Influence of Additional Loads on Chosen Gait Parameters and Muscles Activity

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Abstract

This paper is devoted to human motion analysis and comparison of chosen kinematics parameters during normal gait with and without additional load in a form of backpack. A stability in both cases were compared in both frontal and sagittal planes, by applying a video tracking system. Experimental tests performed on treadmill, passive markers, placed on volunteers bare skin were used. Additionally, an infra-red camera was employed to evaluate muscle activity and its groups involved in the movement. The change of body temperature and distribution of the thermal maps were observed. Analysing these thermograms, loading of different muscle groups was evaluated. During the experiment, an attempt to correlate a results obtained from a thermal imaging camera and video tracking system were made. It is shown that thermal imaging can help to evaluate an asymmetry in muscle load and in some cases can help to detect pathological cases, what was confirmed with motion analysis. Advantages and disadvantages of this method were also described.

Keywords: thermovision, motion capture, motion analysis, ergonomics, gait stability

1. Introduction

Motion analysis plays a key role in understanding of locomotion and some phenomena that occur during the movement. To obtain more information of musculo-skeletal system functionality than just motion trajectories, typically a force platform [9] and/or an electromyography (EMG) method is applied (e.g. [1]). However, to record the signal, a complicated and expensive measurement technique should be employed. Moreover in this method it is obligatory to use an electrodes placed on the skin in a specific muscle area. EMG signal is vulnerable for noise (e.g. cross-talking phenomenon) [4]. For this reason, in this research, both a visual motion analysis and an infra-red imaging is used to evaluate the activity of the chosen muscle groups. This method is also widely used, see for example in papers [2, 5, 6, 8]. In contrary to EMG, there is no need for any electrodes, cables or special recording units, that would disturb the movement; moreover it is a non-contact method, and results can be obtained almost immediately.

2. Methods

2.1. Experiment description

Volunteers were asked not to perform any intensive activities to avoid muscle fatigue. Normal gait on the treadmill without any load and with additional load in a form of a backpack were performed. Both experiments were done with the same velocity (chosen by volunteer) for ten minutes. Video in two planes of motion (sagittal and frontal) were recorded; also thermograms were taken before and after each test.

2.1. Video analysis

In order to analyze recorded videos an authorial software was used during the experiment. It allowed to detect and track position of both passive and active type markers. Examples of the marker placement and its representation after lightening and image filtering, are shown in Fig. 1a and 1b.

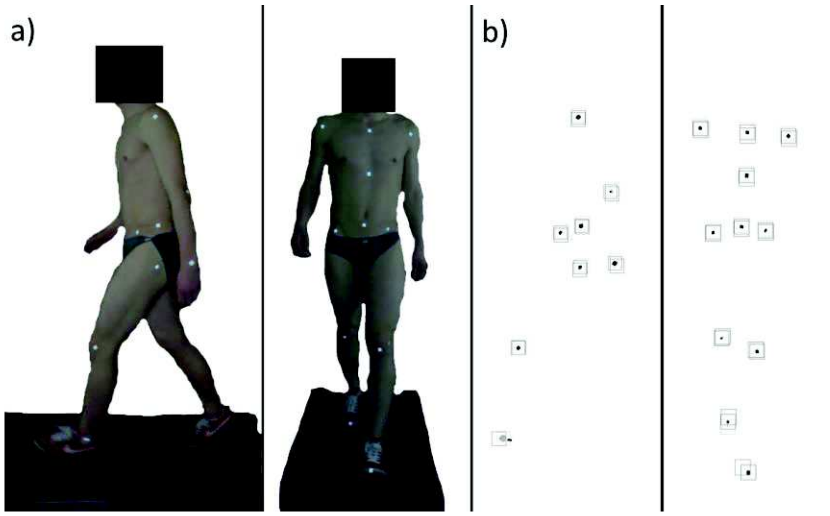

Figure 1. Example of video frame and detected passive markers for front and side of the body: a) markers distribution on the body; b) markers after lightening, filtering and position identification

