Effect of Muscle Length on Voluntary Activation Level in Children and Adults

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ABSTRACT

KLUKA, V., V. MARTIN, S. G. VICENCIO, A.-G. JEGU, C. CARDENOUX, C. MORIO, E. COUDEYRE, and S. RATEL. Effect of Muscle Length on Voluntary Activation Level in Children and Adults. *Med. Sci. Sports Exerc.*, Vol. 47, No. 4, pp. 718–724, 2015. **Purpose**: The aim of the present study was to compare the effect of muscle length on the level of voluntary activation (VA) at short and long muscle lengths between children and adults. **Methods**: Thirteen prepubertal boys (10.2 ± 1.1 yr) and 10 men (23.9 ± 2.9 yr) performed 5-s maximal isometric voluntary contractions of the knee extensor muscles at three muscular angles (20°, 90°, 100°; 0°, full extension) interspersed with at least 60-s passive recovery periods. Single magnetic stimulations were delivered to the femoral nerve during maximal isometric voluntary contractions to determine the level of VA using the twitch interpolation technique. The specific torque was calculated as the absolute torque divided by thigh muscle mass, as assessed using dual-energy x-ray absorptiometry. Finally, the theoretical specific torque that could be produced with a complete (i.e., 100%) activation level (specific torque at 100% VA) was estimated from the values of specific torque and VA. **Results**: Results showed a higher specific torque in adults at 90° and 100° but not at 20°. Accordingly, VA was significantly higher in adults at 90° (94% ± 4% vs 88% ± 8%, $P < 0.05$) and 100° (93% ± 6% vs 86% ± 8%, $P < 0.05$), whereas no significant difference was observed at 20°. Interestingly, the specific torque at 100% VA was not different between groups whatever the joint angle. **Conclusions**: The lower ability of children to fully activate their motor units at long muscle length could account for their lower specific torque because no difference in theoretical specific torque was observed between groups at 90° and 100°. **Key Words:** SPECIFIC TORQUE, MUSCLE ACTIVATION, CHILDHOOD, COACTIVATION, MAGNETIC STIMULATION

It has been widely demonstrated that children produce less strength than adults during maximal voluntary contractions (MVC) (10,22,46). The role of quantitative factors (i.e., muscle mass and muscle moment arm) has been advocated (38,46), but the implication of qualitative factors (e.g., nervous factors) remains unclear (7,46). Indeed, some studies have shown that even when muscle strength is normalized to muscle dimensions, differences between children and adults may persist (46). In that respect, some authors have proposed that differences in voluntary activation (VA) level, i.e., the ability to maximally recruit muscle fibers, may account for these differences (46).

The ability of an individual to maximally recruit its motor units during voluntary contractions partly relies on the excitability of the corticospinal tract, which is affected by the maturation process. Indeed, Koh and Eyre (24) reported that the excitability of the corticospinal tract increases dramatically between 8 and 11 yr of age. Consistently, Grosset et al. (17) observed that the maximal activation level of the plantarflexor muscles increased between 7 and 10–11 yr, where maximal activation level was no longer different from adult values. Similarly, Hatzikotoulas et al. (18) recently reported a comparable activation level of the plantarflexor muscles between 11-yr-old boys and adult men. Finally, Belanger and McComas (5) compared the VA level between prepubertal (11 yr) and postpubertal (16.5 yr) children and also failed to observe any difference between the two groups on the *triceps surae* and *tibialis anterior* muscles. However, other studies reported lower VA on the knee extensor (KE) muscles in prepubertal (10 yr) compared with that in postpubertal boys (16 yr) (6) and between prepubertal children (9 yr) and adults (17,38). Streckis et al. (43) also reported a lower VA level of

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the KE muscles in 12- to 14-yr-old children compared with that in adults. Among the factors that may account for these discrepant results are the sex, the muscle group investigated, the mechanical conditions of muscle contraction, and specifically the length at which the muscle was evaluated.

The results reported in adults on the effect of muscle length on VA are highly controversial. Some studies have shown that the ability to activate the motor units of the elbow flexor and KE muscles is reduced at short muscle length (30°; 0°, full extension) (3,4,14) compared with that at longer muscle lengths (90°). Conversely, Babault et al. (2) reported an increased VA at short versus long muscle length (35° vs 75°) on the KE muscles. Finally, some authors failed to demonstrate any effect of muscle length on VA of the KE muscles (36,37). Therefore, the effect of muscle length on VA in adults is currently unclear.

