Activation of Antagonist Knee Muscles During Isokinetic Efforts in Prepubertal and Adult Males

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The deficit of muscle-force production observed in children can be partly attributed to neural factors, such as an increased level of coactivation. This hypothesis, however, has not been thoroughly investigated under concentric and eccentric isokinetic conditions at different angular velocities. Thus, the purpose of this study was to examine whether prepubescent children present higher levels of activation of the antagonist knee muscles during isokinetic, concentric, and eccentric knee efforts compared with adults. Eighteen prepubertal and 13 young adult males (age: 10.9 ± 0.5 and 18.1 ± 0.1 years, respectively) performed maximal concentric and eccentric knee extensions and flexions at 45, 90, and 180 degrees/s. The vastus lateralis and biceps femoris electromyogram was recorded and the antagonist activation (coactivation) was calculated. Concentric contractions for both groups revealed significantly higher coactivation values (p < .05) compared with the eccentric conditions. Furthermore, increasing the angular velocity increased the level of coactivation significantly only during the concentric efforts for both groups. No significant difference in the antagonistic activity of the vastus lateralis and biceps femoris, however, was found between groups. Therefore, increased antagonist knee-muscle activation, which enhances joint stabilization during isokinetic concentric and eccentric effort, is similar in both prepubescent and adult males.

The fact that children can exert lower amounts of force is attributed to morphological and neuromuscular factors. During childhood the anthropometric parameters increase significantly, muscle cross-sectional area doubles between 5 and 18 years of age, and the proportion of type II fibers increases significantly (40). Concerning the neuromuscular factors, comparisons between adults and younger individuals have shown that the ability of the latter to activate maximally (6,7) and to coordinate their motor efforts (15) is lower. These factors show a neuromuscular immaturity of children that can lead to force deficits in relation to adults.

Moreover, the torque produced is actually the net torque production of the simultaneous activation (coactivation) of the agonist and antagonist muscles. Therefore, an increased coactivation level in children could explain partially, in neuromuscular terms, the observed force deficit. This hypothesis is supported by the fact that the tendon structures in children are more compliant (26), and hence, an

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increased coactivation level in children could act as a compensatory mechanism for stabilizing the knee. This hypothesis, however, has not yet been tested.

The level of antagonistic coactivation has been the subject of detailed investigation under different levels of muscle activation (38), types of muscle contractions (28), joint angles (23), angular velocities (3,16,37), and training level (1,3). Some issues, however, remain controversial. For example, concerning the angular velocity of the movement, it has been reported that increasing the velocity results in an increased coactivation level (24,31), whereas in other studies, there is no velocity effect evident (1).

As mentioned above, the decreased force-production ability shown in children might be caused by an increased coactivation level. According to the study by Frost et al. (14), during walking or running the knee joint muscles’ coactivation is higher in 7- to 8-year-old children compared with adolescents (15- to 16-years old). Nonetheless, during slow isokinetic (knee flexion and extension) concentric and eccentric contractions (30 deg/s), a comparison between adolescents and adults showed no significant differentiation in the antagonist activity of knee muscles (25). Comparing the two above studies, it is not clear whether the different conclusions are attributed to the different age group comparison or the different action mode as leg extension is an open kinetic chain movement whereas walking and running are closed kinetic chain movements. Moreover, the effect of the angular velocity on the coactivation in open kinetic chain movements at different ages has not been documented yet. Higher angular velocities induce higher coactivation level (3,16,37), and this principle is not verified for children. The purpose of this study was, therefore, to examine the effect of angular velocity and muscle-contraction type on the antagonist electromyographic (EMG) activity of vastus lateralis (VL) and biceps femoris (BF) muscles in prepubescent and adult males.

Methods

Participants

Two groups of participants volunteered to take part in the current study: 18 boys (age: 10.94 ± 0.6 years; body mass: 49.2 ± 13.0 kg; height: 150.1 ± 7.7 cm) and 13 men (age: 18.1 ± 0.1 years; body mass: 78.0 ± 10.1 kg; height: 1.81 ± 0.06 cm). All participants were informed about the contents of the experiment. The participants in the adult group and the parents of the children signed a consent form before the experimental assessment. A pediatrician determined all children to be prepubertal (at the first Tanner stage; 39) by. All participants were untrained, healthy, and had no history of lower-limb injury. A doctor of orthopedics verified the good knee health of all participants. Adults were sedentary persons and children participated only in the sport class lesson twice a week.