Light, flat, reflective, passive type markers were chosen, and placed on a volunteer bare skin. This, in authors opinion, helps to prevent movement of the markers, relative to the joint. Moreover, their masses not affect the dynamics of locomotion and no special costume were needed, which would constrain the movement. Example of the front and side body markers detection are presented in Fig. 1c. The following parameters were recorded during treadmill gait:

- k_1 – angle of torso longitudinal axis deviation,
- k_2 – angle of shoulder girdle tilt,
- k_3 – angle of pelvis tilt,
- k_4, k_5 – angle of forearm and arm flexion/extension,
- R_{max} – wrist horizontal displacement,
- X_{max} – step length,
- Y_{max} – shoulder vertical displacement.

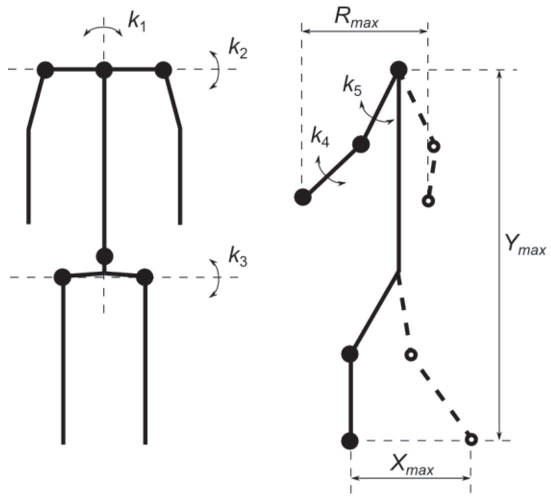

Figure 2. Measured parameters (see text for more details)

After about a half of the exercise time, 1.5 minute was recorded and then 20 seconds were chosen for further analysis. Depending on the visibility of detected markers, approx. 20 to 260 steps were recognised. Even if the number of steps identified was small (in the worst case approx. 20), no additional recordings were performed to prevent any unnecessary fatigue affecting the volunteer.

2.2. Video analysis results

Results, obtained from video analysis are presented in Figures 3-5. It can be noticed that for each volunteer each of the examined parameters have changed, i.e. angles of limb flexion/extension decreased (see Fig. 5), but length of the step increased. Similarly, mean amplitude value of torso longitudinal axis and pelvis oscillation decreased, what was compensated with shoulder girdle movability (see Fig. 4). Reason of such differences is an additional load and probably that volunteers were more accustomed to the treadmill gait after first try (without load). However, it is necessary to emphasise that each of the volunteer had an earlier experience with this type of exercise.

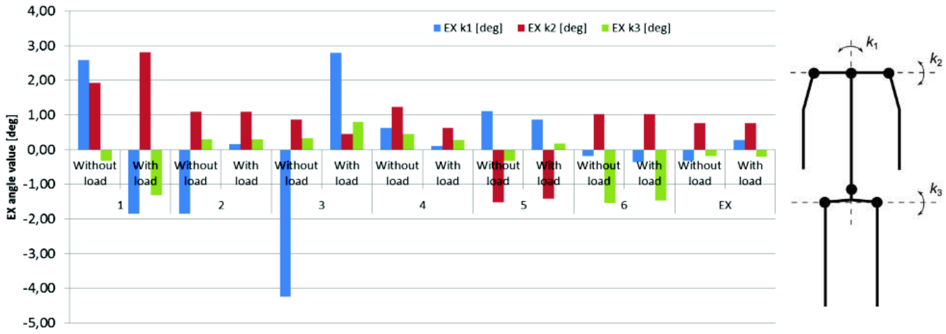

Figure 3. Motion capture results (mean values): longitudinal axis deviation (k_1), shoulder girdle (k_2) and pelvis tilt (k_3); during gait without and with load for each of six volunteers

It can be seen (see Fig. 3) that most volunteers longitudinal axis deviation (k_1) direction changes to the opposite one after adding a load. This alternation is also visible in mean values. Possible explanation is the change of mass distribution of the load. The volunteers tried to compensate this asymmetrycity by rising left or right shoulder. At the same time, shoulder girdle tilt (k_2) and pelvis tilt (k_3) did not changed significantly. The minimal decrease of both value due to the additional load and limit of the movement was expected. It was noticed in almost all volunteers except the first one. Fig. 4 presents mean amplitude values of axes (k_1, k_2, k_3). Unlike the mean values from fig. 3, here it can be easily seen that movability of the longitudinal body axis after adding a load decreases significantly.