Our knowledge of this effect is even more limited in children. To date, only one study has explored the effect of muscle length on VA in children (37). In their experiment, O'Brien et al. (37) explored this relation on the KE muscles and did not observe any effect of muscle length on VA or any difference in the shape of the torque–joint angle relation between children and adults (37). However, O'Brien et al. (37) only explored VA and torque on a limited range of joint angles, i.e., in the optimal range of the torque–angle relation, allowing the production of maximal torque (from 55° to 90°), but did not explore shorter and/or longer muscle lengths. Such "extreme" muscle lengths may challenge the children's ability to activate their motor units. Specifically, the level of VA could be higher during contractions at short muscle length (2) in children than that in adults to compensate for their higher musculotendinous compliance (25,27,47). In addition, the higher tendon compliance in children could affect the amount of stretch transmitted to the muscle spindles at long muscle lengths. Indeed, with more compliant tendons, part of the stretch imposed on the muscle–tendon unit is absorbed by the tendon itself, such that less stretch is transmitted to the muscle spindles (41). This could dampen the increase of the Ia afferent excitatory input to the alpha motoneuron pool in response to muscle stretching in children and, potentially, would contribute to accentuate differences in VA levels between children and adults at long muscle lengths. Therefore, we could formulate the hypothesis that the VA level is much lower in children compared with that in adults at long muscle lengths.

The aim of the present study was thus to compare the effect of muscle length on VA level at short and long muscle lengths between children and adults.

MATERIALS AND METHODS

Subjects

A total of thirteen 8- to 12-yr-old healthy boys (Tanner stage, 1–2) and ten 18- to 30-yr-old healthy men were recruited. All the subjects were involved in different physical activities such as rugby, basketball, athletics, swimming, etc. To be included, they had to exercise less than 4 $h \cdot wk^{-1}$ and be free of any medical contraindication to physical activity. This study was approved by the ethics committee of the University Hospital of Clermont-Ferrand (Protection Committee of People for Biomedical Research South East VI; authorization number, AU929). All participants were informed about the experimental procedures and gave their written consent before any testing was conducted. In addition, the written consent of the parents/guardians was also obtained for the children participants.

Experimental Procedure (Design)

All the participants completed three experimental sessions. After a clinical examination by a medical practitioner (pediatrician for the children), anthropometric characteristics and body composition were assessed during the first visit. The second and third experimental visits consisted in the same tests and procedures aimed at assessing muscle strength and VA, the first one being used as a familiarization session. Those two sessions were separated by 7 d. Both experimental sessions lasted about 1 h, and the participants were asked to perform MVC of the KE muscles at three muscular angles (20°, 90°, 100°; 0°, full extension) to assess the effect of muscle length on VA. The 20° angle was chosen to test a short muscle length, whereas 100° was used to obtain the longest possible muscle length (i.e., the highest knee angle achievable on the Cybex isokinetic ergometer). Finally, the 90° knee angle is commonly used in the assessment of KE muscles force (36). Thus, it allows the comparison of our results with those of the literature (6,37,38).

Anthropometric Measurements and Body Composition

A digital weighing scale was used to measure body mass to the nearest 0.1 kg, and barefoot standing height was assessed to the nearest 0.1 cm with a wall-mounted stadiometer. Sitting height was also measured while the participants sat on the floor against a wall using the same stadiometer. Body mass index was calculated as body mass (kg) divided by height squared (m^2). Leg length was calculated by subtracting sitting height from total height.

Body composition (fat mass and fat-free mass) was assessed using dual-energy x-ray absorptiometry (QDR4500 scanner; Hologic, Waltham, MA). Thigh lean mass was measured according to the method described by Skalsky et al. (42). Briefly, the thigh region was delineated by an upper border formed by an oblique line passing through the femoral neck and a horizontal line passing through the knee. Thigh fat mass and fat-free mass were determined within this region of interest. In addition, thigh muscle mass was calculated using equation 1 proposed by Modlesky et al. (34):

$$\text{thigh muscle mass} = (\text{FFST}_{\text{DXA}} \times 0.648) + (\text{age} \times 27.5) - 114.2 \quad [1]$$

where FFST_{DXA} is the fat-free soft tissue mass expressed in grams (g).

