Knee Flexor:Extensor Isokinetic Ratios in Young Male Gymnasts and Swimmers

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The purpose of the study was to determine young male gymnasts’ and swimmers’ knee flexor:extensor (F:E) ratios during isokinetic testing at different velocities. Nine gymnasts (10.3 ± 0.5 years) and 14 swimmers (10.5 ± 0.5 years) participated. Concentric isokinetic peak torque was measured by a Cybex® Norm dynamometer at different angular velocities (60, 120, and 180°/s) during unilateral knee extensions and flexions after gravity correction. Significant differences were found only in gymnasts’ knee F:E peak-torque ratios between the angular velocities of 60 and 120°/s (p < .01), as well as 60 and 180°/s (p < .01), whereas swimmers’ ratios were unchanged. Gymnasts presented significantly higher F:E ratios than swimmers did at the angular velocities of 120°/s (p < .01) and 180°/s (p < .001). The reciprocal ratios provided some indication that the training context of young athletes can influence the balance between agonistic and antagonistic activity of the lower limbs’ major muscle groups.

The balance between agonist and antagonist muscle groups is an important factor in articular stabilization and in preventing joint and muscle injuries for athletes involved in different sports (6). This can be evaluated with a torque-ratio control of major muscle groups, such as knee extensors and flexors at different concentric angular velocities, using an isokinetic dynamometer (1,2,7,11,17,19,21,22,26). A flexor:extensor (F:E) peak-torque ratio between 0.60 and 0.70 at low angular velocities in male athletes appears to have gained some general acceptance (1,4,7,12,19,22). Nonetheless, there is controversy over ratios at increased angular velocities. The optimal F:E ratio at different velocities varies in the literature, and these ratios are not similar for athletes in different sports (1,7,11,12,19,21,22). Increased ratios with increasing angular velocity, however, are generally accepted (1,2,7,9,11,12,19,22). There are only a few studies showing that the ratio remains stable as angular velocity increases (21,25).

The F:E ratios with increasing angular velocity have not been studied sufficiently, however, especially in pediatric sporting populations, which have been trained intensively since their early childhood in activities requiring specific skills in different environments, such as gymnastics and swimming. F:E ratios might be

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specific to the demands placed on the athletes by the sports in which they compete.
Both gymnastics and swimming require muscle power in lower limbs in order to
achieve good performance. In gymnastics the majority of the exercises are ex-
ecuted at a high speed and are influenced by gravity. The increased heights ob-
tained from the apparatuses and the great landing velocities from the fast tumbling
that precedes dismounts have, as a result, high impact forces (20). On the other
hand, swimmers are trained without the influence of gravity to produce continu-
ously propulsive forces (23) against resistance provided by water during their for-
ward movements (10).

Taking into consideration the particularities of these two sports, is there an
alteration of the knee F:E ratio as a result of the method of training of physically
immature athletes? The determination of significant differences that might exist in
the F:E ratios at various angular velocities is essential in ascertaining specific goals
in strength-training programs and in rehabilitation after injury. Therefore, the present
investigation was conducted to determine young male gymnasts’ and swimmers’
F:E muscle ratios, based on the peak torque achieved in knee testing, using an
isokinetic device at different concentric angular velocities.

**Methods**

**Participants**

Nine gymnasts (10.3 ± 0.5 years old) and 14 swimmers (10.5 ± 0.5 years old), all
prepubescent boys (first Tanner stage), volunteered to participate in the study. Their
physical characteristics are presented in Table 1. Swimmers trained regularly about
10 hr/week, and gymnasts about 12 hr/week, throughout the year. The training
program was different between the two groups, and it was adapted to the athletes’
age and competitive level. The participants avoided any systematic resistance-
training program for 2 days preceding the testing day, and none declared muscu-
loskeletal problems. The measurements were performed in a precompetition period.
All athletes were accompanied by their coaches and their parents, were informed
about the testing procedure, and gave their consent before engaging in the investi-
gation.

**Table 1 Physical Characteristics of the Participants**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Gymnasts (n = 9)</th>
<th>Swimmers (n = 14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>10.3 ± 0.5</td>
<td>10.5 ± 0.5</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>30.5 ± 3.2</td>
<td>38.8 ± 4.8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>132.9 ± 4.1</td>
<td>145.3 ± 6.2</td>
</tr>
<tr>
<td>Training age (years)</td>
<td>4.2 ± 1.1</td>
<td>3.8 ± 0.9</td>
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</tbody>
</table>
Measurements

Concentric isokinetic peak torque during unilateral (right) knee extension and flexion was measured by a Cybex® Norm dynamometer (Cybex Division of Lumex, Ronkonkoma, NY) at different angular velocities (60, 120, and 180°/s) after gravity correction (16) at a rate of 500 Hz. Only one leg was tested, because other studies have established no significant difference in isokinetic torque production between the dominant and nondominant leg (7,13,18,21).

