



## Gastrocnemius muscle tone, elasticity, and stiffness in association with postural control characteristics in young men

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**Abstract.** The association between muscle tone and postural sway characteristics during standing was investigated in 27 healthy men aged 17–31 years. Frequency of muscle oscillations as an indicator of the tone, logarithmic decrement of the dampening of muscle oscillations as an indicator of the elasticity, and stiffness of the medial gastrocnemius (MG) muscle were measured bilaterally using a hand-held Myoton-3 device (Estonia). Postural sway of the centre of foot pressure during 30 s quiet bipedal standing was recorded using a Kistler force plate. As compared to the lying position, at standing on stable ground (SG) as well as on unstable ground (USG) (balance pad) the frequency of muscle oscillations was greater (162% and 166%, respectively) and so was stiffness (199% and 203%, respectively) but no significant differences for the logarithmic decrement of the dampening of muscle oscillations were noted. A greater coefficient of variation at standing on SG and USG as compared to the lying position for frequency of muscle oscillations (403% and 471%, respectively), for stiffness (177% and 187%, respectively), and for the logarithmic decrement of the dampening of muscle oscillations (120% and 122%, respectively) was found. Muscle tone and elasticity characteristics correlated positively with sway characteristics (radius and area of the centre of pressure) at USG standing. The change of posture from the supine to the standing position was accompanied by a marked increase in MG muscle tone and stiffness, but elasticity did not change. Coefficients of variation for the measured characteristics are suggested as new criteria for muscle function in relation to postural stability.

**Key words:** kinesiology, biomechanics, passive resting tone, postural muscle tone, postural sway, body balance.

### Acronyms

AP	anteroposterior	ML	mediolateral
CoP	centre of foot pressure	PMT	postural muscle tone
CV	coefficient of variation	PRMT	passive resting muscle tone
ICC	intraclass correlation coefficient	SG	stable ground
MG	medial gastrocnemius	USG	unstable ground

### INTRODUCTION

The estimation of muscle tone is important in clinical practice, occupational health, physiotherapy, and rehabilitation medicine as well as in other health-related areas. New technical possibilities have been elaborated for the corresponding measuring devices, with good validity and simple usage (Clemmesen, 1951; Davidoff, 1992; Masi and Hannon, 2008; Gurfinkel et al., 2011).

However, their drawback is that for the estimation of measurement results complicated criteria and consensus in applied terms have yet to be achieved and even definitions of tone may differ.

It is appropriate to distinguish between the passive resting muscle tone (PRMT) and postural muscle tone (PMT). According to the definition of Guyton and Hall (2006), tone (or tautness) is a state of muscles at rest when a certain amount of tautness has remained. We agree with this definition. PRMT depends on the region of the muscle and its passive length (Murayama et al.,

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2012). During standing muscles have to provide the body with balance due to the condition of unsteadiness, whereas the lying position can be considered as a state of stability. Erect posture in humans is achieved by the superposition of body segments (head, trunk, and legs) along the longitudinal axis. Postural tone, predominantly distributed among the extensor muscles, plays an important role in maintaining the erect posture.

Posture includes two main functions. First, anti-gravity – the superposition of segments that is performed against the force of gravity and the associated ground reaction forces. Second, the serving as an interface with the external world or perception and action. A global organization of posture is mainly related to equilibrium control. Balance is preserved when the centre of foot pressure (CoP) remains inside the support base (i.e. the surface under the feet). Under static conditions this corresponds to the projection of the centre of gravity (Massion and Woollacott, 2004). PMT is a tautness of the skeletal muscle during which the muscle balancing force torques of body segments caused by the force of gravity maintain equilibrium.

Previous studies demonstrated an increase of tone when the muscle is stretched. Alamäki et al. (2007) noted that the measuring position has an effect on tone measurements when a computerized muscle tonometer (Medirehabook Ltd, Finland) is used. During the stretching of the rectus femoris muscle (knee flexion from 0 to 60 degrees), the muscle work decreases by 9%. A similar correlation between torque output levels, muscle length, and tone was found in the study of Bizzini and Mannion (2003), conducted with a handheld Myoton-2 device (Müomeetria Ltd, Estonia). A significant increase of stiffness, elasticity, and tone characteristics of the relaxed biceps femoris muscle measured by Myoton-2 and a decrease of contraction time measured using the tensomyographic method were observed by Ditroilo et al. (2011) at the neutral position of the knee joint as compared to the muscle stretched at an angle of 45 and 90 degrees.

When using a Myoton device at a constant length of the skeletal muscle, the measuring device evokes a short-time change in the muscle shape by the dosed impact that ends with a quick release and the muscle responds by natural damped oscillations (Vain, 1995). Previously a good repeatability and validity of characteristics measured by the Myoton was noted (Korhonen et al., 2005; Viir et al., 2006a). As compared to the muscle compliance measurement method (Gubler-Hanna et al., 2007), where the duration of the impact on the muscle is expressed in seconds, the present method evokes a mechanical impulse during 15 ms. Thus the latter method excludes the person's voluntary interference in the measurement procedure. Different Myoton devices are used for studies; for example, the Myoton-2 has similar working principles but a larger mass of the testing end as

compared with the Myoton-3 (37 g and 18 g, respectively), which is accompanied by lower values of tone characteristics and larger values of stiffness but no differences in the measurement of elasticity.

