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Full Length Article

Spinal kinematics during gait in healthy individuals across different age groups

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ABSTRACT

Most studies investigating trunk kinematics have not provided adequate quantification of spinal motion, resulting in a limited understanding of the healthy spine's biomechanical behavior during gait. This study aimed at assessing spinal motion during gait in adolescents, adults and older individuals.

Fourteen adolescents (10–18 years), 13 adults (19–35 years) and 15 older individuals (≥65 years) were included. Using a previously validated enhanced optical motion capture approach, sagittal and frontal plane spinal curvature angles and general trunk kinematics were measured during shod walking at a self-selected normal speed.

Postural differences indicated that lumbar lordosis and thoracic kyphosis increase throughout adolescence and reach their peak in adulthood. The absence of excessive thoracic kyphosis in older individuals could be explained by a previously reported subdivision in those who develop excessive kyphosis and those who maintain their curve. Furthermore, adults displayed increased lumbar spine range of motion as compared to the adolescents, whereas the increased values in older individuals were found to be related to higher gait speeds. This dataset on the age-related kinematics of the healthy spine can serve as a basis for understanding pathological deviations and monitoring rehabilitation progression.

1. Introduction

In human locomotion, the importance of the upper body has been emphasized for over forty years (Saunders, Inman, & Eberhart, 1953). Saunders et al. (1953) identified six major determinants of gait, of which three have been related to the motion of the pelvis. Furthermore, they highlighted the motion of the pelvis and trunk to be essential determinants of bipedal gait. The involvement of the upper body in gait stability as well as a variety of changes in motion patterns due to aging and disease were further pointed out by McGibbon and Krebs (2001). Unfortunately, only few studies are available providing normative data on within-trunk or spinal kinematics (Crosbie, Vachalathiti, & Smith, 1997a, 1997b; Frigo, Carabalona, Dalla Mura, & Negrini, 2003; Kavanagh, Barrett, & Morrison, 2005; Konz et al., 2006; Leardini, Biagi, Merlo, Belvedere, & Benedetti, 2011; Menz, Lord, & Fitzpatrick, 2003; Van Emmerik, McDermott, Haddad, & Van Wegen, 2005), leaving us with a limited understanding of the biomechanical behavior of the healthy spine during gait.

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In contemporary biomechanical research as well as in clinics, gait kinematics are usually measured using skin marker-based motion capture systems. However, most of the studies using this method solely included young adults and evaluated either rigid trunk segments or very simple 2D projection angles. A major disadvantage of such approaches is that they allow only a limited assessment of the actual curvature of the spine. To address this deficit, an enhanced trunk marker set (IfB marker set) was previously introduced and validated for the assessment of sagittal spinal curvature in healthy subjects as well as sagittal and frontal spinal curvature in patients with adolescent idiopathic scoliosis (AIS) (List, Gulay, Stoop, & Lorenzetti, 2013; Schmid et al., 2015; Zemp et al., 2014). The importance of measuring spinal curvature angles in addition to general trunk kinematics was further emphasized by Schmid et al. (Schmid, Studer, et al., 2016), showing clear differences in spinal curvature angles between healthy adolescents and patients with AIS using these techniques, but not in angles based on commonly-used rigid trunk segments.

Walking speed is known to have an influence on pelvis and head movements in healthy adults, whereby increased walking speed corresponds to an increase in the magnitude and variability of the acceleration of these segments (Menz et al., 2003). It has therefore been proposed that an individual's comfortable walking speed is selected in order to minimize the level of acceleration variability as well as to ensure smooth and rhythmic pelvis and head movements (Menz et al., 2003). When looking at differently aged populations, this comfortable walking speed was reported to decline with increasing age (Himann, Cunningham, Rechnitzer, & Paterson, 1988; Imms & Edholm, 1981; Murray, Kory, & Clarkson, 1969) suggesting that older individuals might present kinematic changes due to a decreased walking speed. However, walking speed seems not to be the only factor responsible for altered trunk kinematics with advanced age, since older subjects have been shown to exhibit different head and trunk motion patterns compared to younger subjects even when walking at equal speeds (Kavanagh et al., 2005). In addition, Van Emmerik et al. (2005) reported altered movement amplitudes of the pelvis and trunk segments between young, adult and older individuals that were not related to walking speed. These non-walking speed-related changes might be explained by age-related morphological changes that lead to the previously observed decreases in maximal sagittal range of motion of the lumbar, thoracic and cervical spine in older individuals (Kuo, Tully, & Galea, 2009). Although normal trunk motion during gait was described to be small (i.e. less than 5 degrees range of motion) (Frigo et al., 2003), a reduced maximal range of motion might still have an influence on the neuromuscular control of the respective joints.

In order to be able to comprehensively investigate pathologies that directly or indirectly affect the spine, accurate knowledge of the biomechanics of a healthy spine during gait with respect to age is critical. Using a previously validated enhanced non-invasive optical approach, the main aim of the current study was therefore to assess sagittal and frontal plane spinal curvature angles during gait in healthy adolescents, adults and older individuals and to provide a basis for future investigations involving pathologies. In addition, spatio-temporal gait parameters and absolute and relative angles of a rigid pelvis, lumbar, thoracic and cervical segment were calculated in order to support the interpretation of the primary outcomes.

2. Methods

2.1. Participants

Forty-two healthy individuals, divided into the categories adolescents (10–18 years, n = 14), adults (19–35 years, n = 13) and older individuals (≥ 65 years, n = 15), participated in the current study (Table 1). Subjects were included if they were in good overall health, considered of normal weight (no overweight or obesity), presented no history of spine surgery and did not suffer from back problems that required medical consultation or treatment in the previous 6 months. All participants (as well as the legal guardians of the adolescents) provided written informed consent and the study protocol was approved by the responsible ethics committees.

2.2. Data collection

Measurements of the adolescents were conducted in one movement analysis analysis laboratory using a 12-camera motion analysis system (type MXT20, Vicon, Oxford, UK; sampling frequency: 200 Hz), whereas the adults and older individuals were assessed in another laboratory using a 12-camera motion analysis system (type MXV612, Vicon, Oxford, UK; sampling frequency: 100 Hz). After the assessment of relevant anthropometric data, subjects were equipped with retro-reflective markers in the configuration of the IfB trunk marker set (List et al., 2013) (Fig. 1) in combination with the Plug-in Gait full body marker set (Romkes et al., 2007) (adolescents) and the IfB full body marker set (List et al., 2013) (adults and older individuals). Subsequently, all subjects were measured wearing their own comfortable shoes in a standing upright position for 2 s and during walking at self-selected normal

Table 1
Demographics of the healthy adolescents, adults and older individuals expressed as means with standard deviations (SD) and ranges (in brackets).

	Adolescents (n = 14)	**Adults** (n = 13)	**Older** (n = 15)
Age [years]	13.9 SD 1.5 (12–16)	27.0 SD 2.5 (21–35)	69.7 SD 1.8 (65–76)
Height [m]	1.61 SD 1.0 (1.46–1.84)	1.74 SD 0.6 (1.62–1.93)	1.70 SD 0.5 (1.56–1.83)
Mass [kg]	53.8 SD 10.2 (40.3–70.4)	68.6 SD 8.4 (47.0–86.0)	66.8 SD 6.8 (54.0–97.0)
Gender [male/female]	7/7	6/7	6/9