Assessment Procedures

Before testing, a habituation session in the isokinetic apparatus was given, consisting of two submaximal and two maximal concentric isokinetic knee extensions and flexions at each angular velocity tested. On the testing day each participant performed 5 min of warm-up on a cycle ergometer (60 W, 60 cycles/min) followed by the isokinetic tests. The tests were performed on the Cybex from the seated position (hip-flexion angle 115°) with the participants’ arms flexed and crossed in front of the thorax. Velcro™ straps were placed around the waist and crossed over the shoulders to minimize extraneous upper body movements. The upper portion of the thigh of each participant’s leg was stabilized on the chair (approximately 5 cm above the patella) in order to isolate knee extension and flexion. The axis of rotation of the dynamometer was aligned approximately with the axis of the knee (lateral femoral condyle). The active leg was fixed on the Cybex mechanical lever above the malleolus (2–4 cm). The contralateral leg was kept inactive with the knee in 90° flexion.

During testing protocol, each participant performed three maximal concentric knee extensions and flexions alternately at 60, 120, and 180°/s angular velocities in a randomized order. The velocities were chosen to match as closely as possible with other studies in young athletes (2,4,5,17) with respect to our participants’ possibilities. The range of motion of the knee was 90° (0° full extension). The participants had their torque scores as visual feedback on the monitor of the dynamometer, and they were instructed to work as hard as possible in both directions of movement (15). Hamstring and quadriceps force production in the isokinetic dynamometer was greater, as reported by Campenella and associates (8), when combined visual feedback and verbal encouragement were provided. All tests were separated by 3-min rest periods in order to avoid any fatigue effect.

The best score of peak torque of each participant was used for further analysis. Knee F:E peak-torque ratios were computed for each angular velocity (2,7,17,19,21,22,26). Acceptable reliability coefficients for F:E peak-torque ratios have been established (14).

Statistical Analysis

A 2 × 3 (Sport × Angular Velocity) analysis of variance (ANOVA) was conducted to examine the interaction of sport and angular velocity on knee F:E peak-torque ratios. A post hoc Tukey–Kramer test was used to determine the differences between gymnasts and swimmers and the changes in angular velocities. Significance was accepted at a p < .01 level.
Results

The ANOVA revealed significant interaction of sport and angular velocity on knee F:E peak-torque ratios ($F = 22.73, p < .001$). A sport effect ($F = 11.33, p < .01$) on knee F:E ratios was found. Gymnasts presented significantly higher ratios than swimmers did at the velocities of 120°/s ($p < .01$) and 180°/s ($p < .001$). The F:E peak-torque ratios at the lower angular velocity (60°/s) did not differ significantly between gymnasts and swimmers. An angular-velocity effect on F:E peak-torque ratios ($F = 29.53, p < .001$) was also revealed. The knee F:E peak-torque ratios of the gymnasts increased, whereas the swimmers’ ratios did not change as the angular velocity of the limb increased. Particularly significant differences were found in gymnasts’ F:E peak-torque-ratio values between angular velocities of 60 and 120°/s ($p < .01$), as well as between 60 and 180°/s ($p < .01$; Figure 1).

It was found, however, that there was a significant decrease in peak torque ($p < .01$) as the angular velocity increased for knee extensors and flexors in both groups of athletes.

Discussion

The F:E peak-torque ratios were studied in two groups of young male athletes, gymnasts and swimmers, using concentric isokinetic testing for knee muscles at different angular velocities. The main results showed that at the lower angular velocity (60°/s) the F:E ratios of all participants varied between 0.65 and 0.71, which is in agreement with the literature concerning young athletes involved in different sports (4,7,12). Furthermore, the results of the present study concerning the effect of velocity on peak-torque values agreed with those of other research that found that the concentric torque production of the knee extensors and flexors

