Effect of Different Muscle Temperature of Human Kinematic Characteristic

I Kliziene[1], S Sipaviciene[2], G Cizauskas[3] and V Linonis[4]

[1, 4] Department of Physical Education, Kaunas University of Technology,
Studentu Street 48, Kaunas, Lithuania

[2] Department of Applied Biology and Rehabilitation, Lithuanian Sports University,
Sporto Street 6, Kaunas, Lithuania

[3] Department of Mechanical Engineering, Kaunas University of Technology,
A. Mickeviciaus Street 37-118, Kaunas, Lithuania

E-mail: irina.kliziene@ktu.lt

Abstract. The aim of the study is to analyze the effect of different muscle temperature on human kinematic characteristics. Kinematic analysis attempts to explain how the experimental equipment "Biodex Medical System PRO 3" computes kinematic parameters. Subjects were tested using "Biodex Medical System PRO 3", human muscle testing and rehabilitation equipment. Calf extensor and flexor muscle performance testing. Muscle heating methods, the water temperature of $44 \pm 1°C$. Muscle cooling methods, the water temperature was $15 \pm 1°C$. Ten adult males were involved in this experiment. The kinematic analysis is performed by solving a set of equations that result from the kinematic and driver constraints. Gravity correction is admittedly less of a problem in extremity testing since for deriving the percentage deficiency, the contralateral (uninvolved) segment serves as the basis for comparison. Unless indicated otherwise, the weight of symmetrical segments is considered equal. On the other hand, where no collateral segment exists, such as the case with the trunk, the poor accuracy of the commonly employed procedures for correcting this effect or abstaining from using it, has significant ramifications in terms of the correct clinical interpretation.

1. Introduction

Direct limb heating can greatly affect muscle force and power during isokinetic exercises [1, 2]. With the rise in temperature of the muscle, tendons, ligaments and connective tissue can stretch more leading to an increase in the range of motion of the joint [3, 4]. It has been established that when the internal muscle temperature rises by one degree, metabolic processes in cells are accelerated by approximately 13 percent [5]. Heating muscle, unlike cooling, accelerates ATP hydrolysis [6] and anaerobic glycolysis. Research literature suggests that high environmental [1] and increased internal body temperature [7] accelerate the occurrence of fatigue during concentric exercise mode. The originality of the research is that the effect of passive heating and cooling on muscle contraction properties and muscle fatigue depending on muscle contraction rate has been studied and explained, to explain how the experimental equipment "Biodex Medical System PRO 3" computes kinematic parameters.

2. Methods and samples

The research sample consisted of 21 ± 2.2 year-old men ($n = 10$) (height – 177.8 ± 5.8cm, weight – 78.2 ± 6.1kg, body fat mass – 7.5% (5.6 fat mass / kg). The study was conducted in accordance with the principles of human experimentation ethics adopted in the Declaration of Helsinki. The research protocol was approved by the Bioethics Committee of KUM (Protocol No. P1-80 / 2004).

Calf extensor and flexor muscle performance testing. Subjects were tested using "Biodex Medical System PRO 3" (certified ISO 9001 EN 46001), human muscle testing and rehabilitation equipment.

---

[1] I Kliziene, Department of Physical Education, Kaunas University of Technology, Studentu Street 48, Kaunas, Lithuania Lithuania

Additional calf device was attached to the dynamometer. Knee joint anatomical axis was identified. The subject was surrounded by the shoulder, torso and thigh belts [8]. The calf was reinforced by the belt and fastened with the buckle over the lower third of the calcaneus tuberosity, the leg was fixed at the knee joint angle of 90° and weighed when it was fixed at 72±5° angle (at the moment of the gravitational force). Isokinetic mode and concentric contraction type were selected on the control panel. The maximum force moment, the average power, the force moment exercising at maximum speed and the maximum speed were registered.

Muscle heating methods. While sitting, the subjects held their outstretched legs for 45 minutes in a hot bath with the water temperature of 44±1°C, and room temperature of 20-22°C. The water in the bath was filled to the amount that both thighs were completely submerged. At the end of heating, muscle temperature at the depth of 3 cm increased by ~ 2.7°C [1, 8]. Water temperature was measured using water thermometers, and room temperature – air thermometers.