BASIC SCIENCES

Maturation Assessment

Two methods were used to assess children's maturation.

1) Tanner stages were determined from self-reported assessment on the basis of pubic hairs and testicular/penis development (45). The children were assisted by their parents while completing the questionnaire.
2) Age from peak height velocity (APHV) was used to assess somatic maturity and determined using height, sitting height, and body mass. Its calculation was based on sex-specific regression equations according to the method proposed by Mirwald et al. (33).

Experimental Sessions: Muscle Strength and VA Level Assessment

Torque measurements. KE muscle testing was performed using an isokinetic dynamometer (Cybex NORM; Cybex, New York). Participants were securely strapped into the chair to limit extraneous movements of the trunk. The hip angle was set at 30° (0°, supine position) to allow the stimulation of the femoral nerve. Visual feedback and strong verbal encouragement were provided to maximize torque output during MVC. Correction for the effect of gravity was applied. The participants were asked to perform 3-s MVC of the KE muscles. This measurement was repeated three times at each knee angle with at least 60 s of rest between contractions.

VA level. Single stimulations were delivered during contractions after the torque had reached a plateau, and to the relaxed muscle, in a potentiated state 3 s after the cessation of the contraction (29). These superimposed and potentiated responses allowed the quantification of the VA level (see equation 2). VA level (% VA) was quantified using the interpolated twitch technique according to Merton's calculation (32):

$$\%\mathrm{VA} = [1 - (\text{superimposed twitch torque}/\text{potentiated twitch torque})] \times 100 \qquad [2]$$

Femoral nerve stimulation was performed with a 45-mm figure-of-8 coil powered by a Magstim 200^2 stimulator (peak magnetic field strength, 2.2 T; stimulation duration, 0.1 ms; Magstim, Whitland, Dyfed, United Kingdom). The stimulating coil head was positioned high in the femoral triangle just lateral to the femoral artery. The best anatomical location and optimal intensity producing the maximal twitch torque and concomitant *vastus lateralis* and *rectus femoris* maximal compound action potential (M-waves) amplitudes were determined at the start of each experiment. All the stimuli were given at a supramaximal intensity (110% ± 7% of the optimal intensity) (31).

Specific torque. The specific torque of the KE muscles was calculated as the absolute torque divided by thigh muscle mass. The thigh muscle mass was calculated using the equation proposed by Modlesky et al. (34) (equation 1). In addition, the theoretical specific torque that could be produced with a complete (i.e., 100%) activation level (specific torque at 100% VA) was estimated from the values of specific torque and VA, as shown in equation 3:

$$\text{specific torque at 100\% VA} = \text{specific torque}/\mathrm{VA} \qquad [3]$$

where VA is expressed as a percentage.

EMG recordings. After careful preparation of the skin (shaving, light abrading with sandpaper, and cleaning with alcohol) to obtain a low impedance ($Z < 5\ \mathrm{k\Omega}$) at the skin–electrode surface, disposable electrodes (Ag-AgCl; Ambu Blue Sensor N-00-S/25) were positioned on the *vastus lateralis*, *rectus femoris*, and *biceps femoris* (BF) muscle bellies, according to Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles recommendations (19), with an interelectrode distance of 20 mm. The reference electrode was attached to the patella. EMG signals were amplified (Octal BioAmp, ML 138; ADInstruments, New South Wales, Australia) with a bandwidth frequency ranging from 10 to 500 Hz and simultaneously digitized together with torque signals using an acquisition card (Powerlab 8/30, ML 870; ADInstruments, New South Wales, Australia). The sampling frequency was set at 2000 Hz. EMG activity was quantified with the root mean square (RMS) value recorded over a 300-ms analyzing window, located before the stimulation artifact, where torque is maximal. RMS values were normalized to the corresponding M-wave peak-to-peak amplitude ($\mathrm{RMS}/M_{\max}$), measured from the single stimulation of the relaxed muscle in the potentiated state, to account for differences in muscle mass and potential changes/differences in sarcolemmal excitability.

Antagonist coactivation. The level of coactivation of the BF muscle was assessed from its EMG activity during knee extensions, expressed as a percentage of its maximal EMG activity, recorded during a maximal knee flexion. To record this maximal RMS value of the BF muscle EMG activity, the participants were asked to perform 3-s MVC of the knee flexors. This measurement was repeated two times at a 90° knee angle. The best trial was used for subsequent analysis.

