

LOWER CORRELATION BETWEEN BICEPS FEMORIS CONTRACTION TIME AND MAXIMAL RUNNING SPEED IN CHILDREN THAN IN ADULTS: A LONGITUDINAL STUDY IN 9- TO 14-YEAR OLD CHILDREN*

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ABSTRACT

Biceps femoris is a major propulsor muscle in sprinting and its contraction time negatively correlates to the running speeds of adults. Our aim was to compare age- and gender-related correlations between vastus lateralis and biceps femoris contraction times and running speeds during a longitudinal study of 9- to 14-year old children. On a yearly basis, we conducted vastus lateralis and biceps femoris tensiomyographic measurements of muscle contraction time and maximal running speeds measured during 7-metre sprints with flying starts using photocells in 107 children (of which 53 boys). Vastus lateralis contraction time was not correlated with the running speed. However, biceps femoris contraction time was negatively correlated with the running speed only in boys after the age of 12.9 years (Pearson r ranges from -0.391 to -0.426; $p <$

* The paper has been previously published in the hijacked journal *Wulfenia* (Vol. 22(1): pp. 233–252, January 2015). The editor has been notified and he fully agrees with the publication in *Annales Kinesiologiae*. The paper has been modified, double-blind peer reviewed and only then accepted for publication.

0.002). It was concluded that biceps femoris contraction time is far less correlated with running speed than in adult athletes (Pearson $r = -0.60$); however, the correlation is gender- and age-specific. It seems that the knee flexor and hip extensor, biceps femoris, is not as yet the major determinant of running speed in 9- to 14-year old children at that age.

Keywords: skeletal muscle, biceps femoris, vastus lateralis, tensiomyography, pediatrics.

KORELACIJA MED ČASOM KRČENJA MIŠICE BICEPS FEMORIS IN HITROSTJO ŠPRINTA JE PRI OTROCIH NIŽJA KOT PRI ODRASLIH: LONGITUDINALNA ŠTUDIJA 9- DO 14-LETNIH OTROK

IZVLEČEK

Skeletna mišica biceps femoris je pomembna za propulzijo v fazi odziva med tekom in vemo, da je njen čas krčenja negativno povezan z maksimalno hitrostjo teka pri odraslih moških. Zato smo si za cilj zastavili, da preverimo povezavo med časom krčenja mišic vastus lateralis in biceps femoris pri otrocih, glede na spol in starost. V longitudinalni 5-letni študiji smo spremljali 107 otrok (53 dečkov) s periodično letnimi meritvami telesnih značilnosti, maksimalne hitrosti teka in kontraktilnih lastnosti omenjenih mišic z uporabo Tenziomiografije. Otroci so bili na začetku stari 9 let in na koncu 14 let. Ugotovili smo, da čas krčenja mišice vastus lateralis ni povezan z maksimalno hitrostjo teka. Medtem, ko je bil čas krčenja mišice biceps femoris negativno povezan z maksimalno hitrostjo teka, a le pri dečkih po 12.9 letu starosti (Pearsonov r med -0.391 in -0.426 ; $p < 0.002$). Zaključimo lahko, da je čas krčenja mišice biceps femoris bistveno manj povezan z maksimalno hitrostjo teka pri otrocih, kot pri odraslih (Pearsonov $r = -0.60$). Sklepamo lahko, da mišica biceps femoris pri tej starosti otrok še ni poglavitni dejavnik maksimalne hitrosti teka.

Glavne besede: skeletna mišica, biceps femoris, vastus lateralis, tenziomiografija, pediatrija

INTRODUCTION

Nowadays, we are faced with fast lifestyle as a society, which influences individuals' health, social, cultural, and physical statuses. Children are one of the more vulnerable groups within a society. Therefore, we should pay special attention to their development. Childhood is a very sensitive period and is, in general, characterized by various dynamic changes in physiological and psychological development, as well as the establishment of healthy or unhealthy behaviour (Faigenbaum & Myer, 2012). As a result of global health trends, there is a growing interest in children's physical exercise; and, thus, consequently in their body growth and development.

Tensiomyography (TMG) is a non-invasive tool for the assessment of skeletal muscle contractile properties (Valenčič & Knez, 1997) which are related to muscle composition (Dahmane, Valenčič, Knez, & Eržen, 2001; Šimunič et al., 2011). Rodríguez Ruiz, et al. (2011) performed a study amongst 84 males who were divided into four age groups; teenagers, undergraduate students, adults and the elderly, and discovered a decline in V_m (tensiomyographically determined normalized muscle twitch response velocity, contraction time / amplitude of radial displacement) in the vastus lateralis in relation to age. In contrast, V_m values in biceps femoris (BF) did not change between age groups; although, the value was slightly reduced in the older age group. Furthermore, the researchers noted that changes in muscle composition are associated with the physical activity levels of individuals and, therefore, the changes in muscle response may not only depend on age but also on the amounts and types of physical activity (Rodríguez Ruiz et al. 2011).