Instrumentation

An isokinetic dynamometer (Cybex Norm, CYBEX Division of Lumex, Ronkonkoma, NY) was used to measure isokinetic eccentric and concentric torque of the knee flexors and extensors. The EMG activity was recorded using the Neuropack Four Mini device (Nihon Kohden, Four-Pack-Mini) connected with Biopac MP 100 Acquisition unit (Biopac Systems Inc. Goleta, CA).
Testing Procedures

One week before testing, the participants were invited to practice and become familiar with the testing procedures. Additionally, they were advised to avoid fatiguing activities for at least 1 day before the testing appointment. A typical warm-up took place before testing, consisting of 5 min of cycling on a cycle ergometer, stretching exercises for the lower limbs, and several submaximal and two maximal concentric and eccentric contractions.

For fat-mass estimation, two skinfolds (biceps and subscupular) were measured on the right side of the body using a Lafayette caliper. The measurement was made with a precision of 0.1 mm. Three sets of measurements were taken. The mean of the three measurements was used as the representative value for each skinfold. The equation proposed by Slaughter et al. (36) was used for the prediction of percent body fat in order to calculate the fat-free body mass.

The isokinetic tests were performed from the sitting position (hip angle: 115 deg). Velcro straps were used to stabilize the trunk, waist, and upper thigh on the chair in order to prevent any movement that could influence the measurement quality. The leg was located horizontally to the ground and full extension was checked by aligning a level indicator posterior on the medial femoral epicondyle at a point approximate of knee axis of rotation.

The testing protocol consisted of three maximal knee extension and flexion trials at the concentric and eccentric angular velocities of 45, 90 and 180 deg/s. The concentric and eccentric tests were performed in randomized order. The testing movement range of motion was limited for all subjects from 0 to 90 deg of their knee flexion. The participants were able to see their torque scores on the monitor of the dynamometer for visual feedback and were instructed to perform their best in both movement directions (22). All tests were separated by a 3-min resting period to avoid any fatigue effects. The repetition with the highest peak torque was used for further analysis.

Signal Processing

Two pairs of passive bipolar silver-silver chloride surface electrodes (diameter: 0.8 cm, interelectrode distance: 2 cm) were used. The electrodes were placed midway between the lateral epicondyle and the greater trochanter for recording the EMG signal of VL, and for the BF, they were placed halfway between the ischial tuberosity and lateral femoral epicondyle (5). Skin preparation (depilating, abrading, and cleaning with alcohol) reduced the skin impedance to less than 2 kΩ (4). Electrode placement for minimizing cross talk was validated according to the method of Winter et al. (42). The ground electrode was placed on the lateral femoral epicondyle.

EMG signals were amplified by 1000 within a bandwidth of 10 to 500 Hz. The amplifier’s common rejection-mode ratio was less than 110 db. All analog signals (torque, angle, and EMG) were converted to digital using a built-in A/D 12-bit card, with a sample frequency of 1 kHz (MP100 Data Acquisition unit, Biopac Systems, Inc., Goleta, CA). During the data capture, the raw EMG signal was fully rectified and the moving average was calculated for a window of 10 m/s. Furthermore, to estimate the angular velocity, the first derivative of the angle was calculated.
All data were saved for further analysis in a hard drive of a personal computer. The mean EMG (EMG) of the processed signal was calculated during the range of motion for which the angular velocity was constant. Antagonistic activity was expressed as a percentage of the activity of the respective muscle when acting as an agonist at the same muscle action and angular velocity (23).

Statistical Analysis

The dependent variables analyzed were the antagonistic activity of the VL and BF, the ratio of the knee extensors’ torque to lean body mass, and the ratio of the knee flexors’ torque to lean body mass. The statistical model used to detect the differences was a $2 \times 3 \times 2$: group (children, adults) by angular velocity (45, 90, 180 deg/s) by type of contraction (concentric, eccentric). The level of significance was set at $p < .05$. The Sheffe post-hoc test was performed when a factor indicated significant effect.