![Figure 1 — Gymnasts’ and swimmers’ knee flexor:extensor peak-torque ratios at different angular velocities. **p < .01 and ***p < .001.](attachment:image)
decreased significantly with increased angular velocity (4,11,12,13,21,22). The F:E peak-torque ratios of gymnasts, however, increased significantly as the angular velocity of the limb increased. This finding is well documented in studies with participants in different sports (1,2,7,11,12,22). Moreover, Morris et al. (19) pointed out that the hamstring:quadriceps ratio was lowest at angular velocities producing the highest torque. Knee F:E peak-torque ratios in pubescent football players and gymnasts at angular velocities of 60°/s and 180°/s were 0.75 and 0.90, respectively (2). These data were very close to those of the present study (0.68–0.88). A contradictory study has shown that the F:E peak-torque ratio was unusually low (0.50), suggesting that the hamstrings are weak relative to the quadriceps. In addition, this ratio was maintained as angular velocities increased (21). These results are reported for older gymnasts (12–27 years), however, in an attempt to better understand the etiology of anterior cruciate ligament injuries.

The phenomenon of increased ratios with increasing angular velocities might be explained by the fact that as velocity increases, comparing peak torque between 60 and 180°/s, the rate of decrement was greater in knee extensors (34%) than in knee flexors (14%). This observation agrees with previous reports using isokinetic dynamometers (7,11,13,22), which also suggested that as angular velocity increased the decrease in torque output was less for the hamstring than for the quadriceps. This is probably a result of the initial level of flexors, which is significantly lower than that of the extensors during the lower angular velocity. Thus, flexors appeared to be more resistant than extensors in torque loss during higher angular velocities, and consequently the F:E ratios increased.

Wyatt and Edwards (24) supported the finding that at higher angular velocities the hamstrings become the major dynamic stabilizer of the knee and can play a greater role in muscle balance (7). These suggestions should be carefully interpreted, however, because studies during the 1980s failed to correct for the effects of gravity during their isokinetic-testing procedure. This failure has been proven to cause underestimation of quadriceps peak torque and overestimation of hamstring peak torque, thereby increasing the knee F:E ratio (25). It should be noted that in the present study a gravity correction was done for all torque values of the participants. As angular velocity increased, however, the knee F:E ratios of gymnasts increased, as we previously reported, whereas in swimmers the ratios remained unchanged.

The phenomenon concerning swimmers’ peak-torque ratios might be explained by the fact that the peak torque decreased by the same percentage (25%) for knee-extensor and -flexor muscles. It is expected that swimmers, during knee isokinetic testing, can retain their flexor-to-extensor muscle balance at a torque ratio of 0.66, independent of the angular velocity of the limb (shank). This is probably a result of swimming-specific training, which obliges athletes to propel themselves in water, in which they train to undergo a kind of continuous isokinetic muscle contraction (3). Therefore, the alternating powerful contraction of hamstring and quadriceps muscles might render them similarly efficient in torque variations at slow and fast speeds and could contribute to the knee muscles’ balance. Consequently, during peak-torque measurements on the isokinetic dynamometer, the F:E ratios remained unchanged at all angular velocities. To our knowledge, consistent results in swimmers have not been reported in the literature. In contrast, gymnasts presented high ratios (0.80–0.90) as angular velocity increased, whereas in low velocities they did not differ from swimmers’ ratios. It should be noted that
the gymnasts at high angular velocities (180°/s) produced 34% and 25% higher torque ratios than those of the swimmers. This probably reflects the gymnastics training effect, given that with a few years of training the hamstring and the quadriceps would not increase proportionally by exactly the same amount of torque. It seems that this particular mode of training renders flexors more resistant to torque loss at high angular velocities in order to control and stabilize the knee joint.

Isokinetic knee F:E peak-torque ratios provide a useful tool to ascertain muscle imbalances, especially for athletes undergoing intensive training from early childhood and during periods of rapid growth. The results of the present study provide important information for the adjustment of the specific strengthening and training processes that can be used to protect athletes from chronic injuries. Moreover, ratios might help establish safe rehabilitation goals for muscle strengthening during isokinetic therapeutic activity and determine when to return an athlete to full activity after injury.

We acknowledge, however, that a potential limitation of this study is that the athletes participated in a few years of particular training after selection, taking into consideration sports-specific criteria. Therefore, the results described here should be carefully interpreted and not generalized for other pediatric sport populations. The knee F:E ratios probably also depend on athletes’ gender, training age, and competitive level. Further work is needed with a larger sample to establish normative data for torque ratios at lower, as well as higher, angular velocities and with a variety of muscle contractions. Continued research in this area will help elucidate the factors that contribute to the characterization of normal or abnormal F:E ratios for these particular sports.

References