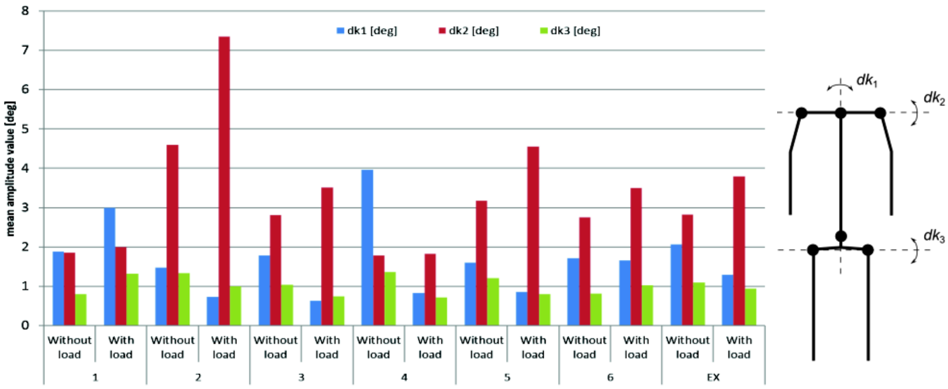

Figure 4. Motion capture results (mean amplitude) in a front view: longitudinal axis deviation (dk_1), shoulder girdle (dk_2) and pelvis tilt (dk_3); during gait without and with load for each of six volunteers

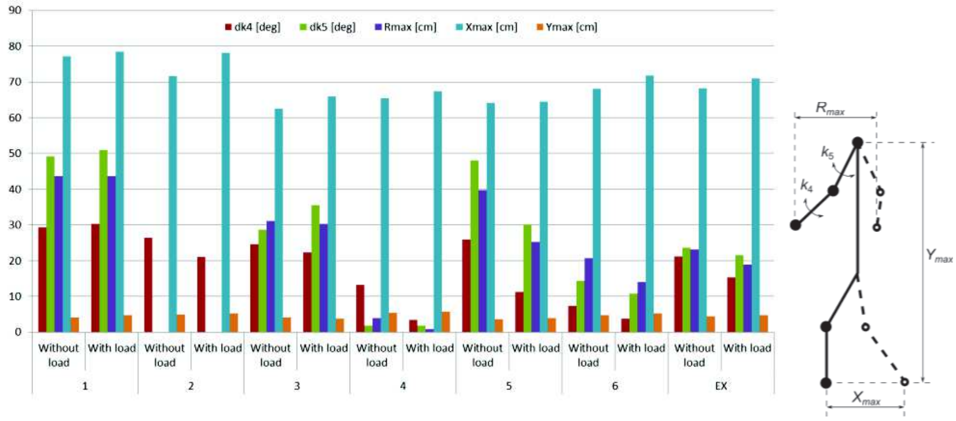

Figure 5. Motion capture results (mean values) in side view: angles of forearm and arm flexion/extension (k_4, k_5), hand horizontal displacement (R_{max}), stride length (X_{max}) and shoulder vertical displacement (Y_{max}); during gait without and with load for each of six volunteers

In Fig. 5, it can be seen, that adding load after free gait causes that the angles of forearm and arm flexion/extension (k_4, k_5) and also hand horizontal displacement (R_{max}) decreases significantly. The hypothesis is that decreasing the amplitude of the arms movement helps to compensate the shoulders load. Simultaneously, stride length increased to improve the stability of the gait. Shoulder vertical displacement (Y_{max}) did not changed significantly what is similar to the results published in reference [1].