Muscle cooling methods. The subjects immersed their feet in a cold bath two times for 15 min (making a 10 min break); the water temperature was 15±1°C. Quadriceps muscle temperature at the depth of 3 cm decreased to 32.5±0.3°C (before cooling it was 36.8±0.2°C) [1, 8].

Research procedures. A total of three experiments were carried out – when muscle temperature was normal (N), when it was heated (H) and cooled (C). No less than a two-three-month break was made between the studies. The experiments differed only in that, that during the second experiment, muscle temperature of the subjects performing concentric exercise test was increased – it was 39.5±0.3°C, and during the third one it was reduced – it was 32.5±0.3°C. The stages of all experiments (when the muscle temperature was normal, the muscle was heated and cooled) were the same. Prior to each experiment, the subjects were introduced to the process of the research and trained to do the exercise. The room temperature was constant throughout the study (20-22°C). While registering knee extensor and flexor muscle performance, control measurements were carried out (before the load, immediately after it, 10, 30, 60min and 24h after it): one set of 3 movements (calf stretching and extending) at the speed of 180°/s. Rest between measurements was 60 seconds, then concentric load was carried out – 50 calf muscle extensions and flexions at the speed of 180°/s.

The results obtained were processed using the methods of mathematical statistics, i.e. by calculating the arithmetical mean and the mean square deviation. The significance of differences was between arithmetical mean ($\bar{x}$) and the mean square deviation (SD). The significance of differences between arithmetical means was established according to the paired-samples t test. The degree of significance of differences between arithmetical means was considered important when the value of p was smaller than 0.05 ($p < 0.05$). Calculations were made making use of the statistic Microsoft Excel 2003 and SPSS 11.5 programs.

3. Physiological and biomechanical aspects

The techniques, be they isometric, isokinetic or other, employed to measure muscle 'force' in live subjects, are based on a different method. Instead of force, which is basically a linear entity, the appropriate term is strength. This is defined as the rotational effect of the force, generated by a single muscle or a muscle group, about the joint under consideration, and is also called the moment. Although strength is defined with respect to any point along the joint range of motion (ROM) in which the muscle(s) exert this effect, the common meaning of strength is the point in the ROM where strength reaches its maximum. Hence the term peak moment or peak torque (see below). Strength also involves the concept of synergy, reference being made, where applicable, to the combined action of a number of muscles rather than of a single muscle [9].

Disregarding for a moment the effect of gravity (see below), strength is measured by recording the force exerted on the sensor of the dynamometer by the body segment distal to the joint, and multiplying the value obtained by the length of the force sensor's lever-arm (Fig. 1) to give a moment, *M*. In other words the mechanical potential of the muscle is only inferred rather than measured directly. Moreover, simple mechanical considerations indicate that the amount of force exerted on the

force sensor is inversely proportional to the distance between the joint axis and the point of force application. Since the length of body segments is generally small, a deviation of even 1 cm from the original placement of the sensor may, upon retesting, introduce errors of approximately 2.5-5% with a corresponding effect on the reproducibility of the test findings.
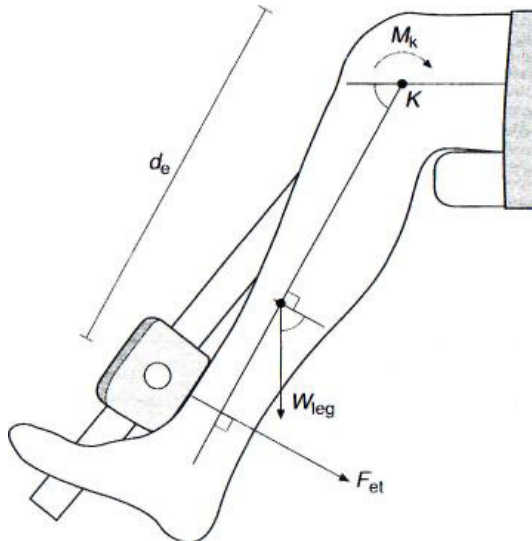

Figure 1. In an isometric or isokinetic gravity-free situation the moment M_k, generated by the muscle (the quadriceps femoris in this case) would be equal to the distance between the force resistance pad and the instantaneous center of rotation of the knee, times the force recorded by the sensor, Fet. W_{leg}, weight of leg (shank + foot) [10].

