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Non-invasive technologies for detecting asymmetric muscle fatigue

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Abstract

Early detection of unilateral muscle fatigue and muscular imbalances is important to prevent injury. This study aimed to evaluate the potential of near-infrared thermography (IRT) and raster-stereography (RS) in detecting asymmetries. After unilateral trunk muscle fatigue, IRT detected changes in the skin surface temperature only immediately after exercise, while RS data showed no statistically significant changes.

Keywords: infrared thermography, raster-stereography, muscle asymmetry, muscle fatigue

Introduction

An asymmetrically performed movement can lead to a muscle overload and therefore to injuries. In the long term, this can lead to an imbalance between the muscles and thus to an asymmetrical posture (Bernetti et al., 2020). To prevent this, early detection of asymmetries is important. A common non-invasive method for posture analysis is raster-stereography (RS). This technology detects asymmetries based on the position of anatomical landmarks (Drerup & Hierholzer, 1987). Muscle fatigue may lead to changes in skin surface temperature. Near infrared thermography (IRT) can be used to detect these changes. IRT, along with a scan of anatomic landmarks, might be a promising non-invasive diagnostic tool. Due to the mobility of IRT and the influence of muscle fatigue on the skin surface temperature, it may be possible to develop a feedback system for unilateral fatigue during an activity. Research on the use of IRT in the context of muscle fatigue is so far inconsistent (Al-Mulla et al., 2011). This study was conducted as part of an investigation by Dindorf et al. (2022) and is to the best of our knowledge the only study investigating the thermographic effects of unilateral fatigue in relation to trunk muscles. The aim of this study was to evaluate the potential of IRT and RS in detecting asymmetric muscle fatigue.

Methods

Data were collected from 41 subjects (22 men and 19 women; age: 22.63 ± 3.91 years; height: 173.36 ± 9.95 cm; body-mass-index (BMI): 24.09 ± 2.71 kg*m^{-2}; body fat: 20.92 ± 9.58 %). The study adhered to the criteria of the Declaration of Helsinki and was accepted by the ethics committee of Technische Universität Kaiserslautern (ethics protocol number: 43). The subjects were requested to arrive in a rested state and not to perform any intense activities or take any drugs for 48 h prior to the study. Furthermore, the subjects were asked not to consume large amounts of liquids or food for 2 h prior to the measurement. The intervention took place under controlled environment factors and a controlled room temperature of 20 °C. Fig. 1 depicts the experimental design.

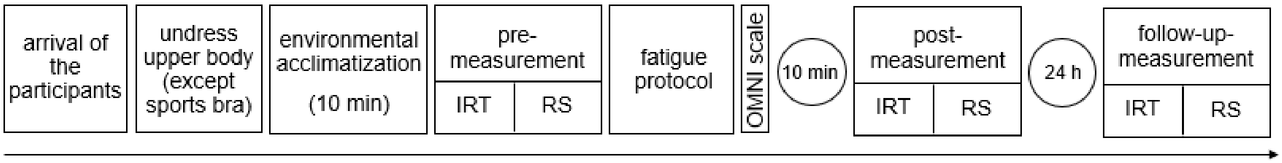

Fig. 1 Experimental design of the present study (IRT = near infrared thermography; RS = raster-stereography)

The fatigue protocol consisted of side bends on a Roman chair on the non-handedness side. The exercise was performed in sets of 20 repetitions to fatigue the lateral trunk flexors unilaterally. Tactile feedback (point of contact with a bar at the endpoint of maximal lateral trunk flexion) was provided to standardise the range of motion. A metronome indicated the movement speed. Sweat was dabbed immediately after it appeared. Termination criteria were defined as (a) inaccurate execution of a movement for more than 4 repetitions of a set, (b) a rated fatigue of more than 7 on the OMNI scale (Robertson, 2004), (c) the inability to perform the full 20 repetitions over 3 sets.

IRT data were determined with the NEC TVS-200 ISS camera (NEC Avionics Infrared Technologies Co., Ltd., Yokohama, Japan) and analysed via the software InfReC Analyzer NS9500 Lite (Nippon Avionics Co., LTD, Yokohama, Japan). To define areas and identify anatomic landmarks for each subject, cork markers were placed on the 12th thoracic vertebra and both posterior superior iliac spines (SIPS). In addition to IRT, RS with a photogrammetric noncontact 3D scanner (Paromed 4D, Neubeuern, Germany) was used. Bony landmarks were marked for measurement using this technique. Only the two posterior upper iliac spines were marked for observing the pelvic position. During the measurement, the subjects stood barefoot at a distance of 2.5 m in front of the scanner in their habitual posture. The locations of all markers were marked on the skin with a waterproof pen to ensure the same position for each measurement.

To analyse the changes in the skin surface temperature and pelvic position for the measurement time points, a repeated-measurement ANOVA was performed. To correct for sphericity violations, Greenhouse-Geisser adjustments were made. Bonferroni correction was performed for post hoc tests. Adjusted p-values were reported and computed with an alpha level of 0.05. For comparison of possible asymmetric differences between the treated side and the contralateral side for the three measurement time points, a dependent t-test for paired samples was calculated. The correlation between skin surface temperature and pelvic position was calculated using the Pearson correlation coefficient. Calculations were performed using SPSS Statistics (version 16, SPSS Inc, Chicago, USA).