2.3. Thermography

In addition to the motion capture method an infra-red analysis was performed. Changes of the body temperature and skin were observed. Acclimatization time was set to about 20 minutes. Volunteers were dressed in the same way as during the examination. Aim of this experiment was to point muscle groups involved in movement and symmetry of the muscular system activity. An example of thermogram before and after each type of experiment are presented in Figures 6-9, an example of muscle activity asymmetry is shown in Fig. 10.

2.3. Thermography results

For each of thermograms series for each volunteer a body surface temperature were measured (see Fig. 11), additionally an attempt was made to distinguish a muscle groups or muscles, which are especially active during gait with additional load, are mentioned below thermograms. Examples of the thermograms where these muscles are seen (more distinct temperature change was observed) are shown in Figures 6-9.

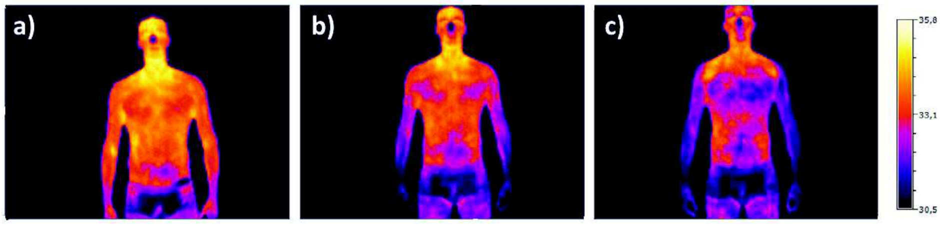

Figure 6. Example of muscle activity observed in infrared, temperature in [°C] – chest, muscles: *serratus, obliquus external abdominis*; a) before experiment, b) after gait without load, c) after gait with load

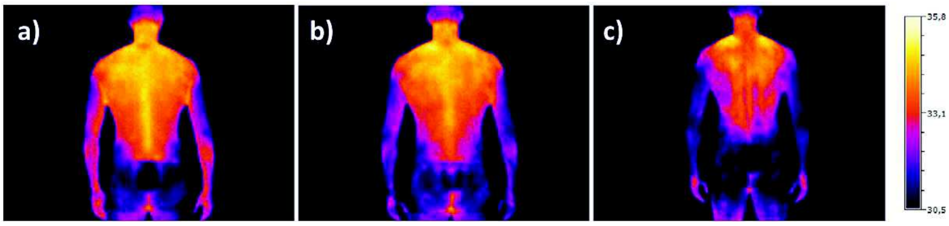

Figure 7. Example of muscle activity observed in infrared, temperature in [°C] – back muscle: *trapezius*; a) before experiment, b) after gait without load, c) after gait with load

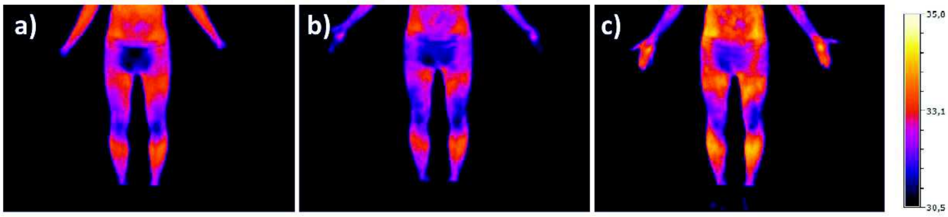

Figure 8. Example of muscle activity observed in infrared, temperature in [°C] – front of the legs muscles: *rectus femoris, pektineus, adductor longus, tibialis anterior, soleus*; a) before experiment, b) after gait without load, c) after gait with load