There is great interest in muscle composition; however, it is more than evident that the invasiveness of the approach used in this research field is the main drawback for obtaining data on muscle composition as a representative sample. Further, the more common muscle to be observed by its composition is the vastus lateralis. Additionally, there is also a huge interest in other muscles that are even more important in childhood for children's health, posture, and motor development. However, sample sizes are rather small and longitudinal studies are very rare. Valenčič and Knez (1997) proposed a non-invasive and selective TMG where several TMG contractile parameters were defined (Valenčič & Knez, 1997), and where contraction time was later correlated to a proportion of slow-twitch muscle fibers within skeletal muscle (Dahmane et al., 2001; Dahmane, Djordjević, Šimunič, & Valenčič, 2005; Šimunič et al. 2011). The TMG contractile parameters were found to be highly reliable (ICC $r > 0.85$; Šimunič, 2012).

Oliver, Lloyd, and Rumpf (2013) claimed that sprinting speed is one of the distinguishing indicators of successful motor performance in children and is developed throughout childhood and adolescence, as children grow and mature. Indeed, a failure to master sprinting may be an enormous barrier preventing children from gaining more complex physical activity skills. These authors also suggest that speed during this period is developed in a nonlinear manner due to the large maturational influence associated with increases in limb lengths, increased muscle mass, and changes in intrinsic muscle-tendon properties. Additionally, gender differences in speed development become

apparent at the onset of puberty, with girls making limited gains in speed throughout adolescence, contrary to boys for whom large gains in speed could be observed. These authors also noted paucity of research studies on speed and muscle development for the above pediatric population (Oliver et al., 2013).

Therefore, we aimed at analysing the correlation between vastus lateralis and biceps femoris contraction time with maximal running speed and, furthermore, at establishing how contraction times of both abovementioned muscles are related to standard anthropometric measures (body height and mass, ROHR index) at different ages and sexes.

METHODS

Participants

Recruitment of participants started in September 2001 in three different Slovenian regions: Ljubljana region, Maribor region, and the Primorska region. Primary schools in these regions were randomly selected. Therefore, the participants come from five different Slovenian towns (Table 1), two of which are major cities covering central and northeast Slovenia, and three small towns covering the coastal region. In this way, we ensured that the sample covered the whole of Slovenia.

Table 1. Selection of regions, primary schools and towns included in the 5-year longitudinal study.

City	Primary School	Town
Ljubljana region	Tone Čufar	Ljubljana
	Valentin Vodnik	Ljubljana
	Dr. Vito Kraigher	Ljubljana
Maribor region	Prežihov Voranc	Maribor
	Slava Klavora	Maribor
	Tone Čufar	Maribor
Primorska region	Anton Ukmar	Koper
	Vojka Šmuc	Izola
	Ciril Kosmač	Piran

Researchers organized short workshops for the school head teachers, physical education teachers, the children, and their parents, with the aim of presenting the purpose and the aims of the research study, the research design, to present the measurement protocols and tools, and to invite potential participants. Throughout the workshop execution, the researchers were available for answering any questions which might occur during the session in order to clarify any dilemmas regarding the study.

In regard to the recruitment process, 300 children in total were selected (100 children from each region), of which 265 children participated in the baseline study (138 boys, 127 girls). In the first follow-up study, 263 children (125 boys, 138 girls) participated, in the second follow-up study 252 children (127 boys, 125 girls), in the third follow-up study 179 children (98 boys, 81 girls), in the fourth follow-up study 175 children (98 boys, 77 girls), and in the last the fifth follow-up study, there were 176 children (96 boys, 80 girls). To summarize, 107 children (53 boys, 54 girls) (initial measurement average age 9.1 ± 0.5 years) who had completed all six longitudinal measurements were selected for the analysis. At the baseline, the study participants attended the third grade of primary school and at the last follow-up study they attended the eighth grade.

The selection process was performed by researchers with the support of teachers in a manner which prevented any possible bias (i.e. gender, geographical distribution, anthropometrical characteristics). However, children eligible to participate in this study had to be in good health. None of the children had had any history of neuromuscular disorders or muscle diseases. During the recruitment process and before carrying out any research study at the baseline or follow-ups, the participants and their parents were informed that any participation in the study was strictly on voluntary basis. Additionally, they were informed that the participants could withdraw from the study at any time and for any reason, and that the collected data would only be used for the research purposes. Therefore, the parents of the children gave their written consent for them to participate in the study. Moreover, all procedures conformed to the 1964 Declaration of Helsinki and were approved by the National Medical Ethics Committee of the Republic of Slovenia.

The organizational settings of the conducted longitudinal study were the same within all three regions.

Procedures

The 5-year-long research was conducted once per school year from 2001 till 2006, and it included single-point quantitative research studies and the following measurements of:

- anthropometrical characteristics;
- contractile properties of skeletal muscles; and
- running speed.

Measurements of Anthropometrical Characteristics

Participants' body masses and heights were measured by using standard tools. The body mass was measured to an accuracy of 0.1 kilograms, while the height was measured to an accuracy of 0.5 centimetres. All participants were barefoot and wearing their sportswear during the measurements. On the basis of the measured variables, each body mass index (ROHR's index) was calculated. ROHR's anthropometric index is a statistical data, which combines a participant's height and mass into a metrical form. Actually, both ROHR's as well as the body mass index (BMI), serve the purpose of classifying individuals into categories of underweight, normal, and obese. BMI measurement projects a two-dimensional square state by measuring the mass per square unit of surface area, while ROHR's index assumes that the body is a three-dimensional cube and, therefore, measures the mass per cubic unit of volume. ROHR's index takes into account both the width and circumference, unlike BMI which projects that the breadth and scope of an individual is proportional to his / her height. ROHR's index was, therefore, chosen as a better indicator of the children's and adolescents' nutritional statuses (Foster, Voors, Webber, Frerichs, & Berenson, 1977; Kokol et al., 1992; Omura, Zinno, Harada, & Inoue, 1993; Freedman & Perry, 2000). The measurements of anthropometrical characteristics were performed on three sport science students.

