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ORIGINAL ARTICLE

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Physical Effort Ability in Counter Movement Jump Depending on the Kind of Warm-Up and Surface Temperature of the Quadriceps

Authors' Contribution:
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

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Key words: *thermography, power, counter movement jump, warm-up, efficiency*

Abstract

Background: *The aim of this research was an attempt at qualifying the influence of various kinds of warm-up on physical effort ability, as well as examining whether there exists any dependence between the surface temperature of the quadricipital muscle of the thigh and the power expressed with the height of counter movement jump (CMJ).*

Material/Methods: *In the research thermographic imaging and dynamometric platform were used. The subjects performed the CMJ test in 3 separate sessions – without any warm-up and then after preparation (1st session – jogtrot; 2nd session – jogtrot and stretching exercises; 3 session – dynamic warm up exercises).*

Results: *In the examined group there was no lineal dependence between the surface temperature of the quadriceps and the power expressed with the height of a jump. Regardless of the kind of the applied warm-up, subjects improved their own results in the CMJ test; however, no such regularity concerning the temperature rise on the surface of a muscle was observed. In a dynamic warm-up lower surface temperature of the quadriceps meant a higher value of CMJ ($r=0.64$; $p<0.05$). This warm-up proved to be most efficient in the preparation for effort.*

Conclusions: *The fact that highest values of a jump and surface temperature were attained after various kinds of warm-up permits supposing that finding individual forms of preparation for effort by an athlete, in order to increase the competition efficiency, is possible.*

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Introduction

Incessant development of sport, moving of limits of human possibilities and even a greater influence of achievements of science often makes details decide about a sports success. Naturally, this produces the necessity for research of new, efficient methods of aiding the physical effort ability. The fundamental matter, and simultaneously not fully recognized, is a suitable preparation of a sportsman for effort. Of course, the meaning of warm-up is universally understood and recognized; yet, adaptive possibilities in effective handling of tasks composed of motor exercises and even extremely energy-exhaustive work, are greatly conditioned by the preparation for effort [1]. Most scientific and methodological elaborations underline physiological and psychological advantages resulting from a well-chosen and done warm-up [2, 3, 4, 5, 6, 7, 8, 9, 10]. In spite of this, comparatively little scientifically recognized is the aspect of selection of an individual form and content of warm-up to optimize its effects [11, 12, 13].

The focus of warming up is, among other things, on the improvement of blood supply by increasing the inflow of blood to working muscles, and due to this delivering oxygen and energy components to them [14, 15]. Selecting a suitable warm-up must, according to Bishop, take into account individually adapted intensity, content or form (active-passive). Doubtless, the evaluation of efficiency cannot be based only on the achieved sport result, because this would lead to interpretative problems in the case of incommensurable sports. So one should also apply some other indicators, e.g. physiological or biomechanical ones [16, 17]. This refers not only to the control of warm-up effects, but also the manner of its execution. The time and intensity of undertaken exercises also appears to be highly individual, because there are considerable differences between people even in the case of representatives of the same sport. At the beginning, this process can be helped by training staff, until the elaboration of suitable examples of conduct. As Mandengue et al. proved, advanced competitors are able to qualify the most suitable for themselves intensity with considerable exactitude (±10%) [18].

However, warm-up must be connected with the specificity of a discipline, thus hitherto existing elaborations suggest that the optimum intensity of warm-up is such which is realized in the zone of mixed (aerobic-anaerobic) transformations. More exact elaborations by Mandengue suggest that it should oscillate within 62% (±10%) of the maximum power, with the heart rate up to 78% (±7) HR_{max} and 75% VO_{2max} (±10%) [19].

The matter of individualisation in selection of content and modality of warm-up, as well as of verification of effects, so that organism would be prepared to specific effort remains open. Technology, which to a greater degree contributes to the achievement or improving sport mastery, can be helpful in this respect [20]. Because both the time and speed of contractions of muscle fibres are strongly connected with the temperature of the muscle itself and with the place in which effort is being made. Assuming the possibility of qualification of body temperature by means of non-invasive methods, it seems that thermography can be of interest to scientific exploration [21].