In dynamic contractions, the external moment, namely the moment which has to be overcome by the muscle, is normally generated by three distinct elements:
1. the individual weight of the segment(s) distal to the joint;
2. the load against which one acts, for instance lifting an object;
3. the inertial resistance of the segment.

As soon as the isokinetic condition is reached, namely the lever-arm proceeds at a constant angular velocity, the accelerational components are negligible. Therefore in order to determine the net muscle force it is necessary to account for the effect of weight. Consider Figure 2 which refers to the isometric measurement of the strength of the knee extensors and flexors in the seated position.
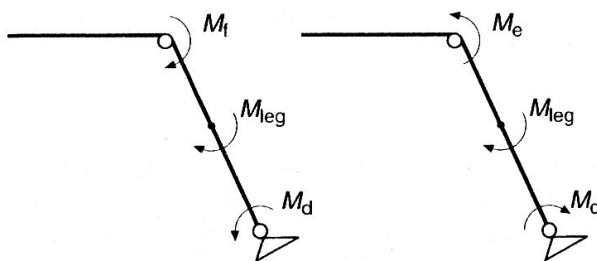

Figure 2. Moment configuration simulated during isokinetic testing of flexors (M_f) and extensors (M_e). M_d, moment generated by the dynamometer's lever-arm; Mleg, gravitational moment of the leg.

The extensors act in the opposite direction to the weight of the leg and the resistance of the dynamometer. The moment exerted by the extensors, M_e (anticlockwise in Fig. 2), must be equal to the moment of weight of the leg (shank and foot), M_{leg} plus the moment exerted by the resistance of the dynamometer, M_d (both clockwise in Fig. 2). This relationship is given by the equation:

$$M_e = M_d + M_{leg} \qquad (1)$$

On the other hand, when the flexors contract isometrically, the moment they generate, M_f, and the

moment exerted by the weight of the leg act in the same direction (clockwise in Fig. 2), and hence the equation is:

$$M_f + M_{leg} = M_d \qquad (2)$$

Or by rearranging:

$$M_f = M_d - M_{leg} \qquad (3)$$

Thus, in the 'gravitational position' the strength of the extensors may be underestimated and that of the flexors overestimated by an amount equal to the gravitational moment.

In isokinetic testing the above argument is valid for the analogous case of extensor and flexor concentric (see below) contractions, i.e. where the muscle is overcoming the weight of the limb and the resistance of the dynamometer. In order to obtain the true value of the muscle strength it is therefore necessary to perform the so-called 'gravity correction' procedure which is incorporated in commercially available isokinetic systems. The procedure is based on 'weighing' of the segment at a given recorded position (normally as close to the horizontal as possible) which is performed by the system's load cell and a simple trigonometric calculation which is incorporated in the force or moment data processing by the computer. However as indicated by a number of recent papers [11] gravity correction procedures are error prone. This error is primarily due to two factors:

1. Biological joints cannot be simulated by a perfect hinge-type joint which serves as the basic assumption of the software procedure.

2. There is a measure of active and passive resistance in addition to the gravitational that must be accounted for (and is not).

The active element is contributed by surrounding muscles that may fire even though when the measurement is done subjects are required to relax completely. The passive element results from the stretch of ligaments, tendons and capsule. Therefore instead of a sinusoidal component, the resistance assumes a different pattern. An effective example is depicted in Wessel et al. [12] where testing of trunk flexor strength and the 'gravitational' components of the trunk were measured. Although the alternative solution – moving the tested segment passively through the ROM and subtracting the obtained resistance from the active strength in order to derive the net strength-partially solves the first difficulty (non-axial movement), it certainly suffers from the same problems regarding the passive/active components. As a result, isokinetic tests should have been done in the non-gravitational position. However this is not only non-functional in many instances but requires awkward subject positioning and special attachments. Gravity correction is admittedly less of a problem in extremity testing since for deriving the percentage deficiency, the contralateral (uninvolved) segment serves as the basis for comparison. Unless indicated otherwise, the weight of symmetrical segments is considered equal. On the other hand, where no collateral segment exists, such as the case with the trunk, the poor accuracy of the commonly employed procedures for correcting this effect or abstaining from using it, has significant ramifications in terms of the correct clinical interpretation.