Measurements of Contractile Properties of Skeletal Muscles

The contractile properties of their skeletal muscles were measured using the TMG method. TMG detects radial displacement of the skeletal muscle belly during maximal isometric twitch contraction (Valenčič, 1990), and has been developed in the Laboratory for Skeletal Muscles and Biomedical Imaging (LBM) at the Faculty of Electrical Engineering, University of Ljubljana, Slovenia. Measurements were performed on two muscles vastus lateralis and biceps femoris of leg-dominant sites. Measurements on the vastus lateralis were performed in supine positions at knee angles set at 30° knee flexion, where 0° represents the extended joint. Measurements on the biceps femoris were performed in prone positions at a knee angles set at 5° knee flexion. A measured muscle was in a relaxed predefined position and muscle contraction was evoked by brief electrical stimulus. To this end, we used a pair of self-adhesive stimulation electrodes (Axelgaard, Pals) within this study with a diameter of 50 millimetres. The muscle was measured in a bipolar way in that we installed the negative electrode (cathode) 5 cm distal, and the positive electrode (anode) 5 cm proximal to the measurement point. The measuring point was selected at a place where the belly muscle was the largest and additionally ensured that the selected place was between the two electrodes. In doing so, we used the experimental measurements, palpation and re-installing the electrodes and sensors if needed. Due to the fact that each muscle has its own specific anatomic structure, we had to make adjustments according to the locations of the measuring equipment. The sensor was set perpendicular to the skin overlying the muscle belly: in vastus lateralis at 30 % of the femur length above the patella on the lateral side; in biceps femoris at the midpoint of the line between the fibula head and the ischial

tuberosity. In order to elicit twitch contraction, we used a single one-millisecond pulse applied through the cathode and the anode. The stimulation current at the start was just above the contraction threshold and then it was gradually increased until the response amplitude did not increase any further. Two maximal twitch responses were recorded and saved.

The maximal displacement amplitude and the contraction times were calculated from each twitch response, as proposed by Valenčič (1990) and Valenčič and Knez (1997). Maximal displacement amplitude (D_m , in millimeters) was defined as the peak amplitude on the displacement-time curve of the TMG twitch response. The contraction time (T_c , in milliseconds) was the time from 10 % to 90 % of D_m being reached. The average value of these parameters, extracted from two twitch responses, was used for further analysis. TMG measurements were performed by an expert from the field of electrical engineering and computer science, four physical education teachers, and five undergraduate sport sciences students. The measurements were supervised by a medical doctor.

Measurement of the Running Speed

Prior to testing the maximal running speed, all the children were appropriately warmed up, which lasted approximately 20 minutes. The warm-up process was composed of running (5 minutes), stretching (5 minutes), and warm-up running practices (10 minutes). The children's warming-up process was always conducted by the same person and by using the same procedure. Each participant had the opportunity of two experimental sprints. Maximal running speed was measured at a distance of 7 meters from a flying start. During the measurement process, the participants performed preliminary runs, then followed the first photocell checkpoint, and after 7 meters the second photocell checkpoint.

We divided up the running distance of 7 meters to include a sprint time from which we calculated the sprint speed. Each participant repeated the sprint twice and the better result was used in the further analysis. Maximum running speed was measured by using a wireless Brower measurement system (Brower Timing Systems Ltd., USA).

Design and Measures

Detailed description of all study procedures and design are presented in Figure 1. We performed six repeated measurements of the children's progress from the third to the eighth grade of their primary schools. Every measurement was performed using the same procedure. A week before the study, each school was notified to follow a specific protocol prior to the measurement, namely, that all major physical or sport activities were discouraged two days before the measurement. All the recruited participants were invited to participate at each study / measurement. A detailed description of the recruitment and data collection is presented in Figure 1.

