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Landing from different heights: Biomechanical and neuromuscular strategies in trained gymnasts and untrained prepubescent girls

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ABSTRACT

The purpose of this study was to examine the biomechanics of the lower limb, during landing in female prepubertal gymnasts and prepubertal untrained girls, aged 9–12 years. Ten healthy participants were included in each group and performed five landings from 20, 40, and 60 cm. Kinematics, ground reaction forces (GRF) and electromyogram (EMG) from the lateral gastrocnemius, tibialis anterior, and vastus lateralis are presented. Gymnasts had higher vertical GRF and shorter braking phase during landing. Compared to untrained girls, gymnasts exhibited for all examined drop heights more knee flexion before and at ground contact, but less knee flexion at maximum knee flexion position. Especially when increasing drop heights the gymnasts activated their examined muscles earlier, and generally they had higher pre- and post landing EMG amplitudes normalized to the peak EMG at 60 cm drop height. Furthermore, gymnasts had lower antagonist EMG for the tibialis anterior compared to untrained girls, especially when landing from higher heights. It is concluded that the landing strategy preferred by gymnasts is influenced by long-term and specialized training and induces a stiffer landing pattern. This could have implications in injury prevention, which requires further investigation.

1. Introduction

Landing is a task encountered in many daily activities and is also part of specialized movements in some athletic events. The ability to land on both feet evolves at the early age of childhood and is improving until maturing age (McKinley and Pedotti, 1992). The objective during landing is to absorb the kinetic energy of the body, while maintaining balance. Although it seems an apparently easy and common task, the underlying neural control is rather complex, including the spatiotemporal prediction of the ground contact, the prediction of the magnitude of vertical ground reaction force (GRF), and the control of the position and angular displacement of multiple joints by activating or inhibiting the appropriate muscles in the right timing and magnitude (Santello, 2005).

Landing after complex gymnastic exercises is very challenging (Panzer, 1987). According to the International Federation of Gymnastics and the Code of Points (2013), gymnasts must comply with general and specific guidelines to achieve better score/performance. Such guidelines include landing with a single placement of the feet on the ground and exerting as little limb flexion as possible. This implies that gymnasts are actually trained to land with stiff lower limbs, which could explain previous findings of the increased load at their hip and ankle joints and the reduced braking phase duration (McNitt-Gray, 1993; Sabick et al., 2005; Seegmiller and McCaw, 2003).

Despite the increased landing heights and the large number of landings, which could cause injury to an untrained person (Teh et al., 2003), the vast majority of landings performed by gymnasts are injury free in a regulated for quality and quantity training environment. However, it is still unexplored which protective mechanisms could be possibly adopted in their landing strategy in order to decrease the probability for injury. One possibility to examine such mechanisms is by comparing biomechanical and neuromuscular properties of gymnasts with untrained subjects. This is particularly important for females since they have 4–6 more frequent anterior cruciate ligament (ACL) injury incidents (Hewett et al., 1999) which occur often during non-contact activities such

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as landings (Boden et al., 2000; Noyes et al., 1983). Considering the above, comparison on the landing technique between young gymnasts and untrained subjects, especially for the female ones, is important not only from a scientific but also from an injury prevention point of view. Evaluating biomechanics and neuromuscular parameters not only documents possible differences in technique between the groups, but also will possibly help us recognize why such differences occur and understand the underlying mechanisms.

The most critical regulating factor that contributes to landing is leg stiffness, which is the result of the segmental configuration at touch-down, and of the neuromuscular activation (Hoffrén et al., 2007; Horita et al., 2002). Regarding the neuromuscular component, stiffness regulation is achieved by the agonist and antagonist muscle activation before the ground contact (pre-activation), and during the braking phase (stretch reflex and voluntary response) (Hoffrén et al., 2007; Horita et al., 2002; Kramer et al., 2012; Lazaridis et al., 2010; Leukel et al., 2008; McKinley and Pedotti, 1992). Pre-activation plays a major role on the strategy of landing, and both timing and amplitude are controlled by the central nervous system (Santello, 2005). The magnitude and onset of the anticipatory muscle activation before touch-down is influenced by several factors such as the age of the subjects (Lazaridis et al., 2010), the examined muscle (Santello et al., 2001; Schmitz et al., 2002; Thompson and McKinley, 1995), the landing surface (hardness, inclination) (Devita and Skelly, 1992; Dyhre-Poulsen et al., 1991; Fu and Hui-Chan, 2002; Kamibayaashi and Muro, 2006; McKinley and Pedotti, 1992; Santello, 2005), and the motor learning experience (Croce et al., 2004; Quatman et al., 2006; Schmitz et al., 2002; Viitasalo et al., 1998). The height of the drop constitutes a controversial factor that could affect preactivation, although most of the studies agree that preactivation increases with increasing drop height (Dyhre-Poulsen et al., 1991; Greenwood and Hopkins, 1976; Santello and McDonagh, 1998; Sidaway et al., 1989; Thompson and McKinley, 1995; Viitasalo et al., 1998). However, it is still unknown how the neuromuscular system of trained and untrained persons of young age adapts, when increasing drop heights in landings. The description of the neuromuscular function at this stage of development, especially for children who undergo a significant load of training, is important to document the adaptability of various neural and muscular components and to explain or even predict the effect of training in their future life.

