Clinical Biomechanics 29 (2014) 1116–1124

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Changes in muscle activity in typically developing children walking with unilaterally induced equinus

Laetitia Houx [a,b,c,*], Mathieu Lempereur [a,b], Olivier Rémy-Néris [a,b,c], Raphaël Gross [d], Sylvain Brochard [a,b,c]

[a] CHRU de Brest, Hôpital Morvan, Service de Médecine Physique et Réadaptation, Brest, France
[b] Laboratoire de Traitement de l'Information Médicale INSERM U1101, Brest, France
[c] Université de Bretagne Occidentale, Brest, France
[d] CHU de Nantes, Pôle de Médecine Physique et Réadaptation, Hôpital Saint Jacques, Nantes, France

ARTICLE INFO

Article history:
Received 10 June 2014
Accepted 29 September 2014

Keywords:
Gait
Fixed equinus
Electromyography
Children
Toe-walking

ABSTRACT

Background: Distinguishing changes in lower limb muscle activation during gait caused by abnormal motor control or adaptations to the presence of a fixed equinus remains a challenge. The objective of this study was to determine a threshold degree of equinus at which changes in muscle activity occur and to characterize adaptive patterns of muscle activity in typically developing children walking with unilateral induced equinus.
Methods: Ten typically developing children were included. A customized orthosis was fitted to the right ankle. Five conditions of dorsiflexion limitation were evaluated: 10° dorsiflexion, 0°, 10°, 20° of plantar flexion and maximum plantar flexion. Muscle activity of the rectus femoris, vastus lateralis, hamstring, tibialis anterior and soleus muscles of both limbs was recorded.
Findings: Significant changes in muscle activation and co-activation occurred from 10° of plantar flexion in the orthosis limb and from maximum plantar flexion in the contralateral limb. Soleus activation occurred prematurely in terminal swing and increased with the degree of equinus. Tibialis anterior activation was increased during initial and midswing and was decreased during terminal swing. From the −20° condition, hamstring activation was increased during the loading response. Vastus lateralis and rectus femoris activation was increased during stance phase. Similar changes in tibialis anterior and soleus activation occurred on the contralateral side. Changes in co-activation occurred in the soleus/tibialis anterior muscle pair in both limbs.
Interpretation: This study provides indications regarding changes in muscle activity during simulation of equinus gait which should be helpful for therapeutic decision making.

1. Introduction

Equinus gait, defined as a reduction in the range of ankle dorsiflexion during gait (Charles et al., 2010), is common in children with neurological disorders such as cerebral palsy (CP) (Svehlík et al., 2010). Equinus during stance phase is either caused by excessive dynamic activation of the ankle plantar flexors (known as dynamic equinus) or contractures of the triceps surae (known as fixed equinus) (Davids et al., 1999). Dynamic electromyography (EMG) (i.e. EMG during gait) is used to assess abnormal muscle activity in children with CP (Dimitrijević et al., 1981; Perry et al., 1974) and is used to select muscles which may benefit from treatments such as intramuscular botulinum injection (Corry et al., 1999; Manganotti et al., 2007; Metaxiotis et al., 2002; Novak et al., 2013; Sutherland et al., 1999) or muscle transfer surgery (Perry et al., 1974). However, dynamic EMG analysis does not provide any information regarding the cause of abnormal patterns. Abnormal muscle activity may be primary (i.e. directly due to abnormal neuromotor control) (Gage et al., 2009) or secondary (i.e. compensatory due to a fixed equinus) (Davids et al., 1999). For instance, early activation of the triceps surae during equinus gait in children with CP could be the direct result of abnormal motor control due to the cerebral lesions, or may be an adaptation to the presence of a fixed equinus (Massion, 1992). This lack of understanding of the alteration about the EMG pattern may lead to the wrong therapeutic decisions being made, such as treating compensatory patterns of activity with botulinum toxin. A greater understanding of the causes of changes in EMG patterns found in children with CP and unilateral equinus is thus necessary.