Results

Torque to Fat-Free Body-Mass Ratio

The ANOVA designs indicated a significant main effect for age on knee-extension torque/fat-free body-mass ratio, $F_{(1,29)} = 7.60, p < .01$, with the adults having a higher ratio than prepubescents (Figure 1). The main effect for muscle action and angular velocity was also statistically significant: $F_{(1,29)} = 101.79, p < .01$, eccentric > concentric, and $F_{(2,58)} = 42.18, p < .01, 45 > 90 > 180$ deg/s, respectively. The interaction of muscle action and angular velocity was also significant, $F_{(2,58)} = 12.27, p < .01$, showing a significant decrease of torque/fat-free mass ratio as angular velocity increased during the concentric but not eccentric contractions.

The ANOVA designs indicated a significant main effect for age on knee-flexion torque/fat-free body-mass ratio, $F_{(1,29)} = 6.322, p < .01$, with the adults having a higher ratio than prepubescents (Figure 2). The main effect for muscle action and angular velocity was also statistically significant: $F_{(1,29)} = 32.36, p < .01$, eccentric > concentric, and $F_{(2,58)} = 66.02, p < .01, 45 > 90 > 180$ deg/s, respectively. The interaction of muscle action and angular velocity was significant, $F_{(2,58)} = 4.50, p < .01$, showing a decrease of torque/fat-free body mass as angular velocity increased during only the concentric and not eccentric contractions.

Antagonist EMG Activity

The antagonist EMG activity of the BF and VL was not significantly affected by age (BF: $F_{(1,29)} = 1.34, p > .05$, and VL: $F_{(1,29)} = 0.01, p > .05$; see Figures 3 and 4). The muscle action and angular velocity, however, affected the antagonistic activity. More specifically, the BF and the VL antagonistic EMG was significantly lower during eccentric contractions: $F_{(1,29)} = 34.99, p < .01$, and $F_{(1,29)} = 29.46, p < .01$, respectively; and during lower angular velocities: $F_{(2,58)} = 10.93, p < .01$, and $F_{(2,58)} = 7.28, p < .01$, respectively. The interaction between the muscle action and the angular velocity was significant: BF: $F_{(2,58)} = 8.90, p < .01$, and VL: $F_{(2,58)} = 3.71, p < .01$, showing the antagonist EMG activity to be affected by the angular velocity only during concentric contractions.
Figure 1 — Mean (±1 SEM) concentric and eccentric knee-extension torque to fat-free body-mass ratio for prepubescents and adults in different angular velocities. Asterisks indicate statistically significant differences between prepubescents and adults (p < .05).

Figure 2 — Mean (±1 SEM) concentric and eccentric knee-flexion torque to fat-free body-mass ratio for prepubescents and adults in different angular velocities. Asterisks indicate statistically significant differences between prepubescents and adults (p < .05).
Figure 3 — Mean (± 1 SEM) antagonistic EMG activity of biceps femoris during concentric and eccentric knee extension for prepubescents and adults in different angular velocities.

Figure 4 — Mean (± 1 SEM) antagonistic EMG activity of vastus lateralis during concentric and eccentric knee extension for prepubescents and adults in different angular velocities.
Discussion

The present results indicated that the antagonist EMG activity of VL and BF were not statistically different between prepubertal boys and young men. The antagonist EMG concentric effort was greater compared with eccentric effort for both muscles tested. There was also a significant effect of angular velocity on the antagonist EMG of both muscles tested during concentric efforts, showing increased EMG activity during higher angular velocities.

Compared with prepubertal boys, adults produced a higher torque normalized to the fat-free body mass. Other researchers reported that torque differences among different age groups were eliminated when absolute strength measures were normalized to body mass (32,34,35) or to estimated muscle mass using limb circumferences (10) and ultrasound measurements (17). In contrast, it has also been reported that differences among age groups remained present even when strength was normalized to the muscle–anatomical cross-sectional area (19) or muscle volume (18,20). There is also evidence that relative torque differences might vary across muscles and between genders (20). Considering the controversy of the foregoing reports, the age-related differences in relative strength seems to require further investigation.

