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Sex differences in trunk, pelvis, hip and knee kinematics and eccentric hip torque in adolescents

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ABSTRACT

Background: Adolescents have a high incidence of knee joint dysfunctions, with up to 28% of adolescents reporting knee pain. Although adolescent females have a greater incidence of knee injuries in comparison to males, few studies conducted biomechanical evaluations in this population aiming to identify sex differences. If trunk and/or lower limb biomechanical impairments are identified in female adolescents, the implementation of early interventions for injury prevention will be better justified. The purpose of this study was to compare the trunk, pelvis, hip and knee kinematics during a single-leg squat task, as well as the isokinetic eccentric hip torque, between male and female healthy adolescents.

Methods: Forty-four healthy adolescents were divided into two groups, group of males ($n = 22$) and group of females ($n = 22$). Kinematics during single-leg squat were assessed using a electromagnetic tracking system. For the evaluation of eccentric hip torque in the three planes an isokinetic dynamometer was used. Group differences were assessed using a one-way multivariate analysis of variance.

Findings: Results showed that adolescent females presented greater hip adduction, hip external rotation and knee abduction, as well as smaller trunk flexion during single-leg squat in comparison to males. Additionally, adolescent females showed smaller isokinetic eccentric hip torque normalized by body mass in all planes in comparison to males.

Interpretation: These sex differences in terms of trunk/lower limb kinematics and eccentric hip torque generation might play an important role in the greater incidence of overuse knee injuries observed in adolescent females.

1. Introduction

Adolescents have a high incidence of knee joint dysfunctions, with up to 28% of adolescents reporting knee pain (Mølgaard et al., 2011; Rathleff et al., 2013a, 2013b). One of the most frequent knee dysfunctions among adolescents is patellofemoral pain (PFP). It has been reported that as much as 50% of the nonspecific anterior knee pain among adolescents may be attributed to PFP (Mølgaard et al., 2011). It is also worth noting that large sex discrepancies regarding the incidence of PFP occur in adolescents, with females being more affected than males (Mølgaard et al., 2011; Rathleff et al., 2013a). In spite of that, few studies conducted biomechanical evaluations in this population, in order to bring further enlightenment on the reasons for these discrepancies.

In a recent prospective study, Rathleff et al. (2013b) accompanied 215 adolescents with anterior knee pain for a period of one-year. They observed that, after this period, approximately 50% of the adolescents still had symptoms, suggesting that adolescent knee pain is not a benign and self-limiting condition (Rathleff et al., 2013b). Prospective and retrospective studies have also shown that a long duration of symptoms and older age decrease the chance of treatment success in the rehabilitation of patients with PFP (Blond and Hansen, 1998; Collins et al., 2010). Therefore, the early identification of biomechanical factors that might be associated with this dysfunction is relevant for rehabilitation and prevention purposes.

It has been demonstrated that young adults with PFP present increased trunk ipsilateral lean, contralateral pelvic drop, hip adduction, hip internal rotation and knee abduction in comparison to healthy counterparts during single-leg squat (Nakagawa et al., 2012a, 2012b; Souza et al., 2010). Previous studies also showed that young adults with PFP present impaired eccentric hip torque generation capacity in comparison to adults without knee pain (Baldon et al., 2009; Boling et al., 2009; Nakagawa et al., 2012b). These biomechanical impairments have been shown to be more exacerbated in females (Nakagawa et al., 2012b), which might explain why there is also a sex discrepancy regarding the incidence of PFP in adults.

Sex differences regarding trunk and lower limb kinematics during single-leg squat (Baldon et al., 2011; Graci et al., 2012; Nakagawa et al., 2012a, 2012b; Zeller et al., 2003) and isokinetic eccentric hip torque (Baldon et al., 2011; Nakagawa et al., 2012b) have been observed

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between young adults. Specifically, in these studies, females showed greater hip adduction (Graci et al., 2012; Nakagawa et al., 2012a, 2012b; Zeller et al., 2003), knee abduction (Graci et al., 2012; Nakagawa et al., 2012a, 2012b), trunk ipsilateral lean (Nakagawa et al., 2012a, 2012b) and contralateral pelvic drop (Nakagawa et al., 2012a), as well as smaller trunk flexion (Graci et al., 2012) in comparison to males during single-leg squat. Adult females also showed diminished eccentric hip torque generation capacity in comparison to males (Baldon et al., 2011; Nakagawa et al., 2012b). However, to date, it is unclear if these biomechanical sex differences are already present in adolescents.

If trunk, pelvis and/or lower limb biomechanical impairments are identified in female adolescents, the implementation of early interventions for injury prevention will be better justified. Therefore, the main purpose of this study was to compare the trunk, pelvis, hip and knee kinematics between male and female healthy adolescents during a single-leg squat task. A second purpose was to compare the eccentric isokinetic hip torque in the three planes between male and female adolescents. The hypothesis was that adolescent females would demonstrate greater hip adduction, hip internal rotation, and knee abduction, as well as smaller trunk flexion and greater trunk and pelvis displacement in the frontal plane in comparison to males, due to less trunk control, during single-leg squat. It was also hypothesized that female adolescents would present diminished hip torque generation capacity in comparison to males.