One method to increase understanding of changes in biomechanical gait parameters caused by equinus gait is to analyze the kinematics, kinetics and EMG patterns of typically developing (TD) individuals

---

Abbreviations: CP, cerebral palsy; EMG, electromyography; OF, orthosis free; TD, typically developing; RF, rectus femoris; VL, vastus lateralis; HA, hamstring; TA, tibialis anterior; SOL, soleus; NG, normal gait; MP, maximal plantar flexion.

* Corresponding author at: CHRU de Brest, Hôpital Morvan, Service de Médecine Physique et Réadaptation, 2 Avenue Foch, 29609 Brest Cedex, France.

E-mail address: laetitia.houx@chu-brest.fr (L. Houx).

http://dx.doi.org/10.1016/j.clinbiomech.2014.09.015
0268-0033/

walking while wearing an external constraint to block the ankle in plantar flexion. Studies using such a method have shown that during the stance phase of gait, equinus increases knee and hip flexion at initial contact (Goodman et al., 2004; Houx et al., 2011; Houx et al., 2013; Matjacic et al., 2006). One study showed that during stance, children adopted one of two strategies: knee flexion or knee hyperextension (Houx et al., 2013). Simulated equinus has also been shown to alter kinematics on the contralateral side, causing increased ankle plantar flexion at initial contact (Goodman et al., 2004; Houx et al., 2013). Most of these changes occur when the equinus is of at least 10° (Houx et al., 2011, 2013). Only a few studies have analyzed patterns of muscle activity during unilateral voluntary equinus gait in TD children (Davids et al., 1999) and adults (Couillandre et al., 2002; Perry et al., 2003; Romkes and Brunner, 2007; Rose et al., 1999). They found premature and increased activity of the soleus (SOL) and gastrocnemius muscles during stance (Couillandre et al., 2002; Davids et al., 1999; Perry et al., 2003; Romkes and Brunner, 2007; Rose et al., 1999), premature cessation of tibialis anterior (TA) activity during swing (Perry et al., 2003) and prolonged activity during stance (Rose et al., 1999). Activity of the vastus lateralis (VL), rectus femoris (RF) and hamstring (HA) muscles varied across the studies (Davids et al., 1999; Perry et al., 2003; Romkes and Brunner, 2007; Rose et al., 1999). One major limitation of these studies is that none of them standardized the degree of equinus induced during gait. This is important because it is thus not possible to establish a threshold degree of equinus which alters the EMG pattern. Such knowledge would be very useful for the interpretation of EMG, particularly to determine alterations found in kinematic and EMG patterns may be adaptations to the presence of equinus, rather than the direct result of the neurological lesions. Equally, none of the studies analyzed patterns of muscle co-activation occurring in the presence of the equines although co-activations frequently occur in children with musculoskeletal disorders and are often a target of treatment. It would be relevant to be able to differentiate between the co-activation of central origin and the co-activation which is secondary to biomechanical changes (Damiano et al., 2000; Gross et al., 2013). Moreover, data in children are scarce (Davids et al., 1999) and it is not always appropriate to transfer findings in adults to children. Studies involving the use of a constraint which can produce standardized positions of equinus during gait in TD children, which include an analysis of muscle activity (including co-contractions) are therefore lacking. Clinicians often have difficulty in differentiating primary neurological related changes in the patterns of muscle activity from changes which are related to altered biomechanics such as the presence of equinus. Such knowledge would improve clinical decision making in children with equinus gait (Davids et al., 1999; Gitter and McAnelly, 1998).

The main aim of this study was therefore to investigate patterns of lower limb muscle activity and co-activation during gait in TD children with different degrees of unilateral induced equinus in order (1) to determine a threshold degree of plantar flexion at which muscle activity changes and (2) to characterize changes in muscle activity in both limbs resulting from kinematic constraints induced at one ankle. The hypothesis was that, based on the kinematic and kinetic changes already described in the literature (Houx et al., 2013), changes in the patterns of muscle activation would occur from 10° of equinus, and that changes in muscle activity would occur mostly in the distal segments of both lower limbs.