Thermography is a field of technology interested in detecting, registering, transforming and, finally, visualizing invisible infrared radiation emitted by bodies of higher temperature than the absolute zero. The received image, called thermogram, is an image of temperature on the surface of an object. Taking into account differences between each sport discipline and each competitor, one ought to seek athlete's "thermal portraits" which, according to some scientists, can be connected e.g. with his or her oxygenic efficiency and sometimes post-effort restitution [22, 23].

Practical experience shows that often preparation for the effort is realized collectively by doing the same exercises (it is especially visible in team sports). The probable effect of such a performance is unequal and, what is worse, still inadequate in the competitors' preparation for effort, because in this case, doing the same does not mean achieving the same effects. Individual differences in reaction to the exercises result, among others, in different distribution of warmth on skin. Thermography gives a possibility of qualifying this specificity, so it seems that it can help with the process of controlling the training. It can support choosing the best methods and forms of warm-up in accordance with the discipline, the character of effort or the competitor [24, 25, 26].

Of course, the influence of body temperature on physical effort ability is various depending on its specificity. In most disciplines the developed power is a key indication of efficiency. Seeking the ways of control of this parameter, it appears that one of the basic and easiest ways of qualification is the ability of raising the body mass centre. Various tests with utilization of maximum jump (e.g. CMJ – counter movement jump, VJ – vertical jump and Bosco test) can be quickly executed almost in every condition [27]. The strength of quadricipital thigh muscles, which are the strongest extensors of the knee joint, plays an important role in the height of a jump.

Taking all this into account, an attempt at qualifying the relationship between the kind of warm-up, the surface temperature of the quadriceps of the thigh and the ability to develop maximum power expressed with the height of a counter movement jump were the aims of this research.

Material and Method

In total 10 non-training men aged from 21 to 24 years participated in the research (Tab. 1). The subjects were characterized with correct proportions of height and body mass (BMI in norm).

Tab.1. Biometrical data of the examined group

Age [years]	Body height [cm]	Body mass [kg]	BMI
22.60±2.32	180.70±5.66	75.60±9.55	23.10±2.18

The examination was executed within 3 consecutive days. Every time the examined group performed twice the test of maximum counter movement jump (CMJ) on a platform. For the test Kistler's platform (Switzerland) with a sampling rate of 1000 Hz with BioWare 3.24 software was used. For further analyses the height of the maximum jump from every test was used.

Before each jump the surface temperature of a subject's quadricipital thigh muscle was measured. The measurement was done twice, before and after a warm-up. On each consecutive day forms of warm-up were changed (Fig. 1).

Scanning of the temperature was done on the dominant leg on the quadriceps muscle of the thigh (*musculus quadriceps femoris*) between the place of diffraction in the hip joint and the head of the knee-cap. Areas marking extreme fields of measurement became appointed markers so that analysis referred to the same surface every time. For analysis average temperature from the field of measurement was used. The place of measurement was bare (lack of clothes) and with removed hair which could disturb the result of measurement.

The measurement was performed with a camera with a valid sampling certificate. Additionally, geometrical and thermal calibration of the camera was made and tests on repeatability and stability of shown results were run in compliance with Glamorgan's guidelines [28].

The measurement was made with MobIR M3 camera, equipped with a micro bolometric detector assuming the shape of the detectors matrix (FPA) of measurements as 160 detectors horizontally by 120 detectors vertically. The temperature resolution of the camera distinguishes temperature with an accuracy of 0.12ºC.

The distance between the camera and the photographed object was marked as 0.5 m, which allowed diminution of artefacts connected with movement during respiration by the examined persons. The temperature of the room was in 22-24ºC range, while humidity 48-50%, and these parameters were in the so-called "Golden Standard". Before each thermometry, moisture was evaluated by means of a hygrometer [29].

Preparation of the subjects for thermometry consisted of 15-minute-long adaptation to conditions prevalent in the room, wherein the examination was made. The adaptation was executed with the exposure of the measured place, which was pictured with a thermo-vision camera. The aim of this adaptation was to achieve a state of thermal equilibrium in prevalent room conditions so that the obtained thermograms would be authoritative, and the potential changes of the thermal image would result from undertaken exercises [30]. The direction of camera observation was ensured to be perpendicular to the examined surface in order to avoid false temperature reduction.