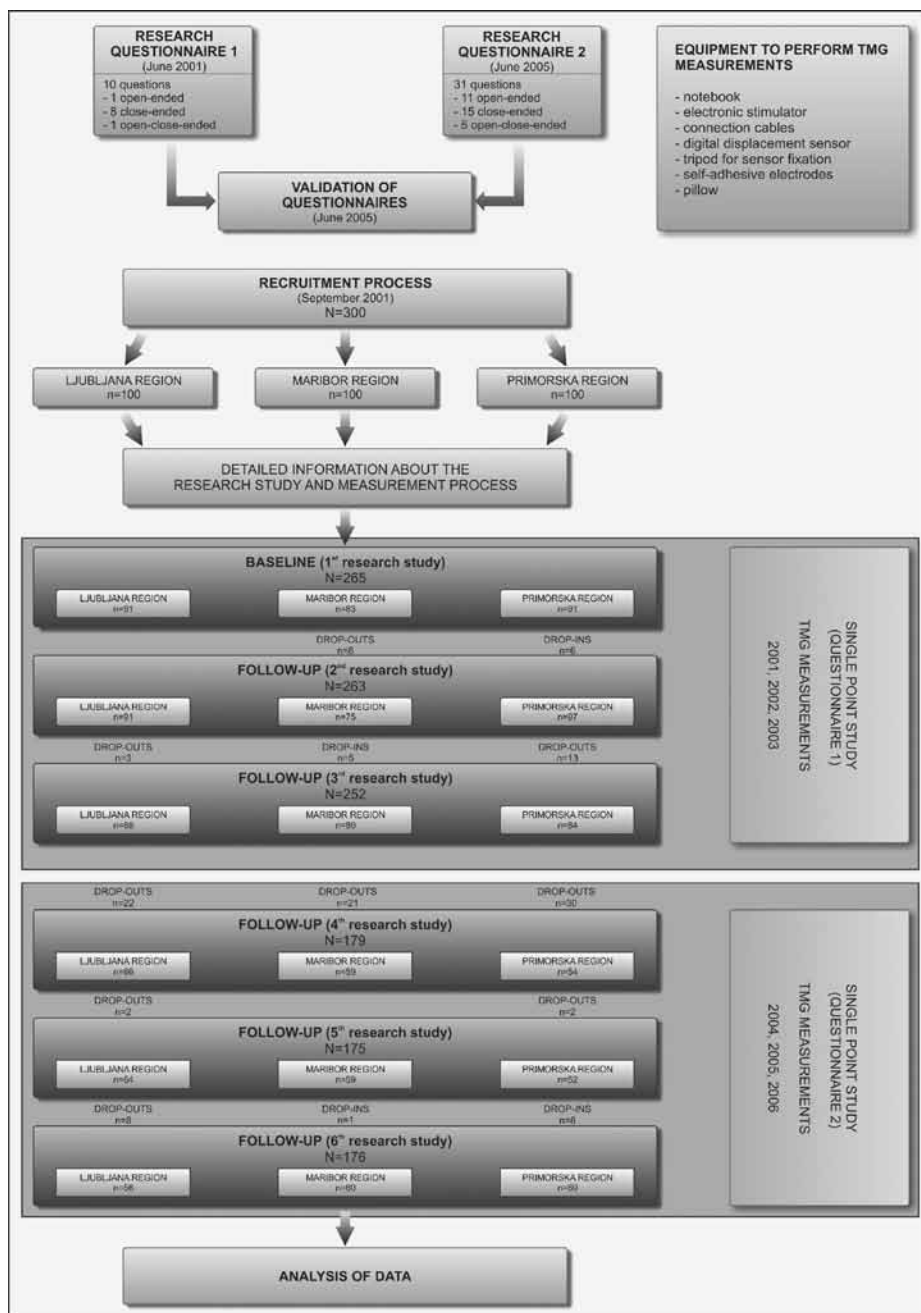


Figure 1. Flowchart of recruitment and data collection procedure

Data Analysis

All data are expressed as means \pm standard deviations. For all variables, the hypothesis of a normal distribution was tested and confirmed using visual inspection supported by D'Agostino's normality procedure and Kolmogorov-Smirnov test. Morphologic growth was analyzed by 2-way RM ANOVA, with age as a repeated measure and gender as a fixed group. For correlating vastus lateralis and biceps femoris Tc with running speed, a Pearson correlation coefficient was calculated. Statistical significance was accepted at $p < 0.05$ level.

RESULTS

Background of the Participants

In all six-measurement points in total, 107 participants being included; their average age, body height and body mass is shown in Table 2.

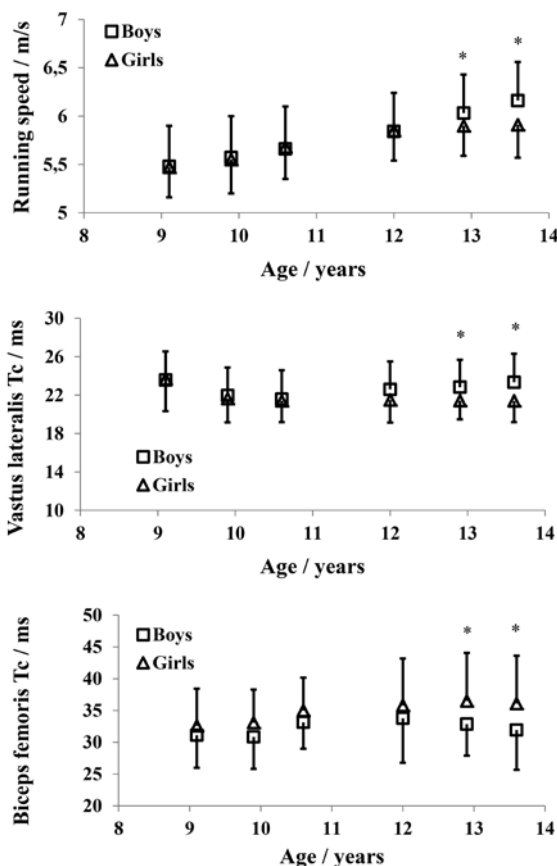
Table 2. Longitudinal descriptive anthropometrical data of 53 boys and 54 girls at different age.