2. Methods

2.1. Subjects

Forty-four healthy sedentary adolescents, 14–18 years of age, volunteered for this study and were divided into 2 groups: group of males [GM, $n = 22$; age $= 16.41$ (1.50) yr, height $= 1.74$ (0.05) m, body mass $= 66.98$ (8.14) kg, body mass index $= 21.98$ (2.00) kg/m^2] and group of females [GF, $n = 22$; age $= 16.55$ (1.14) yr, height $= 1.64$ (0.07) m, body mass $= 56.45$ (5.57) kg, body mass index $= 20.98$ (1.67) kg/m^2]. The subjects were recruited from local schools and were invited to participate in the study. The following exclusion criteria were adopted in the study: 1) current injury or previous surgery in the lower limbs and/or lumbar spine; and 2) regular practice of physical activity, in a frequency of 3 times per week or greater. The Ethics Committee of the University approved the study. The volunteers signed an informed consent form and parental consent was also obtained for subjects younger than 18 years of age.

The a priori sample size was calculated on the basis of the knee abduction excursion data obtained from another study (Nakagawa et al., 2012b). Calculations were made using the Statistica software (StatSoft Inc, Tulsa, OK, USA) and considering $\alpha = 0.05$, $\beta = 0.20$, an expected difference between groups of 3.4°, and a within-group standard deviation of 3.8°. On the basis of the results, twenty-one subjects per group were required to adequately power the study for the variables of interest. The subjects' left or right lower limb was randomly selected for evaluation. The selected limb was submitted to a kinematic evaluation during single-leg squat and to an eccentric isokinetic evaluation. The dominant lower limb was evaluated in 13 subjects of the GM and in 12 subjects of the GF.

2.2. Kinematic evaluation

Trunk, pelvis, hip and knee kinematics were measured using electromagnetic tracking with the Flock of Birds® device (Ascension Technology Corporation, Burlington, USA) integrated with the MotionMonitor™ software (Innovative Sports Training, Chicago, USA) at a sampling rate of 90 Hz. Five electromagnetic sensors were attached to the sternum, sacrum (S2), the distal lateral thighs and the anteromedial aspect of the proximal tibia using adhesive tape (Nakagawa et al., 2012b). The ankle joint and knee joint centers were determined by digitalization of the medial and lateral malleoli and femoral epicondyles, respectively. For estimation of the hip joint center, the functional approach previously described by Leardini et al. (1999) was used. Next, for the determination of the neutral alignment angles of the joints, a static file was taken with the subject in anatomic position.

The subjects were evaluated while performing a single-leg squat task (Fig. 1a). First, they were instructed to flex the knee of the non-tested limb to 90° and cross the arms over the chest. Then, they were instructed to squat down as far as possible during a 2-second period and then return to a single-legged stand during a further 2-second period, monitored using a digital metronome (Nakagawa et al., 2012b). Real time visualization of the task was conducted using the MotionMonitor™ software (Fig. 1b). The subjects were allowed to do 2–3 familiarization trials before data collection. Afterward, three valid trials were collected with 1-min of rest between the trials for analysis. If the subjects performed the single-leg squat with at least 60° of knee flexion within a 4-second period without losing their balance, the trial was considered valid (Nakagawa et al., 2012b).

Using the same methodology for the kinematic evaluation, a prior reliability study verified high between-section intrarater reliability for the variables of interest of this study. In particular, the intraclass correlation coefficients ($ICC_{3,1}$) and standard error of measurements (SEM) were 0.88 (1.4°) for trunk flexion, 0.82 (0.4°) for ipsilateral trunk lean, 0.95 (1.2°) for contralateral pelvic drop, 0.89 (1.8°) for hip internal rotation, 0.96 (1.5°) for hip adduction, and 0.92 (1.3°) for knee abduction (Nakagawa et al., 2014).

2.3. Isokinetic evaluation

A Biodex Multi-Joint System 2 isokinetic dynamometer (Biodex Medical System, Inc., Shirley, NY, USA) was used for the eccentric hip torque evaluations. All procedures, including gravity correction of the torque measures, were conducted according to the specifications of the equipment's instructions manual. Evaluations consisted on maximal eccentric reciprocal contractions of the extensor/flexor, external/internal rotator and adductor/abductor hip muscles at a 30°/s angular speed (Baldon et al., 2012; Scattone Silva et al., 2013). The order of the evaluations was random.

For the eccentric hip extension/flexion torque evaluation, participants were positioned with 90° of trunk flexion and the arms wrapped around the dynamometer chair for trunk stabilization (Scattone Silva et al., 2013). The dynamometer's axis of rotation was aligned with the greater trochanter of the femur on the test limb. The lever arm applied resistance on the posterior aspect of the thigh, just proximal to the popliteal fossa. The non-tested leg supported the body of the participant (Fig. 2a). The participants were instructed to keep 90° of knee flexion during the test. The test's range of motion was from 90° of hip flexion to 60° of hip flexion (Scattone Silva et al., 2013).

In the hip external/internal rotation eccentric test, the participants were placed in sitting position with 90° of knee and hip flexion and with the hip of the limb being tested at 10° of internal rotation (Scattone Silva et al., 2013). The axis of rotation of the dynamometer was aligned with the long axis of the femur and the lever arm was attached 5 cm above the lateral malleolus (Fig. 2b). The range of motion of this test was from 10° of hip internal rotation to 20° of hip external rotation (Scattone Silva et al., 2013).

For the hip abduction/adduction eccentric torque evaluation, the subjects were positioned in side-lying. The tested lower limb was positioned parallel to the ground in a neutral sagittal and transverse plane position. The contralateral hip and knee were flexed and fixed with straps. The mechanical rotation axis of the dynamometer was aligned with a point representing the intersection of two lines. One line was directed inferiorly from the posterior–superior iliac spine toward the knee and the other one was posteriorly and medially directed from the greater trochanter of the femur toward the body's midline (Baldon