Results

After the treatment, the subjects reported a mean score of 8.88 ± 1.01 on the OMNI scale. Fig. 2 shows the exemplary thermographic data of a participant. A comparison of the measurement areas for the measurement times showed the same characteristics for all areas. A statistically significant difference could be found between the three conditions (area a: $F(1.71,54.59) = 25.36$, $p < 0.001$, $n = 33$, $\eta_p^2 = 0.44$; area b: $F(2,64) = 65.10$, $p < 0.001$, $n = 33$, $\eta_p^2 = 0.67$; area c: $F(2,64) = 39.76$, $p < 0.001$, $n = 33$, $\eta_p^2 = 0.55$; area d: $F(2, 64) = 69.49$, $p < 0.001$, $n = 33$, $\eta_p^2 = 0.69$). The skin surface temperature was statistically significantly lower in the post-tests than in the pre- and follow-up tests.

The temperature in the pre- and follow-up tests was not different. The post measurement between the upper areas (*t(34)* = 5.34, *p* < 0.001, *r* = 0.68) and between the lower areas (*t(34)* = 2.92, *p* = 0.006, *r* = 0.45) showed asymmetric side differences. No side asymmetries existed for the pre-test and the follow-up test (*p* > 0.05). A comparison of the upper and lower areas showed no difference (*p* > 0.05). An analysis of the anatomic landmarks via RS showed no statistically significant difference for pelvic inclination in the different measurement times, *F*(1.49,55.22) = 0.307, *p* = 0.672, *n* = 38 (pre: -0.21 ± 2,17°; post: -0.07 ± 2.04°; follow-up: -0.33 ± 2.63°). In addition, the pelvic rotation showed no statistical significance in the different measurement times, *F*(2,74) = 0.411, *p* = 0.664, *n* = 38 (pre: -1.67 ± 2.53°; post: -1.85 ± 2.48°; follow-up: -1.99 ± 2.67°). There was no correlation between the changes in the skin surface temperature and the pelvic position (*p* > 0.05).

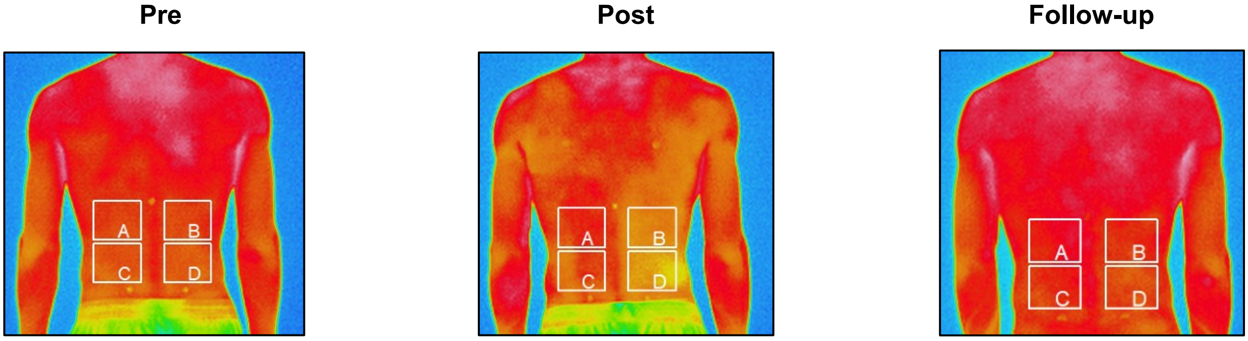

Fig. 2 Exemplary thermographic images of a test person for all three measurement times and visualisation of the measurement areas.

Discussion

The results of the present study show that after unilateral muscle loading, there are thermographic asymmetric changes in skin surface temperature on the treatment side. This is consistent with the muscle fatigue reported by the subjects. The fatigue protocol resulted in a temperature decrease in the skin blood flow of the loaded area immediately after the load (post-test). In the follow-up test (24 h), the temperature increased again and reached a similar level as in the pre-test. This development is consistent with the literature (Fernandes et al., 2016). Compared with the pre-test and the follow-up-test, the post-test showed statistically significant temperature differences from the non-treatment side. The subjects in the study by Stewart et al. (2020) showed a similar effect after fatigue of the knee flexors and extensors. Thus, IRT appears to be a useful technology for detecting asymmetric acute fatigue, since no changes were visible 24 h afterward compared to the pre-test. The RS results showed no systematic effect of unilateral fatigue on pelvic inclination or pelvic rotation. The observed individual differences could be due to different initial muscular states and motor control strategies. In addition, postural stabilisation is achieved through individual activation patterns (Betsch et al., 2011). To the best of our knowledge, there are no studies on RS related to acute unilateral trunk muscle fatigue. RS is not a useful technology to detect acute asymmetric muscle fatigue. Since changes were visible when a single case was observed at a time, RS at the level of individual observation could be a useful tool for detecting postural asymmetries due to the position of bony structures (Drerup & Hierholzer, 1987).

The present study has shown that IRT is suitable for detecting muscular fatigue of trunk muscles after exercise but cannot show the long-term effect. In contrast, acute fatigue does not seem to be visible in the pelvic position considered with RS. However, studies show that continuous unilateral fatigue leads to asymmetries in posture (Bernetti et al., 2020). Therefore, RS seems to provide some necessary information about the long-term effects of asymmetries on posture. For these reasons, IRT should be used in conjunction with RS to detect asymmetries. To apply IRT in wearables, there is a need to further explore the relationship between the progress in changes in the skin surface temperature and muscle fatigue during exercise.

Conflict of interest: The authors declare no conflict of interest.

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