared thermal analysis may measure skin temperature so could help as a screening-test in order to prevent other pathological condition. Further research is needed to test clearly other factors related with equinus, as well as to obtain a better knowledge about different factors that promote to different temperature pattern in different regions.

Competing interest

None.

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References

Abate, M., Di Carlo, L., Di Romualdo, S., Ferreti, A., Romani, G. L., & Merla, A. (2010). Postural adjustment in experimental leg length difference evaluated by means of thermal infrared imaging. *Physiological Measurement, 31*, 35–43.

Ammer, K., & Damiano, F. (2016). Editorial: Does the type of skin temperature distribution matter? *Therm. Internat., 26*(2), 51–54.

Balestra, G., Frasinelli, S., Knaflitz, M., & Molinari, F. (2001). Time–frequency analysis of surface myoelectric signals during athletic movement. *IEEE Engineering in Medicine and Biology Magazine, 20*, 106–15.

Bhave, A., Paley, D., & Herzemberg, J. E. (1999). Improvement in gait parameters after lengthening for the treatment of limb-length discrepancy. *J. Bone Joint Surg. Am., 81*, 529–34.

Blake, R. L., & Ferguson, H. (1992). Limb length discrepancies. *Journal of the American Podiatric Medical Association, 82*, 33–8.

Blustein, S. M., & D'amico, J. C. (1985). Limb length discrepancy. Identification, clinical significance, and management. *Journal of the American Podiatric Medical Association, 75*, 200–6.

Brodersen, A., Pedersen, B., & Reimers, J. (1993). Foot deformities and relation to the length of leg muscles in Danish children aged 3–17 years. *Ugeskr Laeger, 155*, 3914.

Digiovanni, C. W., Kuo, R., Tejwani, N., Price, R., Hansen, S. T., Jr., Cziernecki, J., et al. (2002). Isolated gastrocnemius tightness. *J Bone Joint Surg Am, 84*, 962.

Downey, M. S. (1992). Ankle equinus. In E. D. McGlamry, A. S. Banks, & M. S. Downey (Eds.), *Comprehensive textbookof foot surgery* (2nd ed., Vol. 1, p. 687). Baltimore: Williams &Wilkins.

Downey, M. S., & Banks, A. S. (1989). Gastrocnemius recession in the treatment of nonspastic ankle equinus: A retrospective study. *Journal of the American Podiatric Medical Association, 79*, 159.

Formenti, D., Ludwig, N., Rossi, A., Trecoci, A., Alberti, G., Garganob, M., et al. (2017). Skin temperature evaluation by infrared thermography: Comparison of two image analysis methods during the nonsteady state induced by physical exercise. *Infrared Physics & Technology, 81*, 32–40.

Gomes Moreira, D., Costello, J., Brito, C., & Quintana, M. (2017). A checklist for measuring skin temperature with infrared thermography in sports and exercise medicine. *Therm. Intern., 27*(4), 141–143.

Gurney, B., Mermier, C., Robergs, R., Gibson, A., & Rivero, D. (2001). Effects of limb-length discrepancy on gait economy and lower-extremity muscle activity in older adults. *J Bone Joint Surg. Am, 83-A*, 907–15.

Knutzen, K. M., & Price, A. (1994). Lower extremity static and dynamic relationships with rearfoot motion in gait. *JAPMA, 84*, 171.

Lamm, B. M., Paley, D., & Herzenberg, J. E. (2005). Gastrocnemius soleus recession: A simpler, more limited approach. *JAPMA, 95*(18).

Lavery, L. A., Armstrong, D. A., & Boulton, A. J. M. (2002). Ankle equines deformity and its relationship to high plantar pressure in a large population with diabetes mellitus. *JAPMA, 92*, 479.

Mahar, R. K., Kirby, R. L., & Mcleod, D. A. (1985). Simulated leg-length discrepancy: Its effect on mean center of pressure position and postural sway. *Archives of Physical Medicine and Rehabilitation, 66*, 822–4.

Nuber, G. W. (1988). Biomechanics of the foot and ankle during gait. *Clinics in Sports Medicine, 7*(1).

Rodriguez-Sanz, D., Losa Iglesias, M., Lopez Lopez, D., Calvo Lobo, D., Palomo Lopez, P., & Becerro De Bengoa Vallejo, R. (2017). Infrared thermography applied to lower limb muscles in elite soccer players with functional ankle equinus and non-equinus condition. *PeerJ, 5*, e3388. https://doi.org/10.7717/peerj.3388.

Root, M. L., Orien, W. P., & Weed, J. H. (1977). *Normal and abnormal function of the foot* (Spanish edition). Los Angeles: Clinical Biomechanics Corp.

SilfverskiöLD, N. (1924). Reduction of the uncrossed two-jointmuscles of the leg to one-joint muscles in spastic conditions. *Acta Chirurgica Scandinavica, 56*, 315.

Surface ElectroMyoGraphy for the non-invasive assessment of muscles. n.d, Roessingh Research and Development http://www.seniam.org/. (Accessed 19 December 2018).

Vink, P., & Huson, A. (1987). Lumbar back muscle activity during walking with a leg inequality Acta. *Morphol. Neerl.Scand., 25*, 261–71.

Winter, D. A. (1984). Kinematic and kinetic patterns in human gait: Variability and compensating effects. *Human Movement Science, 3*, 51.

Wrobel, J. S., Connolly, J. E., & Beach, M. L. (2004). Associations between static and functional measures of joint function in the foot and ankle. *JAPMA, 94*, 535.

Zontak, A., Sideman, S., Verbitsky, O., & Beyar, R. (1998). Dynamic thermography: Analysis of hand temperature during exercise Ann. *Biomedical Engineering, 26*, 988–93.