The tone of leg muscles and postural sway were studied in geriatric rehabilitation of stroke and Parkinson's disease patients (Merkert et al., 2011; Franzén et al., 2012) using qualitative assessment of muscle tone in scores (in the former study) or a device measuring the resistance of the hips to yaw rotation at standing. In the study of Saenko et al. (2011) postural corrective responses were analysed in cosmonauts by the anterior–posterior body sway and electromyographic activity of leg muscles during postural perturbation in microgravity before and after a long-term space flight.

Viir et al. (2006b) studied PMRT and PMT during quiet standing using a Myoton-2 device and noted a decrease of the upper trapezius tone and stiffness characteristics during the transfer from the standing or sitting position to the lying position in young healthy women. Another research (Rubini et al., 2012) demonstrated an increase in the integrated electromyographic activities of antigravitational muscles of the lower extremity (soleus and gastrocnemius muscle) in young healthy volunteers at rest in the standing position as compared to the supine position; it was suggested that the increased metabolic rate in the standing position is partially due to the antigravitational muscle tone. It has also been suggested that during standing on a stable surface young persons use mainly (70%) somatosensory information for postural control, while on an unstable surface the importance of the vestibular system and visual information increases (Peterka, 2002). To our knowledge, no studies have been performed on establishing the influence of sensory information on the tone, elasticity, and stiffness of the gastrocnemius muscle in different postural control situations – at lying or at standing on stable ground (SG) and unstable ground (USG).

The aim of the present study was to compare the tone, elasticity, and stiffness of the medial gastrocnemius muscle (MG) characteristics between supine and standing postures and to explore the effect of SG and USG on postural sway. We hypothesized that one of the important criteria of the muscle function in relation to postural stability is the coefficient of variation (CV) of measured characteristics. We also evaluated the possible influence of the measurement procedure by the Myoton-3 device on postural control characteristics during standing on SG and USG.

## MATERIALS AND METHODS

### Participants

Twenty-seven healthy physically active men with no balance impairments, vision problems, neurological or

orthopaedic diseases, or any other complaints participated in the study. The age of the participants was between 17 and 31 years (mean±SD: 21.3±3.1 years); the mean height of the persons was 183.6±7.2 cm (range 172–195 cm), body mass 75.8±6.2 kg (range 64–87 kg), and body mass index 22.5±1.5 kg m<sup>-2</sup> (range 19.7–25.6 kg m<sup>-2</sup>). The majority of the studied persons had their right leg dominant. Within two days prior to testing the procedure was demonstrated and a practical session was conducted to familiarize the attendants with the procedure. The persons were asked to refrain from caffeine for 24 h before the experiment and avoid participation in any sports activity one day before the testing. The direct ergogenic effect of caffeine on the skeletal muscle has been shown (Tarnopolsky, 2008), and it has also been demonstrated that caffeine causes dose-dependent increases in the force and duration of the contraction of the skeletal muscle (accompanied by an increased release of calcium ions from the sarcoplasmic reticulum) (Olorunschola and Achie, 2011).

To minimize any effect from walking to the laboratory, before the testing the persons had a rest of about 25 min sitting on the chair with a back support. The room temperature was continuously controlled and maintained at 24°C. All participants were informed of the procedures and the purpose of the study and their written informed consent was obtained. The study carried the approval of the Ethics Committee at the University of Tartu for human studies.

### Equipment

Myometer Myoton-3 (Müomeetria Ltd, Estonia) is a hand-held device that induces oscillation of the muscle tissue by a mechanical impact with a force up to 0.4 N. The mass of the device's testing probe is 18 g, diameter 2 mm, and the kick time 15 ms. Muscle oscillations are registered by the accelerometer of the device with a sampling rate of 3200 Hz, and a graph is formed based on this recording. Software version 3.15.0 was used.

The following characteristics were analysed (Fig. 1).