Thermograms were compiled with the use of IR Analyser program attached to the MobIR M3 camera. Errors of distortion disfiguring geometry as well as systematic measuring deviation of temperature appearing on the edges of images were eliminated from the images.

On the first day, only 10-minute-long jogtrot was applied as a warm-up. On the second day the warm-up consisted of 5-minute-long jogtrot and then a series of dynamic stretching exercises (swings, circulations, attacks, etc.). On the last day a dynamic warm-up was applied. It was of average intensity and performed in a mixed zone, considered the most efficient in preparation for most of types of effort [8, 31, 32, 33]. The schema of research is presented in Fig. 1.

For comparison of changes of temperature and the height of jump in subsequent measurements, Wilcoxon's test was used. The relationship between the value of temperature and the height of jump was analysed by means of Pearson's correlation coefficients. Values at the level of $p \leq 0.05$ were accepted as significant ones.

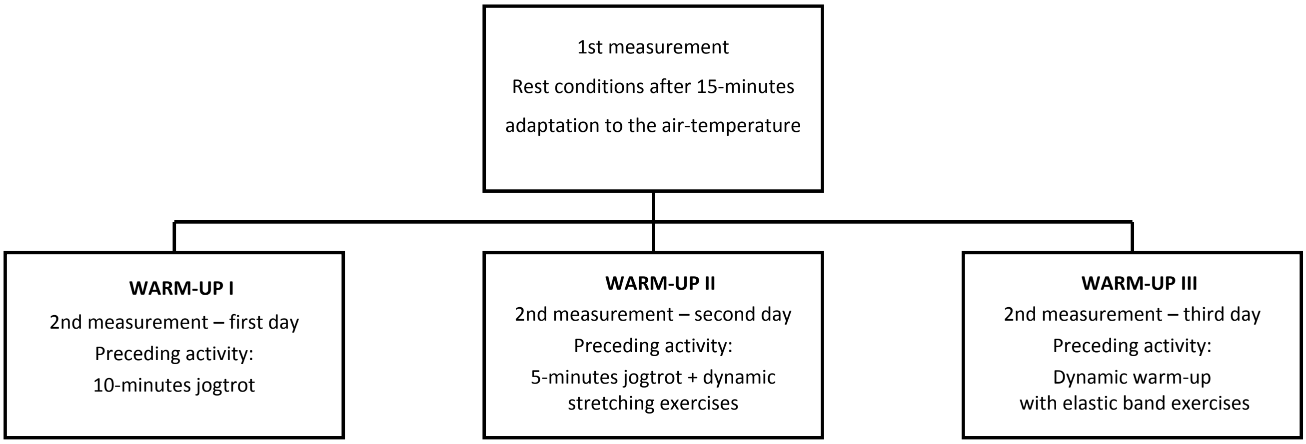

Fig.1. Schema of the study with regard to the specificity of the applied warm-up

Results

With relation to the height of jump obtained without any warm-up, every following measurement after the preparation for effort brought improvement in results of the examined persons. The greatest rise of height of jump was obtained at a dynamic warm-up (warm-up III) and only in this case the obtained change was statistically significant with relation to the first measurement (Fig. 2).

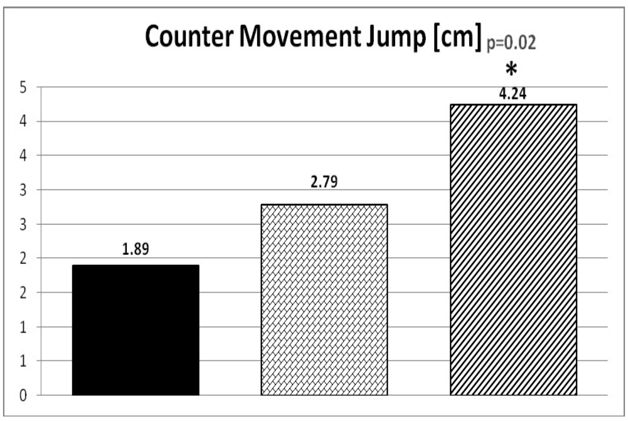

Fig. 2. Changes in the CMJ results depending on the kind of warm-up, with relation to the values obtained at rest