The antagonistic activity is ruled by central (9,30), spinal cord (30), and peripheral neuronal mechanisms (13). These mechanisms seem to regulate the antagonist activity in both open and closed kinetic chain movements. More specifically, the antagonistic activity of the knee-joint muscles is higher during closed kinetic chain actions compared with open kinetic chain actions, resulting in a greater decrease of the stress on the anterior cruciate ligament (ACL; 27,33). Relevant studies have shown that prepubertal and pubertal children present higher coactivation values compared with adults during closed kinetic chain movements such as the support phase of gaiting (14). On the contrary, no difference in coactivation was reported between adolescents and adults during isokinetic knee extension and flexion (25).

Surprisingly, the antagonistic activity of VL and BF during concentric and eccentric efforts revealed no significant difference isokinetically between young men and immature prepubescent boys. Of course, it must be noted that isokinetic knee extension/flexion is an open kinetic chain movement, which provides a secure experimental environment, and probably the amount of coactivation required for the stabilization and protection of the joint is rather diminished. Our main hypothesis, however, was that immature prepubescent children would need higher activation of their antagonist muscles compared with adults in order to effectively stabilize the knee joint.

According to the literature, coactivation of the antagonist muscle contributes to joint stability by reducing the magnitude and widening the distribution of forces exerted around the joint (3,8). Furthermore, immature children’s knees are anatomically different from that of adults (12), the tendon structures are more compliant in younger children compared with older children and adults (26), and it has not been clarified whether the immature ACL is strong enough to stabilize the knee joint (12,29). According to the results obtained, however, prepubertal boys do not activate their antagonist knee-joint muscles more than adults do in order to compensate for the increased muscle compliance or to stabilize the knee joint during concentric and eccentric isokinetic efforts at the selected angular velocities.
At this point it should be noted that coactivation is related to strength level (21) and is higher during isometric contractions (2). Therefore, a basic explanation for the results obtained could be an underestimation of children’s coactivation level as a result of their strength deficit and the dynamic nature of the measured contractions. Because coactivation is intensity dependent (2), the intensity used in the present study was probably not enough to cause a higher strain on the children’s ACL compared with the adults’ resulting, thus, in the same level of antagonistic activation. This assumption is further supported by a previous report (27) that pointed out that antagonist activity in prepubertal populations tends to increase relative to adults during isometric contractions.

Numerous studies have examined the velocity effect on agonistic and antagonistic activity. Concerning the velocity effect on torque production and agonistic EMG activity, it was pointed out that it depends on the inhibitory effect of the central nervous system (11). Previous studies concerning the effect of muscle action and velocity on the antagonist EMG in adults, however, revealed equivocal results. In agreement with our results, some studies indicated higher antagonist EMG during concentric compared with eccentric efforts and an increase of antagonistic coactivation level with increasing velocity during concentric efforts (8,9,24,31,37). In contrast, Amiridis et al. (1) reported similar antagonist EMG of the semitendinosus in concentric and eccentric knee extensions, which remained unaffected by angular velocity. This disagreement is probably a result of examining different muscles (semitendinosus vs. biceps femoris) and the different normalization methods used. Amiridis et al. expressed EMG of antagonists as a percentage of the EMG during a very slow concentric angular velocity. This normalization method might underestimate the level of coactivation because muscle activity during a certain muscle action and angular velocity are different (23).

The present findings revealed an increase of 53–64% in antagonistic activity of the hamstring and 18–46% of the vastus lateralis during concentric efforts, but no significant increase was observed during eccentric efforts. No previous study, however, has examined the velocity effect on antagonistic activity in children for comparison. Other studies in adults reported an increase of 128% (16) from 15 to 240 deg/s during concentric isokinetic efforts, whereas Kellis & Baltzopoulos (21) reported an increase of 30% from 30 to 150 deg/s for concentric and eccentric efforts. These increases were attributed to the increase of the acceleration and deceleration phases of the movement at faster angular velocities (16,24).

According to the present results, the age-associated relative torque differences at the specific angular velocities and for the muscles tested could not be attributed to a higher coactivation level of antagonist muscles in children but rather to the lower efficiency of their neuromuscular system in effectively activating the agonist muscles (6,7,32,41).

Taking into consideration the cross-sectional design of the present study, it can be concluded that the antagonist activation of knee muscles during isokinetic open kinetic chain concentric and eccentric efforts at the selected angular velocities is similar in both prepubescent and adult males. Further research in various muscle actions and velocities in both open and closed kinetic chain movements is needed, however, to confirm whether these findings are representative of antagonist activity for children across developmental stages.
References