Frequency of muscle oscillations  $F$  indicates the tone of the muscle or tautness:

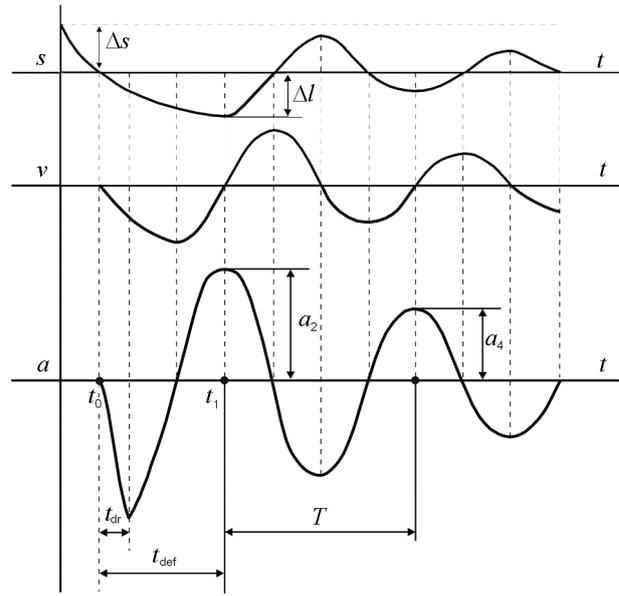
$$F = 1/T, \text{ Hz}, \quad (1)$$

where  $T$  is the period of the oscillation.

Logarithmic decrement of the dampening of muscle oscillations  $D$  shows the elasticity of the muscle or the ability of the muscle to restore its shape:

$$D = \ln(a_2/a_4), \quad (2)$$

where  $a_2$  and  $a_4$  are amplitudes of the 2nd and the 4th peak of muscle oscillation.



**Fig. 1.** Principles of the calculation of muscle tone, elasticity, and stiffness characteristics by the software of the Myoton-3 device. The lowest curve is the acceleration of the device's testing probe as a result of muscle oscillations after external mechanical impulse, the middle curve presents the velocity of oscillations, and the upper curve gives an overview of tissue deformation; the dotted line demonstrates superficial tissue surface;  $a$  – acceleration (m s<sup>-2</sup>),  $v$  – velocity (m s<sup>-1</sup>),  $s$  – waveform of the displacement of the tissue (m);  $a_2, a_4$  – amplitudes of the 2nd and 4th peaks of oscillation;  $T$  – period of oscillation (s),  $t_{dr}$  – time of drive impulse,  $t_{def}$  – time of deformation of the tissue,  $t_0$  – start of the testing probe drive impulse,  $t_1$  – finish of the testing probe impulse;  $\Delta l$  – deepest deformation of the tissue (m),  $\Delta s$  – displacement of the tissue (m) from weight of the testing probe.

Stiffness of the muscle  $S$  indicates the ability of the muscle to resist the changes in its shape caused by an external force:

$$S = a_2 \cdot m / \Delta l, \text{ Nm}^{-1}, \quad (3)$$

where  $a_2$  is the amplitude of the 2nd peak of muscle oscillation,  $m$  is the mass of the testing probe, and  $\Delta l$  is the deepest deformation of the tissue after mechanical impact (the double integral of the acceleration graph from the start of the testing probe drive impulse  $t_0$  to the moment of the deepest deformation  $t_1$ ).

The MultiScan mode (5 continuous measurements from the same point) was used and mean data were accepted (Vain 1995, 2002; Gapeyeva et al., 2005). Two Myoton-3 devices were calibrated prior to the testing on the test body for ultrasound devices (SonarAid gel 090327, Geistlich Pharma, Switzerland) with the dimensions of 130 mm × 120 mm × 10 mm. The intra-class correlation coefficient (ICC) for the tone, elasticity, and stiffness characteristics was 99% for both devices. As

a result of 20 measurements performed on the test body, the relative measurement error was established for the frequency of muscle oscillations (0.3% in both cases), logarithmic decrement of the dampening of muscle oscillations (1.0% and 1.9%, respectively), and stiffness (0.6% and 3.1%, respectively). Previously it was found that the acquired data of tone, elasticity, and stiffness did not depend on the measurer: the ICCs between two measurers were 0.99 (95% CI: 0.98 to 0.99) for the frequency of muscle oscillation; 0.99 (95% CI: 0.98 to 1.00) for stiffness, and 0.97 (95% CI: 0.95 to 0.99) for the logarithmic decrement of the dampening of muscle oscillations (Viir et al., 2006a).

For determining the postural sway characteristics during quiet bipedal standing the force platform Kistler 9286A (Kistler Instrumente AG, Switzerland; dimensions 40 cm × 60 cm) and biomechanical movement analyser system Elite Clinic with Sway software® (BTS S.p.A., Italy) were used. The subject was asked to keep static body balance and to look at a picture of a circle with the diameter of 10 cm on the level of his eyes at a distance of 3.5 m. Postural stability was investigated so that the subject was standing on a force platform (SG) and on a balance pad (USG) (Alcan Airex AG, Switzerland; dimensions 39.5 cm × 48.5 cm and thickness 6 cm) placed on the force platform. The following sway characteristics were analysed: CoP sway range in the anteroposterior (AP) and the mediolateral (ML) direction, CoP trace length, CoP trace and equivalent radius, CoP sway velocity, and CoP sway equivalent area.

## Testing procedures

### Measurement of the PRMT

Characteristics of the tone, elasticity, and stiffness of the MG muscle in the lying prone position on a massage table were recorded by a Myoton-3 device. To avoid stretch of the plantar flexor muscle, a half-cylindrical pad with a height of 8 cm was placed under the ankle joint (Gapeyeva and Vain, 2008). Before measurements, the persons had a 5-min rest in the lying position, and the measurement point of the muscle (centre of muscle belly) was marked symmetrically for the right and left body sides. Measurements were performed by the same experienced researcher.