2. Methods

2.1. Subjects and equinus simulation

An anterior right ankle orthosis was specifically designed for the study (Houx et al., 2011). The aim was to mimic limited dorsiflexion due to a fixed equinus, similar to a contracture of the triceps surae. The use of a turnbuckle with a sliding mechanism allowed free plantar flexion during swing but the ankle could be blocked in 5 successive positions. The orthosis was custom molded for each child and was well tolerated. Its structure was specially designed so as not to interfere with the surface EMG recording and the reflective markers (Houx et al., 2011).

Ten TD children (4 girls, mean age = 9.7 years) were included. The age range 8–12 years old was selected because the EMG patterns during gait are known to be consistent in this age-group (Lauer et al., 2010). The exclusion criteria were neurological or orthopedic pathology of the spine or the lower limbs. The protocol was approved by the Regional Institutional Ethical Research Committee and children and parents signed informed consent for participation and publication.

2.2. Experimental conditions

First, gait was recorded barefoot without the orthosis (normal gait/NG). The orthosis was then fitted to the child's right ankle and gait was recorded without the turnbuckle (orthosis free/OF). The orthosis was then adjusted with the child in standing, knee extended. Dorsiflexion motion was blocked using the turnbuckle and a goniometer was used to ensure that the positions were standardized (center positioned over the lateral malleolus, proximal arm lined up with the midline of the fibula and distal arm parallel to the lateral aspect of the fifth metatarsal (Norlin and White, 2003)). Five successive positions of the orthosis were tested: 10° of dorsiflexion (+10°), 0° of dorsi/plantar flexion (0°), 10° of plantar flexion (−10°), 20° of plantar flexion (−20°) and at the maximum plantar flexion angle (MP) allowed by the system (mean MP was 28° as calculated by the system after the gait analysis) (Houx et al., 2011). Each child carried out four 10-meter trials in each experimental condition. A 16 channel EMG system (MA-300, Motion Lab Systems, Baton Rouge, LA, USA) was used to simultaneously record the activity of RF, VL, HA, TA and SOL muscles of both limbs at a sampling frequency of 1080 Hz. Pre-amplified surface electrodes (MA-411, Motion Lab Systems, Baton Rouge, LA, USA) with a 17 mm inter-electrode distance and a signal bandwidth of 20 Hz to 3.5 kHz (−3 dB) were positioned according to the SENIAM recommendations (Hermens et al., 2000). The children wore the surface electrodes at the same location and without any removal during the whole experiment in order to ensure that the mean muscle activations would be comparable across conditions.

A 3D motion analysis system (Vicon MX 13, Oxford metrics, Oxford, UK) with nine infrared cameras and two AMTI force platforms 120 cm $*$ 60 cm (Advanced Mechanical Technology Inc., Watertown, MA, USA) was used to record spatio-temporal, kinematic and kinetic parameters. A total of 16 reflective markers were positioned on the lower limbs according to the protocol by Davis et al. (1991). Kinematic and kinetic data were computed using Plug-in gait (Vicon, Oxford Metrics Ltd., Oxford, UK).

The children were given several minutes to become accustomed to each new adjustment before trials were recorded. The children were trained to walk at a velocity close to 1 m/s, since gait velocity influences both kinematic, kinetic, and spatiotemporal parameters and muscle activation (Den Otter et al., 2004; Hof et al., 2002). With regard to the orthosis, all children were simply asked to walk to the end of the walk way and no instructions were given regarding the gait strategy. Degree of equinus was progressively increased to ensure that the orthosis was well tolerated throughout the experiment.

2.3. Data processing: gait analysis with EMG

Raw EMG signals were full-wave rectified and low-pass filtered (4th order zero lag Butterworth filter, cut-off frequency: 8.9 Hz) to construct linear envelopes (Shiavi et al., 1998). Maximal value from all gait trials was used to normalize the range of the linear envelope for each muscle. In order to evaluate differences in the EMG patterns between the different conditions, the gait cycle was divided into nine biomechanically relevant intervals (Perry, 1992): loading response (0–10%), midstance I