Age / years	Body height / cm		P	Body mass / kg		P	ROHR's index / kg / m ³		P
	Boys	Girls		Boys	Girls		Boys	Girls	
9.1 \pm 0.5	139.6 \pm 6.5	139.5 \pm 7.2	0.905	34.9 \pm 7.2	32.7 \pm 6.8	0.110	12.7 \pm 1.78	12.0 \pm 1.66	0.025
9.9 \pm 0.5	143.4 \pm 6.9	143.5 \pm 7.5	0.962	37.8 \pm 8.2	36.1 \pm 7.5	0.257	12.7 \pm 1.96	12.1 \pm 1.70	0.097
10.6 \pm 0.5	147.6 \pm 7.2	148.4 \pm 7.6	0.602	39.5 \pm 8.8	37.4 \pm 7.8	0.188	12.2 \pm 1.88	11.3 \pm 1.54	0.015
12.0 \pm 0.5	156.5 \pm 7.9	158.4 \pm 7.5	0.215	48.5 \pm 10.8	45.8 \pm 9.0	0.160	12.5 \pm 1.92	11.4 \pm 1.59	0.002
12.9 \pm 0.5	162.6 \pm 8.1	162.4 \pm 6.9	0.883	53.5 \pm 11.6	50.7 \pm 9.3	0.166	12.4 \pm 2.12	11.8 \pm 1.68	0.109
13.6 \pm 0.5	167.2 \pm 8.0	164.5 \pm 6.5	0.058	56.8 \pm 11.7	54.3 \pm 8.7	0.016	12.1 \pm 1.96	11.6 \pm 1.49	0.162

Child anthropometrical growth could be classified as normal, following general trends. There was a significant age effect on body height ($p < 0.001$), body mass ($p < 0.001$) and ROHR's index ($p < 0.001$) with a significant age \times gender interaction effect on body height ($p < 0.001$), body mass ($p = 0.028$), and ROHR's index ($p = 0.026$).

Vastus lateralis and biceps femoris Tc and running speed correlation analysis

In Figure 2, a descriptive data for vastus lateralis and biceps femoris Tc is presented, as well as for maximal running speed for both muscles and genders. In Tables 3 and 4, a correlation analysis is presented for both muscles and genders. We found sex-related differences only after the age of 12.9 years in all three presented variables. Furthermore, a longitudinal trend reveals that there was no significant correlation between running speed and vastus lateralis Tc; however, significant negative correlation for biceps femoris Tc and running speed could be confirmed in boys after the age of 12.9 years (Figure 3).



* $p < 0.05$ between sexes

Figure 2: Longitudinal descriptive analysis for vastus lateralis and biceps femoris contraction time (Tc) and maximal running speed.

Table 3. Pearson correlation between vastus lateralis contraction time and running speed.

Age / years	Boys		Girls	
	Pearson r	p	Pearson r	P
9.1 ± 0.5	-0.048	0.367	-0.033	0.408
9.9 ± 0.5	-0.062	0.331	-0.053	0.352
10.6 ± 0.5	-0.118	0.201	-0.070	0.309
12.0 ± 0.5	-0.167	0.115	0.037	0.396
12.9 ± 0.5	-0.170	0.112	0.351	0.399
13.6 ± 0.5	-0.172	0.109	0.043	0.380

Table 4. Pearson correlation between biceps femoris contraction time and running speed.

Age / years	Boys		Girls	
	Pearson r	p	Pearson r	P
9.1 ± 0.5	0.118	0.200	0.130	0.175
9.9 ± 0.5	-0.021	0.441	-0.020	0.390
10.6 ± 0.5	-0.195	0.081	0.085	0.270
12.0 ± 0.5	-0.177	0.097	0.128	0.178
12.9 ± 0.5	-0.426	0.001	0.117	0.200
13.6 ± 0.5	-0.391	0.002	0.125	0.182

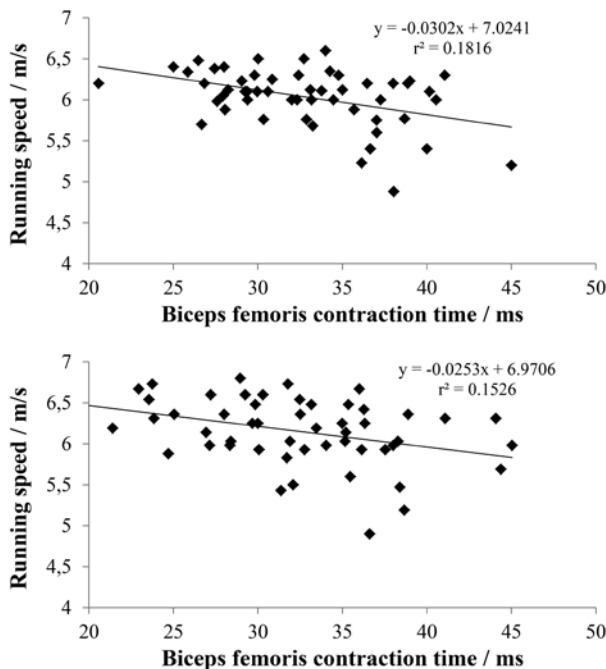


Figure 3: Pearson correlation for biceps femoris contraction time (T_c) and maximal running speed at age 12.9 (left) and 13.6 (right) years.