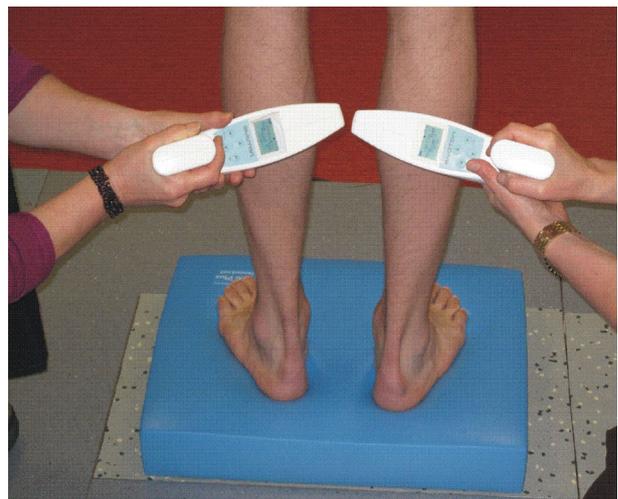
### Measurement of the PMT

For bilateral measurements of the muscle tone, elasticity, and stiffness characteristics at standing two previously calibrated Myoton-3 devices were used simultaneously. Due to the limited performance capability of the device, measurements were made under a 45-degree angle in relation to the vertical axis (Fig. 2). Two measurements were performed: first at the begin-

(a)



(b)



**Fig. 2.** Measurement of muscle tone characteristics with Myoton-3 devices during standing on stable (a) and unstable ground (b).

ning (during 1–10 s) and second at the end (during 20–30 s) of each standing test simultaneously with postural sway recording on SG and USG.

### Postural stability assessment

The following sequence of testing was used for measuring the postural sway with and without using the Myoton device:

- (i) 5-s standing on SG (for adaptation to this posture) followed by the measurement of postural sway during 30-s standing on a force plate;
- (ii) 2-min seated rest (on a chair with a back support);

- (iii) 5-s standing on SG followed by the measurement of postural sway during 30-s standing on SG with the measurement of PMT;
- (iv) 2-min seated rest;
- (v) 5-s standing on USG (for adaptation to this posture) followed by the measurement of postural sway during 30-s standing on a balance pad;
- (vi) 2-min seated rest;
- (vii) 5-s standing on USG followed by the measurement of postural sway during 30-s standing on a balance pad with the measurement of PMT.

### Statistical analysis

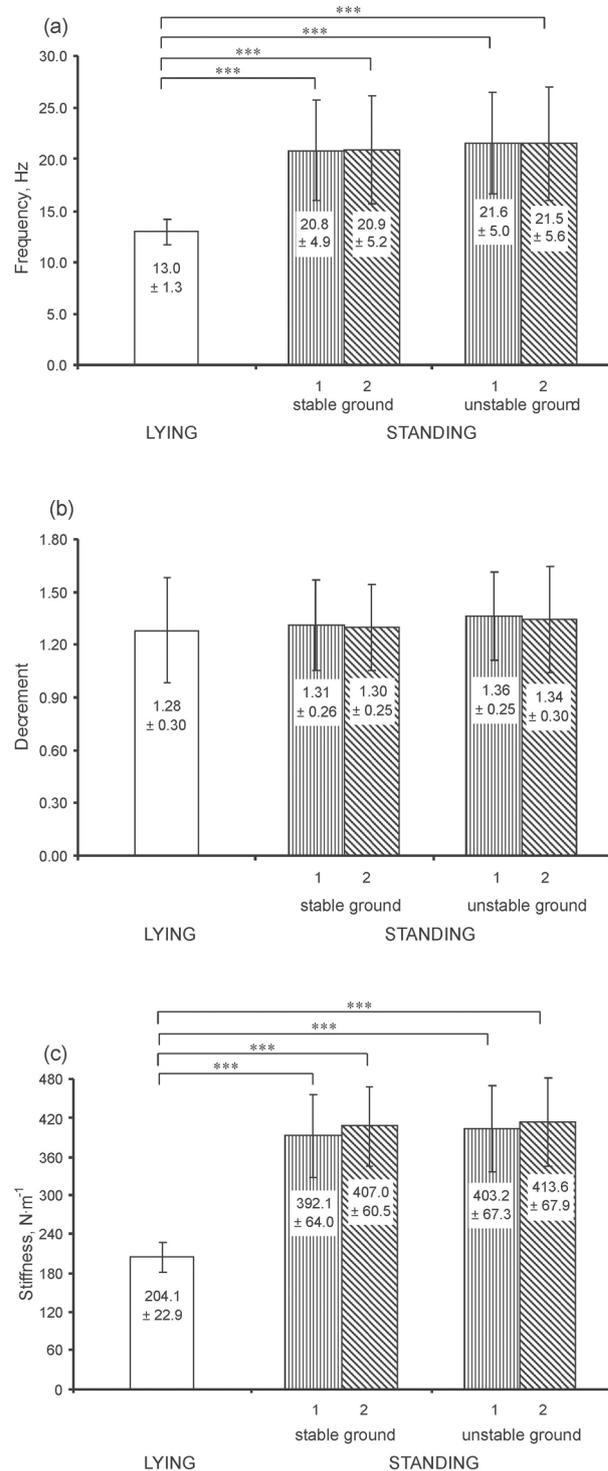
Data are presented as means ( $\pm$ standard deviation) as well as CV. Muscle tone, elasticity, and stiffness characteristics (pooled data of the right and left sides) were analysed. Normal distribution of the data by the Kolmogorov–Smirnov test was observed. One-way analysis of variance (ANOVA) was made and followed by Scheffe's post hoc comparisons. Pearson's correlation analysis was used to observe the associations between measured characteristics. The lowest level of statistical significance was set at  $p < 0.05$ .