Statistical Analysis

Data were screened for normality of distribution and homogeneity of variances using the Shapiro–Wilk normality test and the Barlett test, respectively. The conditions of ANOVA application being met, a two-way ANOVA with repeated measures was used to assess the effect of the different factors (knee angle–group) on the KE torque and VA. Fisher LSD *post hoc* tests were applied to determine between-mean differences when the ANOVA revealed a significant main effect for any factor or interaction of factors. Unpaired Student's *t*-tests were used to analyze the effect of age on anthropometric variables and body composition. Values were expressed as mean ± SD. The limit for statistical significance was set at $P < 0.05$.

RESULTS

Anthropometric data and population characteristics. Anthropometric characteristics were all significantly different between groups (Table 1). More specifically, thigh fat-free mass and muscle mass were significantly higher in adults compared with those in children. In children, APHV was 14 ± 1 yr and their chronological age was about −4 ± 1 yr from APHV.

Absolute and specific torque. There was a significant main effect for joint angle and a significant interaction of group–knee angle on absolute torque ($P < 0.001$) (Fig. 1).

The absolute torque was significantly higher in adults whatever the knee angle (Fig. 1). The difference remained significant even when MVC torque was related to thigh muscle mass at 90° and 100° of knee extension ($P < 0.05$) (Fig. 2). However, no significant difference was observed at 20° between children and adults (19 ± 5 vs 19 ± 3 N·m·kg^{-1}, respectively) (Fig. 2).

VA level. There was a significant main effect for knee angle and a significant interaction of group–knee angle on the VA of the KE muscles ($P < 0.05$) (Fig. 3). The twitch interpolation technique revealed that VA was significantly higher in adults than that in children at 90° (94% ± 4% vs 88% ± 8%, $P < 0.05$) and 100° (93% ± 6% vs 86% ± 8%, $P < 0.05$) (Fig. 3), whereas no significant difference was observed between both groups at 20° (adults, 87% ± 9%, vs children, 90% ± 6%). Moreover, whereas VA tended to decrease across knee angles in children (20°, 90% ± 6%, vs 100°, 86% ± 8%; $P = 0.11$), VA was significantly higher at 90° and 100° compared with that at 20° in adults ($P < 0.01$ and $P < 0.05$, respectively).

RMS/$M_{\max}$ ratios. RMS/$M_{\max}$ ratios were not significantly different between children and adults whatever the knee angle.

Antagonist coactivation. The antagonist coactivation level was not significantly different between groups at any knee angle (Fig. 4). Furthermore, no significant effect for knee angle was observed on the level of antagonist coactivation.

Specific torque at 100% VA. As illustrated in Figure 5, the specific torque at 100% VA was not significantly different between children and adults whatever the knee angle.

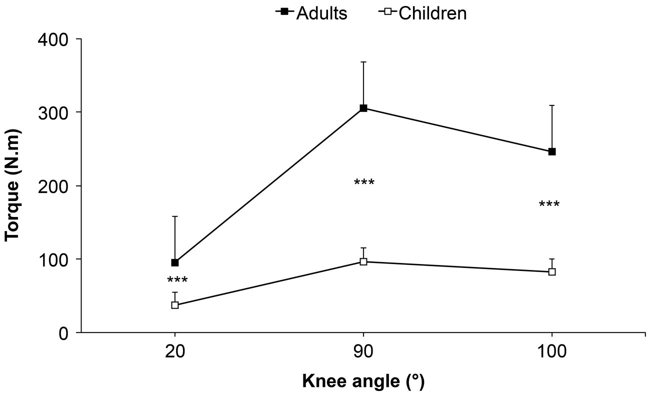

FIGURE 1—Relations between absolute torque and knee angle in adults (*black squares*, ■) and children (*white squares*, □). Values are expressed as mean ± SD. ***Significant differences between groups, $P < 0.001$.