Correlation between body mass, height, ROHR index, and T_c of vastus lateralis and biceps femoris

While the TMG measurement tool or running speed measurement equipment are not readily available to parents, average school sports teachers or sport club trainers, we decided to analyse how simple anthropometrical measures like mass, height and ROHR's index are correlated to T_c of vastus lateralis and biceps femoris muscles to enable them to have some indicators for predicting the muscle developments and sport talents of young adolescents. Table 5 presents the correlations between body mass, height, and the ROHR index and the T_c of biceps femoris and vastus lateralis muscles for all six measurement points (baseline and 5 follow-up studies). It is evident, that the correlations between the contraction times of the vastus lateralis muscle and the anthropometrical measurements is more frequent than for the BL muscle. To be precise, at least one anthropometrical measurement correlated with the contraction time of the vastus lateralis muscle for the 4th till 6th measurement points. On the contrary, the biceps femoris muscles contraction times are more correlated with anthropometrical measures

at the baseline and the first and the second follow-up compared to the third, the fourth and the fifth follow-up studies.

Table 5. Significant correlations between body mass, height, ROHR index, and contraction time of biceps femoris (BF) and vastus lateralis (VL) muscles.

Average age / years		9.1 ± 0.5	9.9 ± 0.5	10.6 ± 0.5	12.0 ± 0.5	12.9 ± 0.5	13.6 ± 0.5
	Anthropometrical measurements						
9.1 ± 0.5	Body mass	-BF			+VL	+VL	+VL
	Body height				+VL	+VL	+VL
	ROHR index	-BF					-BF
9.9 ± 0.5	Body mass				+VL	+VL	+VL
	Body height				+VL	+VL	+VL
	ROHR index	-BF	-BF				-BF
10.6 ± 0.5	Body mass				+VL	+VL	+VL
	Body height			+VL	+VL	+VL	+VL
	ROHR index	-BF			-BF		-BF
12.0 ± 0.5	Body mass				+VL	+VL	+VL
	Body height				+VL	+VL	+VL
	ROHR index	-BF					-BF
12.9 ± 0.5	Body mass	-BF	-BF		+VL		-BF, +VL
	Body height		+VL		+VL	+VL	+VL
	ROHR index	-BF			-BF		
13.6 ± 0.5	Body mass	-BF	+VL		+VL	+VL	-BF, +VL
	Body height		+VL	+VL	+VL	+VL	+VL
	ROHR index	-BF			-BF		-BF

Interestingly, the ROHR's index is obviously a better predictor of contraction times for biceps femoris muscles compared to mass and height, indeed, it only correlates with biceps femoris muscles and not in any instance to vastus lateralis muscles. On the other hand, the height is a better predictor for the vastus lateralis muscle contraction time than the mass.

DISCUSSION

Our longitudinal study contributed with an insight into children's skeletal muscle development, focusing on skeletal muscle composition. Using a non-invasive TMG, we assessed muscle composition related to the contractile parameter (Tc) in two skeletal muscles. Although there were initially 263 children included in the study, representative subsamples of 107 children (42 %) were present in all six measurements. TMG assessment requires electrical stimulus to evoke muscle contraction and some of the children found this as being less appropriate for them and so they were not forced to cooperate during the measurement. This was also the main reason for not performing the TMG assessment. Other reasons were illness or injury, absence from school, changing schools, etc. Skeletal muscle composition is very difficult, if not even ethically impossible, to measure in healthy children. Therefore, using a non-invasive approach we presented age- and gender-related longitudinal trends in Tc in the two skeletal muscles.

There are numerous data about vastus lateralis composition in adults but only few in children (Bell, MacDougal, Billeter, & Howald, 1980) and in adolescents (Glenmark, Hedberg, & Jansson, 1992). Johnson, Polgar, Weightman, and Appleton (1973) reported 37.8 % and 46.9 % at muscle surface and deep site, respectively. In a longitudinal study, Glenmark et al. (1992) found different developments of fibre type composition with increased age from 16 to 27 in women and men: the type I percentage tended to increase in the women from 51 % to 55 % and decrease significantly in the men from 55 % to 48 %. Fibre cross-sectional areas remained unchanged in both genders. They suggested gender-related fibre type 1 adapted during increased age. In children, Bell et al. (1980) found 58.8 % type1 fibers and concluded that the distribution patterns and ultra-structures of skeletal muscles in six-year-old children was not different from normal adult tissues. However, this study showed no correlation between vastus lateralis contraction time and running speed in both sexes at any age, which is rather logical since the fact that vastus lateralis muscle is not the most important muscle for maximal running speed (Praprotnik, Valenčič, Čoh, & Šimunič, 2002). However, from this study we also found positive proportional correlations between the contraction time of the vastus lateralis muscle and anthropometrical measurements (i.e. body mass, body height) in children older than 12.0 ± 0.5 years; meaning that heavier and taller participants have shorter contraction times for the vastus lateralis muscle.

Vastus lateralis muscle

In the lateral muscle of the knee extensors on the dominant side, we found that the contraction time changes with age, in boys faster than in girls. In boys, according to the third grade results (at the baseline) we found significantly lower contraction times in the fourth and the fifth grades, while in girls we measured significantly lower contraction times in the sixth and the seventh grades. A short contraction time means that the muscle is faster in younger boys than in girls. Differences between correlations according to sex showed significant deviations; meaning that the girls in the seventh and eighth grade had shorter contraction times, due to the fact that their outer knee extensor muscles on the dominant side were faster during this period of time.