## RESULTS

### Influence of posture on muscle tone, elasticity, and stiffness

Muscle tone, elasticity, and stiffness characteristics of the MG (pooled data for the right and left sides) measured when the subject was in the lying position and standing on two different grounds are presented in Fig. 3. The frequency of muscle oscillations was significantly greater in the standing position than in the lying position. It was greater ( $p < 0.001$ ) at standing on USG than on SG in comparison to the lying position: at the beginning of the test 166% and 161%, respectively; at the end of the test 166% and 162%, respectively. No significant difference ( $p = 0.21$ – $0.79$ ) in the logarithmic decrement of the dampening of muscle oscillations between any position was found. Similarly to the frequency of muscle oscillations, stiffness was the greatest ( $p < 0.001$ ) at standing on both grounds as compared to the lying position: at the beginning of the test 198% and 192%, respectively, and at the end of the test 203% and 199%, respectively.

Comparison of data for the two different grounds did not indicate any significant difference ( $p = 0.85$ – $0.98$ ) in the frequency of muscle oscillations, logarithmic decrement of the dampening of muscle oscillations, or stiffness between the measurements on SG and USG in general, neither were these parameters influenced by habituation. Likewise, the exploration of a possible



**Fig. 3.** Characteristics of tone (frequency of muscle oscillations) (a), elasticity (logarithmic decrement of the dampening of muscle oscillations) (b), and stiffness (c) of the gastrocnemius muscle in the lying position and during 30-s standing on stable and unstable ground in young men ( $n = 27$ , mean  $\pm$  SD). Data for the right and left sides are pooled; 1 – first 10 s; 2 – last 10 s; \*\*\*  $p < 0.001$ .

influence of a 30-s standing on the measured characteristics did not reveal any significant difference ( $p = 0.85\text{--}0.98$ ) between the frequency of muscle oscillations, logarithmic decrement of the dampening of muscle oscillations, and stiffness measured at the beginning of the test and at the end of test either for standing on SG or on USG.

#### Coefficient of variation of muscle tone, elasticity, and stiffness characteristics

The CV of MG muscle tone, elasticity, and stiffness characteristics showed significant differences between the lying and standing positions (Table 1). At lying, the lowest CV was noted for the frequency of muscle oscillations (1.4%) and the highest for the logarithmic decrement of the dampening of muscle oscillations (7.4%).

Compared to the lying position, a significant increase of the CV was noted both in the cases of standing on SG and USG for all measured characteristics, but the greatest difference was observed for the frequency of muscle oscillations. When subjects stood up on SG or on USG, the CV of the frequency of muscle oscillations measured at the beginning of the test rose immediately by 403% and 471%, respectively, and was higher at the end of the test by 375% and 436%, respectively ( $p = 0.002\text{--}0.001$ ) as compared to the lying position. The CV rise was lower for stiffness: at the beginning of

the test it was 177% and 187% greater, respectively, and at the end 160% and 168% greater, respectively ( $p < 0.001$ ). The lowest increase was noted for the CV of the logarithmic decrement of the dampening of muscle oscillations: at the beginning of the test 120% and 122%, respectively, and at the end 116% and 114%, respectively ( $p = 0.041\text{--}0.047$ ). The difference in the CV of measured characteristics was significant ( $p > 0.05$ ) between standing on SG and USG.

Analysis of changes in the CV for the measured characteristics between the first and the last 10 s of the standing test showed that the CV had a tendency to increase. The increase was greater during standing on USG in comparison to SG (for the frequency of muscle oscillations by 7.4% and 5.9%, respectively; for logarithmic decrement of the dampening of muscle oscillations by 6.9% and 4.1%, respectively; and for stiffness by 10.8% and 9.7%, respectively). However, this difference was not statistically significant ( $p = 0.57\text{--}0.74$ ).