Considering the above, the purpose of this study is twofold. Firstly, to describe from a biomechanical point of view the adjustments that children do when landing from different heights, and secondly, to investigate how children with training background in landings, such as gymnasts, adapt to this task. We hypothesize that untrained children could adopt a more immature technique during landing compared to gymnasts, whose technique might have similar characteristics to the adults' one, as described previously (Lazaridis et al., 2010). To test this hypothesis, we analyzed the sagittal kinematics (hip, knee and ankle), the electromyographic activity of 4 major lower limb muscles and the vertical GRF when landing from three different heights (20, 40, and 60 cm).

2. Methods

2.1. Participants

Twenty prepubescent girls (10 gymnasts, 10 untrained girls), 9–12 years old participated in the study voluntarily (Table 1). The gymnasts had a training experience of 5–8 years and they trained 6 times weekly for about 4 h per day. The untrained girls did not participate systematically in any sports training program during the past 2 years. Body fat was determined with a skinfold caliper (Lafayette, Lafayette Instrument Co., Lafayette IN, USA) by measuring the triceps brachii and subscapular skinfolds (Slaughter et al., 1988). All children were determined as prepubescent according to Tanner's scale (Tanner, 1962), were free of any neuromuscular disorder that could influence lowerextremity performance and did not have any back or lower extremity injuries history. Before testing, the prepubescents' parents read and signed a written informed consent statement.

Table 1
Age and anthropometric characteristics of the participants (mean ± standard deviation). Last column represents the statistical p-value comparing the groups using an unpaired *t*-test.

	Gymnasts (n = 10)	Untrained (n = 10)	p-value
Age (in years)	10 ± 1	11 ± 1	0.699
Body height (in cm)	139 ± 7	150 ± 7	0.002
Body mass (in kg)	33 ± 4	44 ± 8	<0.001
Body fat (in % of body mass)	11 ± 2%	18 ± 2%	<0.001

2.2. Instrumentation

Kinematic data were captured at 100 Hz using a six-camera 3D motion analysis system (VICON 612, Oxford Metrics Ltd., Oxford, Oxfordshire, UK). Sixteen reflective markers (14 mm diameter spheres) were placed at anatomical bony landmarks of lower extremities according to Davis et al. (1991). GRF were recorded with a ground mounted 40×60 cm force plate (Bertec Type 4060, Bertec Corporation, Columbus, OH, USA). Prior data collection, the motion analysis system was calibrated according to the manufacturer's recommendations.

The EMG activity was recorded with a wireless EMG device (BTS Telemg, Milano, Italy; sampling rate 1 kHz, CMRR >110 dB at 50/60 Hz, gain: $\times$1.000, bandwidth: 10–500 Hz) using bipolar surface Ag/AgCl disc electrodes (diameter: 0.8 cm, interelectrode distance: 2 cm). The EMG electrodes were placed on the right lateral gastrocnemius (LG), tibialis anterior (TA), and vastus lateralis (VL) muscles, following the SENIAM guidelines (Hermens et al., 1999). The ground electrode was placed over the bony surface of the contralateral wrist. Skin was shaved and cleaned with an alcohol solution and skin impedance was maintained below 2 kΩ.

2.3. Procedures

One investigator assessed all measurements. Initially, the anthropometric data required for the kinematics and the GRF were measured. Then the participants followed a warming-up program (5-min treadmill walking-jogging, and stretching) and finally the EMG electrodes and markers were placed.

The participants performed 5 landings from 20, 40 and 60 cm, in random order, with 2 min rest interval in-between. They were barefoot and the starting position was akimbo, with the landing initiated by stepping out from the platform (without pushing or hopping) with their leg of preference. Any landing that was not stable and required extra steps or hops after touch-down, were repeated.

2.4. Data analysis

Each trial was analyzed and the mean value of all landings was used for further statistical analysis. The peak vertical GRF was normalized to the body mass and the square root of drop height, because based on the impulse-momentum relationship and the properties of uniformly accelerated motion, the average vertical