DISCUSSION

The main purpose of the present study was to compare the effect of muscle length on VA level at short and long muscle lengths (from 20° to 100°) between children and adults. The results show that the level of VA does differ between boys and men as a function of muscle length. Whereas a higher VA level was measured in adults compared with that in children at long muscle lengths (90° and 100°), no significant difference was observed at very short length (20°). The higher VA level observed in adults at 90° and 100° was associated with a significantly higher specific muscle torque but not at 20°. However, when the VA level differences were taken into account, no significant difference of theoretical specific force was observed between the two groups. These results suggest that differences in specific strength at long muscle lengths between children and adults are accounted for by nervous factors.

Among the nervous factors that may contribute to the observed differences, the antagonist activation and the VA level of the agonist muscles have been frequently advocated. However, unlike some studies that attributed strength differences to a higher antagonist coactivation in prepubertal children (17,38), we did not report any antagonist coactivation differences between children and adults. This result is nevertheless consistent with other reports (1,11).

TABLE 1. Anthropometric characteristics of the experimental groups. Values are expressed as mean ± SD. The statistical difference between groups is indicated in the right-hand column.

	Children (*n* = 13)	Adults (*n* = 10)	*P*
Age (yr)	10.2 ± 1.1	23.9 ± 2.9	<0.001
Body mass (kg)	34.3 ± 7.4	76.3 ± 9.4	<0.001
BMI (kg·m^{-2})	17.2 ± 3.5	24.3 ± 3,1	<0.001
FM (%)	18.2 ± 7.6	16.2 ± 5.2	NS
FFM (kg)	25.5 ± 5.1	60.0 ± 6.4	<0.001
Thigh FFM (kg)	2.9 ± 0.6	7.1 ± 0.9	<0.001
Thigh MM (kg)	2.0 ± 0.4	5.1 ± 0.5	<0.001

BMI, body mass index; FFM, fat-free mass; FM, fat mass; MM, muscle mass; NS, not statistically significant.

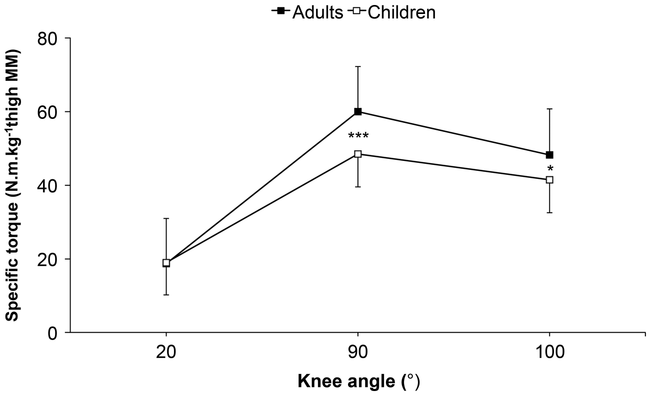

FIGURE 2—Relations between specific torque (i.e., related to thigh muscle mass) and knee angle in adults (*black squares*, ■) and children (*white squares*, □). Values are expressed as mean ± SD. Significant differences between groups: *$P < 0.05$ and ***$P < 0.001$.

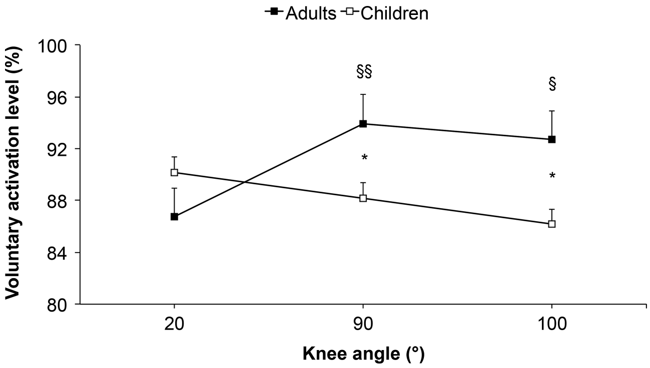

FIGURE 3—Relations between VA level and knee angle in adults (*black squares*, ■) and children (*white squares*, □). Values are expressed as mean ± SD. *Significant differences between groups, $P < 0.05$. §§Significant difference between 20° and 90°, $P < 0.01$. §Significant difference between 20° and 100°, $P < 0.05$.