4. Results

During maximum voluntary contraction of the muscle men's MFM of the force of dynamic contraction with the leg being extended and flexed in the knee joint at the fixed 180 °/s speed is dependent on time ($p = 0.000$) and on temperature ($p = 0.000$). During leg extension and leg flexion in the knee joint significant interaction between time and muscle temperature ($p = 0.000$), between time and the work performed by the muscle (extension-flexion) ($p = 0.000$), as well as between time, temperature and the work (extension-flexion) performed by the muscle ($p = 0.000$), have been established (Table 1).

Table 1. Analysis of variance of three factors of the maximum force moment

Dependence on:	Knee extension	Knee flexion
Time	$p = 0.000$	$p = 0.000$
Temperature	$p = 0.000$	$p = 0.001$
Interaction (time—temperature)	$p = 0.000$	$p = 0.000$
Work performed by the muscle (extension—flexion)	$p = 0.149$	
Interaction (time—work performed by the muscle)	$p = 0.000$	
Interaction (temperature—work performed by the muscle)	$p = 0.000$	
Interaction (temperature—time—work performed by the muscle)	$p = 0.000$	

5. Conclusions

The kinematic analysis is performed by solving a set of equations that result from the kinematic and driver constraints. Gravity correction is admittedly less of a problem in extremity testing since for deriving the percentage deficiency, the contralateral (uninvolved) segment serves as the basis for comparison. Unless indicated otherwise, the weight of symmetrical segments is considered equal. On the other hand, where no collateral segment exists, such as the case with the trunk, the poor accuracy of the commonly employed procedures for correcting this effect or abstaining from using it, has significant ramifications in terms of the correct clinical interpretation.

References

[1]   Sargeant A J 1987 Effect of muscle on leg extension force and short-term power output in humans *Eur. J. Appl. Physiol*. **56** 693-8.
[2]   Ball D, Burrows C and Sargeant A J 1999 Human power output during repeated sprint cycle exercise: the influence of thermal stress *Eur. J. Appl. Physiol*. **79** 360-6.
[3]   Strickler T, Malone T and Garret W E 1990 The effects of passive warming on muscle injury *Am. J. Sports. Med.* **18** 141-5.
[4]   Kirkendall D T and Garret W E 2002 Clinical perspectives regarding eccentric muscle injury *Clin. Orthop. Relat. Res.* **403** 81-9.
[5]   Febbraio M A 2000 Does muscle function and metabolism affect exercise performance in the heat? *Exerc. Sport. Sci. Rev*. **28** 171-6.
[6]   Galloway S D R and Moughan R J 1997 Effects of ambient temperature on the capacity to perform prolonged exercise in humans *Med. Sci. Sports. Exerc.* **29** 1240-9.
[7]   Gonzalez-Alonso J, Teller C, Anderson S L et al. 1999 Influence of body temperature on the development of fatigue during prolonged exercise in the heat *J. Appl. Physiol.* **86** 1032-9.
[8]   Ramanauskienė I, Skurvydas A, Sipavičienė S et al. 2008 Influence of heating and cooling on muscle fatigue and recovery *Medicina* **44** 687-93.
[9]   Herzog W, Hasler E and Abrahames S 1991 A comparison of knee extensor strength curves obtained theoretically and experimentally *Med. Sci. Sport. Exerc.* **23** 108-14.
[10]   Nisell R and Ericson M 1989 Tibiofemoral joint forces during isokinetics knee extension *Am. J. Sport. Med.* **17** 49-54.
[11]   Bygott I L, McMeeken J and Carroll S 2001 A preliminary analysis of the gravity correction procedures applied in trunk dynamometry *Isokinet. Exerc. Sci.* **9** 53-64.
[12]   Wessel J, Ford D abd van Drietsum D 1992 Measurement of torque of trunk flexors at different velocities *Scan. J. Rehabil. Med.* **24** 175-180.