Vastus lateralis muscle is an anti-gravitational muscle and as such receives a lot of mechanical stimuli for its adaptation – hypertrophy. Shorter contraction times in the fourth and the fifth grades were witnesses to increasing in physiological cross-section of the rapid muscle fibres, which may be the answer to the intense movement triggered by muscles in the legs. However, the subsequent extension of Tc does not confirm the long age-range. One of the possible causes for an extension of the period Tc in the 6th grade can be with age and physical habits associated with an increase of the pennation angle of the muscle fibres and, thus, less effective transfer of forces to the tendons or bone. In the more pennant muscles, the forces are transferred slower to the attachment of the bone. We assume also that the cause of the extension of Tc in the period from the 6th to 8th grades could be a less active lifestyle at this age. Differences in girls during this period of age could be explained by developmental delay, which is also identified in the speed of sprint.

Biceps femoris muscle

Analysis of the biceps femoris muscles on the dominant side of the body showed that the times of contractions varied with the ages of the children. However, post hoc analysis did not show significant variations in the boys belonging to the third grade. The girls belonging to the third grade did have significant longer contraction times in the fifth, sixth, seventh and eighth grades. Analysis by sex showed significant deviations, namely that the girls had longer contraction times in the seventh and eighth grades, which means that girls compared with boys have slower biceps femoris during the second half of elementary school.

Biceps femoris is not an anti-gravitational muscle and, therefore, there has little everyday mechanical stimuli. This alone can explain the longer Tc versus vastus lateralis muscle. It is interesting that the Tc observed in girls extends through this period, while in boys only to the sixth grade and then it decreases again. This finding coincides with the kind of changes in muscle biceps femoris, which can be confirmed by the characteristics of the life-style, since boys use their legs more from a certain age, while the girls use their hands more. The biceps femoris muscle is used mainly

during various high-speed runs, changing directions, jumps, the trends of which are more typical of boys.

The relation between the contractile properties of the vastus lateralis and biceps femoris skeletal muscles and the maximum running speed

In order to see the connection between the contractile properties of the skeletal muscle and the maximal running speed, we first present the development of the maximal running speeds and the contraction times of the vastus lateralis and the biceps femoris, by age:

- maximal running speed of the boys over the whole measurement period grew, while for the girls it only grew up to the seventh grade;
- the contraction times of the vastus lateralis first declined to the fourth grade and later went upwards, significantly more in boys than in girls;
- the contraction times of the biceps femoral increased over the whole measurement period.

Analysis of the results showed that there was a significant negative correlation between the maximal running speeds and the contraction times of the biceps femoris in boys. This relationship was characterized only from the sixth to the eighth grade and amounted to between -0.21 and -0.29. Regression analysis of the variance showed that the correlation was relatively low, as it was represented by only 8.4 % of the explained variance. As for the girls, the correlation was not determined during any of the measurement period. There was also no evidence found of any correlation between the maximal running speeds and the contraction times of the vastus lateralis, neither in boys nor in girls.

A negative correlation was found confirming that there was a significant correlation between the biceps femoris and the maximum running speed. It is known that the period between the ages 6 to 11 years, or the early school period, as we like to call it, is the most suitable period for the development of children's motor potentials and the learning of movement patterns. The child learns new movement techniques very quickly and without much effort (Shaffer & Kipp, 2009; Koffka, 2002). When children develop coordination, they also change their ways of running. It seems that boys run technically more correctly and they do include a biceps femoris during the running process. The correlation though was only -0.29 but this was the result of poor technique just at the start of a proper running process. In the study (Praprotnik et al., 2002), the correlation between the femoral biceps muscle and the maximum speeds of the adult athletes was studied, specifically male sprinters. They found a correlation of -0.60. A greater coherence was the result of optimal running using a proper technique and by taking advantage of the biceps femoris muscle. In the girls, we did not detect correlations, which can be attributed to their later motor development. Dolenc and Pistotnik (2001) found that in most tests of coordination boys perform better than girls. At the age of 8 or 9, the only statistically significant differences between sexes occur in their capacities to

carry out rhythmic structures, namely, in the benefit of girls, meaning that during this period the girls are not using the biceps femoris as much as boys. It is also true that to date there is no known correlation with adult female sprinting events.

Gender differences in the contraction times of vastus lateralis and biceps femoris skeletal muscles and the maximal running speeds

After identifying the impact of regular sporting activity on the maximal running speed and to the biceps femoris, we checked if the contraction time of the skeletal muscle and maximal running speed differed between the sexes. We found that:

- contraction times of the skeletal muscle were significantly different between the sexes. Throughout the period of the measurements, the following were discovered: vastus lateralis contraction time is shorter in girls, while contraction time of the biceps femoris is shorter in boys;
- maximum running speed differs between sexes where boys reach a higher maximum speed of running than girls. Significant differences were not confirmed only at the age of 10 to 12 year olds.

The vastus lateralis muscle has shorter contraction time in girls during the period of the seventh and eighth grade. In reviewing the periods in which the muscles in girls are faster than in boys, the question appears as to the impact of growth and maturing of the nervous system. It is known that the myelination of the nervous system is crucial for the responsiveness of the muscles, significant differences in the speed of muscle coincides with the so-called blast growth in the middle and late childhood and adolescence (Tomazo-Ravnik, 2004). The period of late childhood, which is from the age of 7 to 10 for girls and from the age of 7 to 12 for boys, is characterized by rapid linear growth of the limbs. The following growth surge occurs during adolescence, beginning with pre-puberty and lasts for about two years, from 11 to 13 years of age in girls and from 12 to 14 years of age in boys. At this stage, a rapid increase occurs in some of the dimensions of the body. Faster growing and maturing of girls could have an impact on their faster muscle responses.