#### Influence of ground and measurement procedure with the Myoton device on postural stability

Postural sway characteristics changed during standing on two different grounds and under the influence of the measurement procedure with the Myoton device (Table 2). The increase in the CoP sway in the AP and ML directions and in the CoP sway radius and area was

**Table 1.** Coefficient of variation (CV, %) for characteristics of tone, elasticity, and stiffness of the gastrocnemius muscle in the lying position and during quiet 30-s standing on stable (SG) and unstable ground (USG) in young men ( $n = 27$ , mean  $\pm$  SD). Data for the right and left sides are pooled

Characteristic	Lying	CV (%), standing on SG		CV (%), standing on USG	
		First 10 s	Last 10 s	First 10 s	Last 10 s
Frequency of muscle oscillations	1.39 $\pm$ 0.57	5.61 $\pm$ 3.11***	5.26 $\pm$ 1.98***	6.60 $\pm$ 2.63***	6.11 $\pm$ 1.81***
Logarithmic decrement of dampening of muscle oscillations	7.46 $\pm$ 2.86	9.00 $\pm$ 2.81*	8.63 $\pm$ 2.83*	9.15 $\pm$ 2.55*	8.51 $\pm$ 2.16*
Stiffness	4.13 $\pm$ 1.38	7.31 $\pm$ 3.83***	6.60 $\pm$ 3.72**	7.76 $\pm$ 3.60***	6.92 $\pm$ 2.64***

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$  as compared to the lying position.

**Table 2.** Postural sway characteristics during 30-s quiet standing on stable (SG) and unstable ground (USG) without (A) and with (B) simultaneous bilateral measurement of gastrocnemius muscle tone characteristics in young men ( $n = 27$ , mean  $\pm$  SD)

Characteristic <sup>a</sup>	Standing on SG		Standing on USG	
	A	B	A	B
CoP sway in anteroposterior direction, mm	19.3 $\pm$ 6.4	19.7 $\pm$ 6.5	36.7 $\pm$ 9.9*	37.2 $\pm$ 11.4 <sup>#</sup>
CoP sway in mediolateral direction, mm	11.4 $\pm$ 4.1	11.5 $\pm$ 3.9	26.3 $\pm$ 6.3*	28.4 $\pm$ 8.0 <sup>#</sup>
CoP sway length, mm	2863 $\pm$ 322	2888 $\pm$ 324	2969 $\pm$ 336	2967 $\pm$ 307
CoP sway velocity, mm s <sup>-1</sup>	95.5 $\pm$ 10.7	96.3 $\pm$ 11.0	99.1 $\pm$ 11.2	99.0 $\pm$ 10.3
CoP radius, mm	36.2 $\pm$ 6.6	35.3 $\pm$ 5.7	49.6 $\pm$ 7.7*	50.6 $\pm$ 8.0 <sup>#</sup>
CoP area, cm <sup>2</sup>	42.4 $\pm$ 15.9	42.1 $\pm$ 13.3	79.0 $\pm$ 25.0*	82.3 $\pm$ 27.8 <sup>#</sup>

<sup>a</sup> CoP – centre of pressure.

\*  $p < 0.001$  between A and A and <sup>#</sup>  $p < 0.001$  between B and B.

significantly ( $p < 0.001$ ) greater in the case of USG as compared to SG for both measurement conditions.

Comparison of postural sway data during quiet standing with and without measurement of PMT demonstrated that the measurement procedure did not influence postural stability. Neither CoP sway in the AP and ML directions, CoP sway velocity, CoP sway length, radius, or area differed significantly ( $p = 0.30$ – $0.85$ ) between standing on SG and USG with and without PMT measurement.

### **Correlation of the MG muscle tone, elasticity, and stiffness with postural sway characteristics during standing on SG and USG**

At standing on SG, a medium positive correlation was observed between the CV of the frequency of muscle oscillations measured at the beginning of the standing test and the CoP sway area ( $r = 0.38$ ,  $p = 0.049$ ). No significant correlations between other measured characteristics were found.

At standing on USG, medium positive correlations were established between the CoP sway radius and muscle tone and elasticity characteristics (frequency of muscle oscillations and logarithmic decrement of the dampening of muscle oscillations) measured at the beginning of the standing test ( $r = 0.47$ ,  $p = 0.013$  and  $r = 0.51$ ,  $p = 0.007$ , respectively) and at the end of the test ( $r = 0.41$  and  $r = 0.38$ , respectively,  $p < 0.05$  in both cases). Also the CoP sway area showed medium positive correlations with these characteristics both at the beginning ( $r = 0.48$  and  $r = 0.53$ , respectively,  $p < 0.01$  in both cases) and at the end of the test ( $r = 0.39$  and  $r = 0.41$ , respectively,  $p < 0.05$  in both cases).

A medium negative correlation was found between the CV for muscle stiffness at the end of the standing test and CoP sway length as well as CoP sway velocity (in both cases  $r = -0.46$ ,  $p = 0.019$ ). No significant correlations were observed between other measured characteristics.