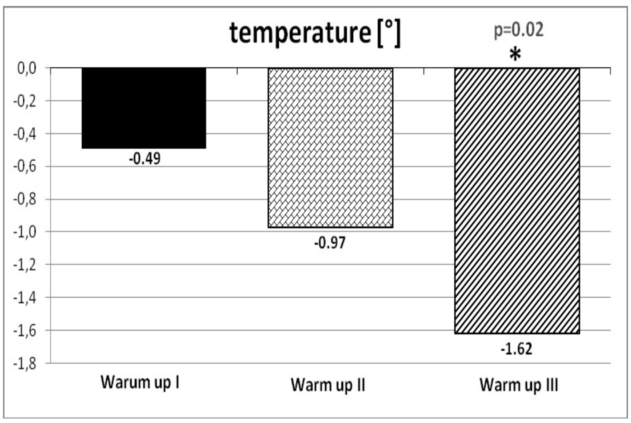

Fig. 3. Changes in surface temperature of the quadriceps, with relation to the values at rest depending on the kind of warm-up

Thermometry made before and after a warm-up, regardless of its kind, brought temperature reduction of the surface temperature of the quadriceps muscle in the second measurement. The statistically important temperature reduction was noted down only for the second measurement after warm-up III (Fig. 3). The range of temperature changes was considerably diverse and in extreme cases reached even -3.9°C. Only in the case of two subjects, surface temperature rise of the quadriceps was ascertained regardless of the kind of warm-up, and the values were from 0.1 to 1.1°C (Tab. 2).

Tab.2. Arithmetical average, minimum and maximum values of changes in the surface temperature of the quadriceps and the height of jump (CMJ) in different kinds of warm-up

	M	Min	Max	±SD
Warm-up I				
Temp (°C)	-0.49	-1.7	0.5	0.69
CMJ (cm)	1.89	-1.0	7.2	3.41
Warm-up II				
Temp (°C)	-0.97	-3.7	1.1	1.73
CMJ (cm)	2.79	0.0	11.0	4.07
Warm-up III				
Temp (°C)	-1.62	-3.9	0.4	1.85
CMJ (cm)	4.24	-1.5	15.0	4.65

Most subjects (8 out of 10 cases) obtained the highest CMJ values after warm-up III, while the surface temperature of the muscle was then the lowest. A significant relationship ($p<0.05$) between both parameters in warm-up III was ascertained, where lower surface temperature of the quadriceps meant a higher value of the jump (Tab. 3).

Tab.3. Results of analysis of correlation (r) between the height of jump and the surface temperature of the quadriceps of the thigh, in the examined group

Kind of exercises			
Rest	**Warm-up I**	**Warm-up II**	**Warm-up III**
-.052	-0.61	-0.23	**0.64**

Discussion

In compliance with expectations of the research, it appeared that a warm-up exerted a favourable influence on results attained in agility tests. The necessity to raise the temperature of muscles to an optimum value of about 37°C is a frequently underlined aspect in the preparation for effort [14, 15]. The obtained results do not confirm this argument. Each time, regardless of the kind of preparatory exercises, the temperature on the surface of the quadriceps dropped. It cannot be ruled out that an intra-muscular measurement would bring a little different values reflecting temperature rise as a result of warm-ups. This would, however, demand a use of invasive methods, which significantly lowers possibilities of application uses. On the other hand, the temperature of tissues of internal organs, transmission of the muscular and fatty tissue and thermal emission of the skin decide about the disintegration of temperature on the body surface. Therefore, the temperature which we measure on the skin surface is a function of temperature of an internal organ or muscles and the properties of thermal tissues separating them from the body surface. This confirms the rightness of the applied methodology of research [34].