Boys had higher maximal running speed, significantly in the seventh and eighth grade. The exception was in the fifth and sixth grades, where girls were faster but it was not significant.

The previous study (Praprotnik et al., 2002) that was also confirmed by our findings, reported that the biceps femoris muscle was correlated to the maximal running speed ($r = -0.60$). Furthermore, they reported also significant correlation for gastrocnemius lateralis Tc with a maximal running speed ($r = -0,39$) and even bigger correlation was found between half relaxation time of biceps femoris with a maximal running speed ($r = -0.66$). It seems that time-based contractile parameters assessed using TMG are negatively related to maximal running speed. The study of Praprotnik et al. (2002) was conducted on twenty-seven Slovenian adult sprinters and confirmed the primary

importance of the biceps femoris muscle when implementing the propulsive phase of sprint running.

In the analysis of the results, several questions were raised, why the biceps femoris muscle contraction time appears equal for both sexes, and why boys experience higher maximum running speeds than the girls. The answer could be sought in the differences in the muscle masses of children. It is well known that the key biomechanical parameter that affects the speed of running is muscle power, which is the product of force and speed. Using the contraction times of muscles, we measured the rate of shortening, however, this did not cover the muscle mass which affects the maximum force. Šimunič, Volmut, and Pišot (2010) presented that overall muscle mass in boys is higher than in girls by 13 % to 17 % between the ages of 8 to 13. This may explain the higher running speed of boys, although the contraction times of the biceps femoris are the same.

It is known that the biceps femoris can be trained to a greater extent, because it contains the largest number of fibers of type IIc or satellite-based fibers which can be, depending on the functional requirements of the body, transformed into fibers of type I or II.

Djordjević, et al. (2000) measured biceps femoris contraction time in two groups: in non-athletes and sprinters. The difference in the biceps femoris contraction time between both groups was 35.5 %, which confirms the correlation between muscle contractile property and maximum running speed. Differences between athletes and non-athletes were also found by Šimunič, Pišot, and Rittweger (2009), who measured the contractile properties of biceps femoris and vastus lateralis in master athletes and comparable controls. These findings suggest that regular exercise affects muscle properties and were also confirmed by our results.

Undoubtedly, the maximum running speed is affected by the development of the child and, consequently, in the correct technique of running the maximum running speed is also affected by the proper integration of the biceps femoris muscles during the process of running. Among other determinants of the maximal running speed (body dimensions, muscle power, stiffness, etc.) described by Åstrand et al. (2003), Schepens et al. (1998) found also significant increase in step frequency after the age of 12 years, where strengthening of the muscles has a decisive impact on the run, however, differs by gender. In a number of conducted studies, a difference was found in the choice of discipline. Men are more often involved in team sports, while girls prefer to engage in individual sports disciplines (Pears Dawes, Vest, & Simpkins, 2013). When choosing a discipline, it is also important considering their popularity. Boys are often involved in football, basketball, and athletics, while the girls engage in gymnastics, swimming, and athletics (Volmut, Pišot, & Šimunič, 2013). A possible answer would be different muscle compositions by gender but research to date does not support such a hypothesis. Significant differences in the percentage of fibre types between the sexes do not exist (Drinkwater, 1984; Staron et al., 2000). Although women have a smaller cross-section of muscle fibres than men (Always, Grumbt, Gonyea, & Stray-Gundersen, 1989), a possible explanation of shorter contraction time in women can also be in a smaller weight of the body in which the muscles work.

Study Limitations

The limitations of the study are in the selection of the research environment, namely, only three of twelve Slovenian regions were selected for performing this study. Although instructions and test sprinting trials were clearly stated, we did not check for achievement of maximal sprinting speed using redundant photocells setup.

CONCLUSION

The research focuses on studying children's motor development, specifically the biomechanical properties of skeletal muscles in relation to the physical development and growth (anthropometrical characteristics). After the age of 12.9, girls have shorter Tc in vastus lateralis but boys have shorter Tc in biceps femoris. Furthermore, shorter Tc in biceps femoris was found to correlate with higher running speed; however, the correlation was much lower than in adults. Non-invasive and selective assessment of muscle's contractile parameters in two skeletal muscles contributed to some important understanding of children's skeletal muscle development.

Acknowledgement

This study was funded by the Slovenian Research Agency through two three-year projects and performed by the Institute for Kinesiology Research, Science and Research Centre, University of Primorska in cooperation with Dr. Adolf Drolc Healthcare Center Maribor. The authors would like to thank the research group of the TMG-BMC Company and the research group of the Department of Muscle Biomechanics at the Faculty of Electrical Engineering, University of Ljubljana. Finally, we are thankful to school head teachers, their physical education teachers, all the participants in the study, and the parents for their willingness to participate in a study of such magnitude.

Funding

The presented longitudinal research study was a part of two national projects financed by the Ministry of Education, Science and Sport of the Republic of Slovenia: the applicative project with the title "The role of the biomechanical skeletal muscle properties in children's motor development" and the basic project with the title "Monitoring the biomechanical properties of skeletal muscles in childhood and adolescence" performed by the Institute for Kinesiology Research, Science and Research Centre, University of Primorska in cooperation with Dr. Adolf Drolc Healthcare Centre Maribor.

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