## **DISCUSSION**

To our knowledge, this is the first paper presenting muscle tone, elasticity, and stiffness in association with postural control characteristics in young men.

The significant difference between the PRMT and PMT characteristics of the MG muscle noted in the present study is in line with the work of Viir et al. (2006b). The CV of PMT was over four times greater during standing as compared to the resting tone. Differences in stiffness characteristics in the present study were similar to tone parameters. The condition of the muscle changes during a postural task; therefore, our results confirm that the muscle tone can be charac-

terized not only by the frequency of muscle oscillations but also through the CV demonstrating the variation of the means of the measured characteristics. Our results demonstrated also that the CV described the balancing of the force moments of body segments caused by the force of gravity to maintain an equilibrium position.

The capacity to maintain postural balance in stance is the base for complex cooperation between the vestibular system, vision, proprioception, and components of the support and movement apparatus, being one part of a greater conception of movement coordination. Improvement of postural control is an important strategy in sports in the prevention of injuries and is vital in physical and rehabilitation medicine (Hahn et al., 1999). It is generally known that constant activation and deactivation of contraction take place in muscle cells during isometric contraction. In case of poorer elasticity of the muscle the maintaining of balance occurs with a greater sway of CoP and the muscle has a greater state of tension. This is also supported by the positive correlation between postural stability (CoP sway radius and area) and muscle tone and elasticity characteristics at standing on USG. Subjectively, walking and running on a soft surface are more difficult as compared with these activities on hard ground. However, this is confirmed also objectively: the energetic cost of locomotion during walking and running on hard surface and on dry sand was measured in ten healthy persons (mean age 24.1 years) and a greater relative increase of oxygen consumption of locomotion on sand was found, which can be explained by greater energy loss from the body and replacement of the energy at each step by the muscles, at an overall muscle–tendon efficiency considerably less on yielding than on hard surface (Lejeune et al., 1998).

In previous studies PMRT was characterized through the natural oscillation frequency of the muscle evoked by the Myoton device's testing probe (Vain, 1995; Hein and Vain, 1998; Veldi et al., 2000; Korhonen et al., 2005). It can be assumed that a tissue that can oscillate has the property of elasticity. Magid and Law (1985) referred to the fact that '...the resting tension of intact skeletal muscle fibers is equivalent to that of mechanically skinned skeletal muscle fibers'. According to Maruyama et al. (1981) and Nave (1990), a large protein called titin plays a significant role in keeping the passive resting tone in the muscles. Recently it was shown that in an atrophied muscle the content of titin, nebulin, and myosin heavy chain is significantly lower (by 13.6%, 29.4%, and 17.7%, respectively) as compared to the control (Aru et al., 2013). In previous publications passive resting tone has been expressed as a single number per a particular investigated muscle, characterizing passive recovery conditions of the skeletal muscle. The skeletal muscle tone can be observed as an indicator of an immediate adaptation

reaction, describing the level of intramuscular pressure that directly determines the blood supply of muscle cells. In a previous study (Vain, 2006) the internal pressure of the biceps brachii muscle (long head) was measured invasively and synchronized with the measurements of the Myoton device during load and in the recovery period. A strong correlation between the internal pressure and the tone of the biceps brachii muscle was found (Vain, 2006).

The PMT plays an important role in maintaining body balance and viscoelastic properties of muscles are important during active movements (dynamic behaviour of viscoelastic materials) (Fung, 1981). In the latter case, resistance to the stretch of antagonist muscles is proportional to the speed of the stretch, the characteristics of the natural oscillation of the muscle (frequency), the dissipative loss of mechanical energy in the muscle, and the mass of the muscle (Remington, 1955; Athanasiou and Natoli, 2008). Regarding muscle elasticity, the values of the logarithmic decrement of the dampening of the oscillation of the investigated muscle did not differ significantly between the PRMT and the PMT. So the present study confirmed the findings of the previous research Gavronski et al. (2007) in which characteristics of tone, elasticity, and stiffness of eight muscles in male triathlon athletes aged 18–19 years were compared and a significant increase of elasticity (in case of a decrease of logarithmic decrement of the dampening of muscle oscillations) for upper extremity muscles (biceps and triceps brachii), trunk muscle (pectoralis muscle), and thigh muscles (rectus femoris and biceps femoris) was noted in the contracted state as compared to the relaxed state while no changes between these states for the tibialis anterior and gastrocnemius muscle were found.

Earlier studies demonstrate that the electromyographic activity of posture-maintaining lower extremity muscles is very low at lying and sitting but also during standing (Tokuno et al., 2007; Tikkanen et al., 2013). It is suggested that passive structures – the connective tissue and fascias – play an important role in postural stability. Perrin et al. (2002) studied 21 men and 21 women aged 20–34 years and did not find any differences either in dynamic or static postural stability characteristics that could be correlated with gender. In a study of patients with ankle trauma, a significant decrease in the postural sway was found in the quiet standing test (with eyes closed); this indicates a trauma-induced postural sway disturbance, caused by worsened perception and deficiency in proprioception (Akbari et al., 2006). Depending on the training type, the related influence can also appear more on one side of the body when the activity is asymmetrical. The quality of postural control improves according to the training type (Tai Chi, karate) (Guillou et al., 2007; Filingeri et al., 2012; Vando et al., 2013).