The basic question that remains is why, despite a warm-up, the surface temperature of exercising body did not increase together with progress of exercises? The fact that among the subjects the temperature dropped in subsequent measurements can be explained, on the one hand, with a hypothesis that in consideration of an active character of warm-up, muscles were cooled during movement by the surrounding air. However, it seems most probable that the temperature reduction took place as a result of perspiration, and then evaporation of sweat from the skin surface. This is the most efficient form of elimination of warmth produced by working muscles [35]. This would be confirmed by the observation of the subsequent measurement, because more dynamic forms of warm-up (causing greater perspiration) brought greater temperature reduction of the quadriceps muscle surface. Consequently, in spite of changes of the internal temperature of the muscle, the external surface can be cooled. Similar observations, although concerning the places directly engaged in work, were perceived by Anwajler and Dudek [36]. Besides, it also ought to be emphasised that together with warm-up the efficiency of thermoregulatory mechanisms rises. As a result, the temperature of organism needs not to surrender to an essential rise [14, 15, 37]. In the absence of a lineal relationship between the surface temperature of the quadriceps and effort ability in the test of power, looking for information on the subject of adaptive changes happening in muscles themselves, e.g. by simultaneously applied EMG, seems interesting.

The method applied in the research allowed the evaluation of changes in surface thermology of the quadriceps. Monitoring muscles activity by means of thermo vision is possible, because, as it is proved, there is a correlation between metabolic processes and performed mechanical work, which results in production of warmth [36]. An indubitable advantage of this method is non-invasiveness and a possibility of morphological as well as functional picturing of the examined body surface. In sport, where most actions happen in very dynamic conditions, this is essential. What is important, a possibility of evaluation at a distance was obtained, which, with a limited contact between a coach and a competitor in progress of the contest, enlarges diagnostic options. Moreover, this technique permits the evaluation of an extent to which muscles, ligaments or joints are engaged during physical effort. Another field of use can be physiotherapeutic aid at physical effort by a potential finding of trauma connected with an inflammatory process [38]. Changes in surface distribution of temperatures can also be connected with past and present injuries and they can also testify to overloads [39]. All these elements have a great meaning in sport.

Thermovisual research is, of course, the subject of certain limitations and the realization of true measurement in not possible in each case. Exemplary picturing, e.g. of stout persons, can be wrongly interpreted and lead to diagnostic errors [40]. This results from a considerable level of subcutaneous adipose tissue which influences the warmth distribution. The so-called bronze-adipose tissue causing enlarged release of warmth can have special meaning, too [41].

Diverse reactions noted down in the surface temperature of the subjects' quadriceps during thermographic imaging can result from different physiques. Akimov et al. explain the potential differences in distribution of warmth with three kinds of factors. Firstly, those resulting from blood supply of a given place, which is connected with the thickness of capillary vessels; secondly, they can be explained by the intensity of perspiration; lastly, the already mentioned degree of accumulation of subcutaneous adipose tissue can be a differentiating factor, too [22]. To avoid this, the selection of subjects was made so that each person was of correct height-weight proportions, which of course does not exclude individual differences in the quantity and topography of arrangement of subcutaneous adipose tissue.

Obtaining the highest values of a jump after a dynamic warm-up can show best neuromuscular adaptation during warming up to a given kind of effort. The fact that some of the examined persons obtained the highest CMJ results in other kinds of exercises testifies to individual reaction to the practiced warm-up. The found differences testify to the differentiation of needs within the range of preparatory exercises. This confirms the rightness of the accepted assumption that for every competitor individual optimization of preparation for effort should be sought. This can have a special importance in the case of team sports [42].

The applied method brings promising results and offers hope on its uses in optimization and individualisation of warm-up. There are also other interesting areas which demand scientific verification. We have in mind the measurement made in progress of breaks in trainings as well as in start conditions, also during various types and loads of work. It seems also probable that surface body temperature is connected with the level of lactic acid and speed of its utilization [43]. While evaluating cognitive values resulting from the described research, one can notice considerable possibilities for extending the exploration field.

Conclusions

1. In the examined group no lineal correlation between the temperature of the quadriceps surface and the height of jump was noticed. The improvement of CMJ results confirms, however, that warm-up fulfils its own assignment in increasing the effort possibilities.
2. A dynamic warm-up proved to be the most efficient form of preparation for a CMJ. One can, therefore, reason that the greater the resemblance to the starting activity, the more efficient processes of neuromuscular adaptation.
3. A differentiation of the results and attaining the maximum disposition at various surface temperatures of a muscle allows supposing that there are individual differences in adaptation to effort.
4. The obtained results encourage to wider utilization of thermography for the purpose of research of optimum-temperature of working muscles and the most efficient individual form of preparation for effort for every competitor.

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