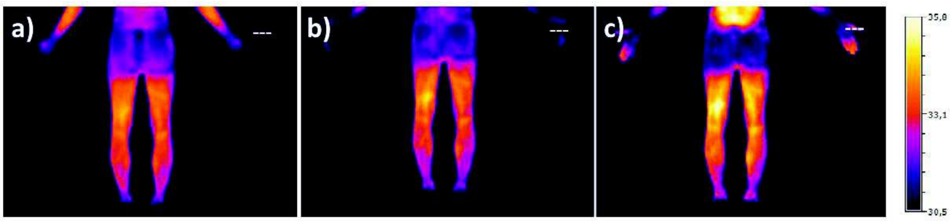

Figure 9. Example of muscle activity observed in infrared, temperature in [°C] – back of the legs muscles: *biceps femoris, semimembranosus, gastrocnemius*; a) before experiment, b) after gait without load, c) after gait with load

Moreover, when an asymmetry of gait was observed during video analysis, an asymmetry of the temperature distribution were observed. Thus implicates that both methods (video analysis and thermography) can help to detect asymmetry of the body movement and muscles load. Disadvantage of thermographic method is that it is sensitive to many factors. For example, sweat secretion results in an uneven cooling of the skin, as observed during experiment (also by other authors, see [8]); see Fig. 8c – some colder and warmer "dots" are seen. Also a backpack insulates the heat transfer from the back and it is necessary to stabilize temperature and humidity in the laboratory. Moreover, it is mandatory to "prepare" volunteer in a very specific way (requirements are described among others in works [5, 6]). Muscle asymmetry can be also observed in Figures 6-9 and in Fig. 10. In this case, it can be seen that left leg carried more load in both cases – gait without and with additional load. In all cases, where asymmetry were observed also a asymmetrical wear of shoe soles for left and right foot were noticed. In all cases asymmetry of gait parameters were confirmed by infra-red imaging. Remarkably, similar method was used in a paper [10] for evaluating compensation of asymmetrical load applied to the pectoral girdle.

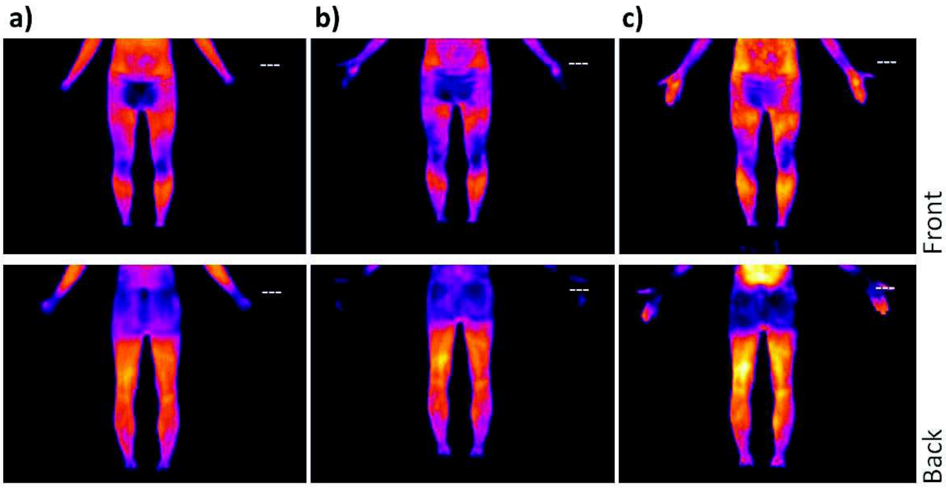

Figure 10. Examples of muscle activity asymmetry; a) before experiment, b) after gait without load, c) after gait with load for front and back of the body; in this example left leg was more loaded in both cases