During the static standing test on an USG positive correlations were found between the CoP sway area and PMT characteristics (frequency of muscle oscillations and logarithmic decrement of the dampening of muscle oscillations). In case of poorer elasticity of the muscle (value of logarithmic decrement of the dampening of muscle oscillations is greater) the maintaining of balance occurs with a greater CoP sway and an increase of the muscle tautness. This is further confirmed by the positive correlation between the CoP sway area and the CV of muscle stiffness at the end of the standing test. In the present study we did not find significant differences in the characteristics of muscle tone, elasticity, and stiffness measured at the beginning of the standing test as compared to the end of the test on either surface. This can be explained by the fact that the participants were healthy physically active young men. Previously a significantly higher frequency of the muscle oscillations of the tibialis anterior muscle and greater values of the stiffness of the tibialis anterior and MG muscles (9.3% and 10.6%, respectively) were noted in young ballerinas aged 14 years who had had foot, ankle, or knee problems in anamnesis 2–24 months before the testing as compared to healthy age-matched ballerinas (Gapeyeva et al., 2005). Future studies might focus on comparing associations of postural control and muscle tone characteristics in healthy persons and in persons with an injury of a lower extremity.

The bilateral measurement procedure with the Myoton-3 device performed simultaneously with the postural sway measurement did not change significantly postural stability characteristics (CoP sway in the AP and ML directions, sway length, velocity, radius, and area) during the 30-s quiet standing test in both conditions (standing on SG and USG) as compared to analogous data without simultaneous PMT measurement.

## CONCLUSIONS

The main findings of the present study were as follows: (1) tone and stiffness characteristics of the MG muscle were significantly higher in the standing position compared to the supine position. No differences occurred in elasticity. Neither surface nor standing time had any significant influence on the average values of these parameters but affected significantly their variability (CV); (2) the CV of the frequency of muscle oscillations was by 403% greater at standing on SG and by 471% greater at standing on USG as compared to the lying position; (3) postural stability characteristics (CoP sway radius and area) correlated positively with muscle tone and elasticity characteristics when standing on USG, and greater variability of stiffness of the MG muscle was associated with a greater CoP sway length and

velocity; (4) the muscle tone measurement procedure using the Myoton-3 device did not influence postural stability during a 30-s quiet standing on either on SG or USG.

It can be recommended that new criteria be used for muscle function investigation in relation to postural stability (coefficients of variation of measured characteristics).

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## Kaksik-sääremarjalihase toonuse, elastsuse ja jäikuse seosed asendikontrolli näitajatega noortel meestel

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Töö eesmärgiks oli uurida kaksik-sääremarjalihase (MG) toonuse, elastsuse ja jäikuse ning asendikontrolli näitajate seoseid noortel meestel. Uuritavateks olid 27 kehaliselt aktiivset meest vanuses 17–31 aastat (pikkus 172–195 cm ja kehakaal 64–87 kg). MG toonus (lihase võnkesagedus) ja biomehaanilised omadused (lihase elastsus, mida isoleerustatakse lihase võnkumise kustumise logaritmilise dekremendi kaudu, ning lihasjäikus) määrati bilateraalset, kasutades portatiivset seadet Myoton-3 (Müomeetria OÜ, Eesti). Asendikontrolli näitajad (survetsentri kõikumine) registreeriti 30-sekundilisel seismisel Kistleri jõuplatvormi stabiilsel ja ebastabiilsel pinnal (Airexi tasakaalumatil). Lamamisasendiga võrreldes (vastavalt 162% ja 166% ning 199% ja 203%) nähtus nii stabiilsel kui ka ebastabiilsel pinnal seismisel MG toonuse ning elastsuse näitajate märgatav suurenemine, kusjuures lihase elastsuse näitaja ei erinenud nendes asendites oluliselt. Lamamisasendiga võrreldes ilmnas stabiilsel ja ebastabiilsel pinnal seismisel suurem variatsioonikoefitsient nii lihase toonuse (vastavalt 403% ja 471%), jäikuse (vastavalt 177% ja 187%) kui ka elastsuse (vastavalt 120% ja 122%) näitajate osas. Oluline positiivne korrelatsioon esines seismisel registreeritud survetsentri kõikumise raadiuse ja pindala ning MG toonuse ja elastsuse näitajate vahel. Tööst järeldub, et lamamisasendiga võrreldes suurenevad seismisel MG toonus ja jäikus, aga lihase elastsus ei muutu oluliselt. Lihase toonuse uurimisel on soovitatav seisundi hindamiseks täiendavalt kasutada registreeritud näitajate variatsioonikoefitsienti.