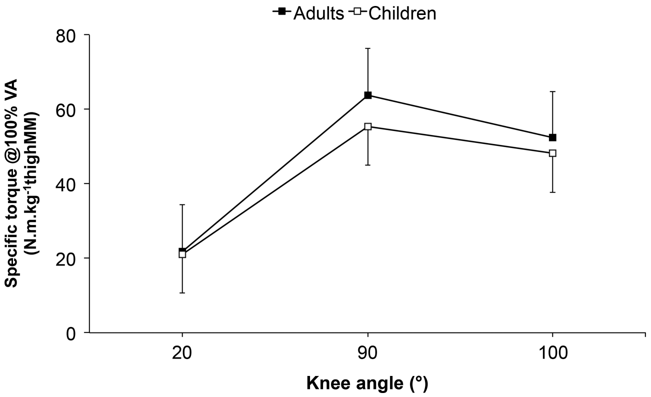

FIGURE 5—Relations between specific torque (i.e., related to thigh muscle mass) at 100% VA and knee angle in adults (*black squares*, ■) and children (*white squares*, □). Values are expressed as mean ± SD. No significant difference was observed between groups.

The lower level of VA observed at longer muscle lengths in children explains their lower specific strength at these muscle lengths. This result is quite consistent with those of Blimkie (6), who reported that 11-yr-old boys had a reduced VA level compared with adolescents during MVC of the KE muscles performed at 90°. Streckis et al. (43) and O'Brien et al. (38) also observed differences of KE VA levels between children and adults at knee angles of 60° and 90°, respectively. However, it should be pointed out that when the effect of sex was examined, both studies found no difference of activation level between boys and men but a significantly lower activation level in girls than that in women. Therefore, sex may affect VA differences between children and adults. Finally, Grosset et al. (17) observed that the maximal activation level of the plantarflexor muscles increased between 7 and 10–11 yr, where maximal activation level was no longer different from adult values.

The lower VA levels observed in prepubertal children have been frequently ascribed to the immaturity of the corticospinal pathways. Some studies support this assumption. For example, Koh and Eyre (24) studied the maturation of the corticospinal tract with transcranial magnetic stimulations and found that the excitability of the corticospinal tract increases dramatically between 8 and 11 yr of age. In addition, these authors estimated that the conduction velocity within motor pathways reached adult values at around 11 yr of age. This has been attributed to the myelinization process and to the increase in nerve fiber diameter (15,28,35). Therefore, we could suggest that the relative immaturity of the corticospinal tract accounts for the reduced VA observed in our sample of 10-yr-old boys. Yet, it is unlikely that this phenomenon would vary as a function of muscle length, as observed for VA levels in the current study. Thus, other factors such as the musculoskeletal stiffness or specific reflex mechanisms (2) may have affected VA level differences between children and adults across knee angles.

Our results show that at short muscle length, children have a similar specific strength and even display a trend toward higher VA than adults (Fig. 3). Interestingly, Babault et al. (2) previously suggested that an increase of VA at short muscle length (as observed in adults) may represent a strategy to compensate for the mechanical disadvantage of a shortened muscle and especially the low musculotendinous stiffness and the slackening of the muscle–tendon unit. Because the musculotendinous stiffness has been reported to be lower in children (25,27,47), it could be suggested that children increase their VA level to compensate for the mechanical disadvantage of a shortened muscle position.

The lower musculotendinous stiffness may also affect the shape of the VA–angle relation at long muscle lengths, via its effect on muscle spindle responses to stretching, and the resulting facilitation of the alpha motoneuron pool by the spindle afferents (4). Indeed, Rack et al. (41) demonstrated that part of the stretch imposed on the muscle–tendon unit is absorbed by the tendon itself, such that with a more compliant tendon, less stretch is transmitted to the muscle spindles. In that respect, Grosset et al. (16) previously demonstrated that the amplitude of the stretch reflex increases with age in prepubertal children and that this increase is strongly correlated to musculotendinous stiffness. Because children have more compliant tendons than adults

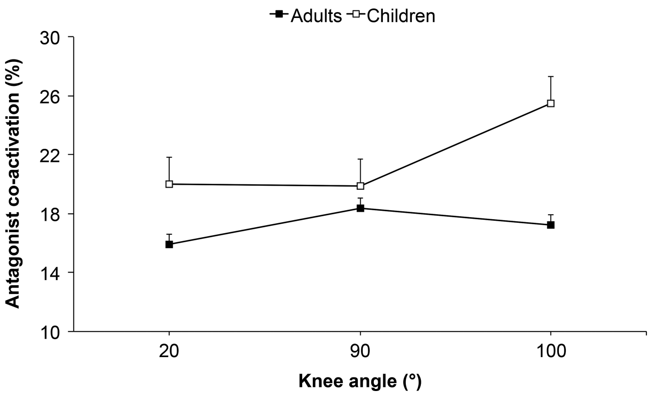

FIGURE 4—Relations between antagonist coactivation and knee angle in adults (*black squares*, ■) and children (*white squares*, □). Values are expressed as mean ± SD. No significant difference was observed between groups.