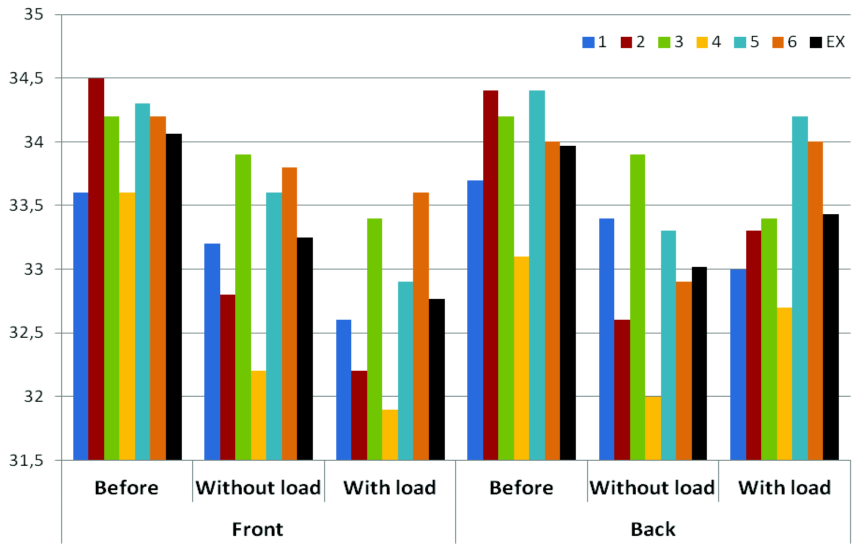

Figure 11. Results of thermographic measurements, temperature in [°C]: front and back of the body shell just before experiment, after gait without and with load for each of volunteer and mean value

3. Additional measurements

During experiment some additional measurements were made: temperature of the body core, systolic and diastolic blood pressure, pulse and blood oxidation. Results are shown in Fig. 12. It can be observed that these parameters were almost constant.

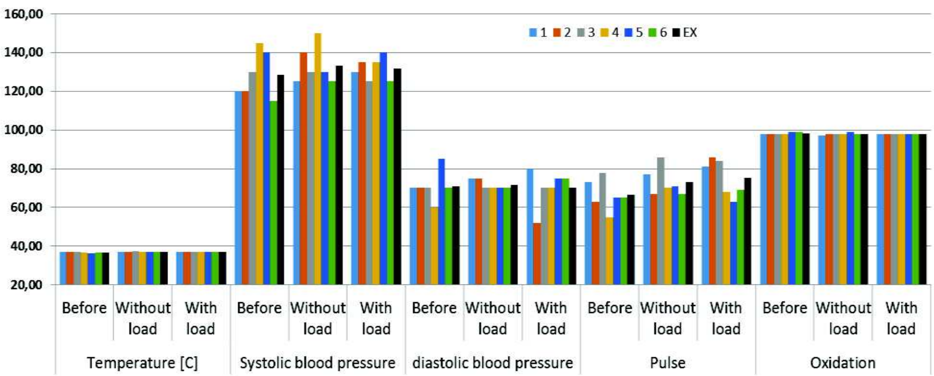

Figure 12. Results of additional measurements: core temperature, systolic and diastolic blood pressure, pulse and oxidation

4. Concluding remarks

A method of complex movement analysis with evaluation of muscle activity has been employed and presented. Its advantages and disadvantages have been discussed. Additionally, a video analysis has been carried out and the obtained results have been validated via comparison with the results reported in other publications. The change in several gait parameters like maximal angle of deviation and the angle vs. time in case of the gait with and without load has been detected and monitored. For example, EX of angle of the main body axis changes from -0.32 deg in case of gait without load up to +0.29 deg with load. Exemplary results are presented in Fig. 3. Changes in muscle activity and overall body temperature have been also observed and reported. The infra-red imaging can also give a qualitative information about symmetry of muscular system load. Moreover, other important detected issues follow:

- Marker-based motion tracking methods are the most effective and precise ones, in comparison to e.g. special inertial sensors, which belong to relatively heavy and inconvenient [7].
- It was observed that many parameters have changed during gait with additional load: stability, pelvis and pectoral girdle tilt, step length (and frequency).
- An activity of muscle groups can be observed in infra-red and groups of muscles involved in the movement can be indicated.
- Asymmetry of the gait is correlated with temperature changes and revealed by infra-red measurements – thermography can be proposed as a method for evaluating various gait pathology.
- In case of gait with an additional load in the form of backpack a lower pectoral girdle tilt and higher value of pelvis tilt was observed.
- The sign of the longitudinal axis deviation (k_1) in most volunteers changes after adding a load. Possible explanation is the change of mass distribution of the load or some asymmetric placement of backpack belts or load.

Acknowledgments

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