(25,27,47), this would imply that at long muscle lengths, the muscle spindles would be less stretched in children than that in adults, resulting in a reduced Ia excitatory input to the alpha motoneuron pool. This could explain the specific shape of the VA–angle relation in children as observed in our study; whereas VA levels increased as a function of muscle length in adults, they tended to decrease in children (Fig. 3).

We cannot rule out the possibility that inhibitory reflexes originating from other mechanoreceptors, such as Golgi tendon organs, ligament, or joint receptors, may have limited the expected increase of VA at long muscle lengths in children (4). Indeed, while both torque and VA levels increased with muscle stretching in adults, VA levels tended to decrease in children whereas torque increased with increasing muscle length. This could represent the intervention of inhibitory mechanisms at high force levels in children aimed at reducing VA and, thus, force output to ensure the integrity of the musculoskeletal system. The existence of such force-limiting mechanisms has previously been referred to by Westing et al. (48) and Babault et al. (2) in adults under the high-tension loading conditions induced by eccentric contractions. These authors suggested that the inhibitory feedback from the free nerve endings located in the muscle, joint, or pain receptors and from the Golgi tendon organs (8) may reduce the neural drive to maintain muscle tension within safe limits (20). However, the idea that the autogenic inhibition mediated by Golgi tendon organs increases with force level during isometric contractions has been questioned (9). Indeed, the single available study on Golgi tendon organ function in human adults shows a reduction in autogenic inhibition during a moderate contraction (12). Furthermore, the sensory system seems to be mature in the first years of life, such that 10- to 12-yr-old children would have a proprioceptive functioning similar to adults (23). Therefore, it is unlikely 1) that maturation may have an effect on autogenic inhibition and 2) that it could affect the force production and the VA level. Additional studies are thus required to verify the existence of a force-limiting mechanism in children and its potential origins.

A few limitations of our study could be noted. First, the amplitude of the potentiated twitch was used for the calculation of the VA level, as recommended in the literature (13,26,40). Although Pääsuke et al. (39) reported that the postactivation potentiation was similar between prepubertal boys and adult men on the plantarflexor muscles at an ankle angle of 70°, it is currently unknown whether this is the case for the KE over the range of muscle lengths investigated here. Nevertheless, as mentioned by Gandevia (13), the rationale of the twitch interpolation technique assumes that the degree of potentiation is equivalent for the control (potentiated) and the interpolated twitches, such that the outcome of the calculation of the VA level should not be biased when the degree of potentiation varies across knee angles or between groups. The second limitation is the lack of agreement between the VA and normalized EMG data, the latter being comparable between children and adults, whereas the former differed. This discrepancy between the results of EMG and the interpolated twitch method probably originates from the fact that surface EMG is not sufficiently sensitive to measure small differences in VA level (21). Other studies previously reported this lack of consistency between EMG and the twitch interpolation data (30,44). Another difference between the two methods is that the twitch interpolation technique reflects the activation of the entire KE muscle group whereas EMG assesses the activity of individual muscles. Therefore, we cannot rule out the possibility that reduced EMG activity may have been observed on the KE muscles that were not measured here (i.e., on the *vastii medialis* and *intermedius* muscles).

To conclude, the results of the present study show that the level of VA differs between prepubertal boys and men as a function of muscle length. Although a higher VA level was measured in adults compared with that in children at long muscle lengths (90° and 100°), no significant difference was observed at very short length (20°). These differences accounted for the variations in specific torque between children and adults across muscle lengths. The low musculotendinous stiffness and/or specific inhibitory/excitatory modulations may account for the specific shape of the VA–muscle length relation in children. However, the existence and relative contributions of these different mechanisms remain to be determined.

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The authors report no conflict of interest.

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