Age related changes in EMG profiles and muscle length patterns during gait in healthy growing children and adults

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***Abstract*— Lower limb EMG activity, as well as muscle length patterns were estimated for a large group of healthy growing children and adults. Variability in EMG phases and muscle length patterns (determined from the 3D kinematic data using a musculoskeletal model) were described for six age groups. Different types of EMG patterns were observed per muscle group, in all ages. In addition, significant developments with age could be recognized for a variety of EMG parameters. Differences between age groups were mainly found in stance phase. Except for the quadriceps, the duration of activity (expressed as percentage of gait cycle) decreased with increasing age. Except for the triceps, the muscle length patterns (lengthening, shortening, isometric) were mature at 3 years of age.**

Keywords-EMG; muscle length, normal gait

I. Introduction

EMG and muscle length profiles have become an important adjunct to gait analysis data in assisting with the analysis of pathological patterns. More insight into the muscle activity patterns and contraction modalities of gait for normal adults and children of different age groups is crucial to allow for a full exploitation of pathological gait. Significant differences in normal activity patterns of major muscle groups during walking have been described for adults. However, there is still much inconsistency in the results of different studies on muscle activity in walking adults. Despite of the large amount of clinical gait analysis studies in children, little information has been published about normal pediatric EMG profiles during walking. There is also a lack of objective studies evaluating the muscle length patterns or contraction modalities (concentric, eccentric, isometric) of activated muscles during gait, in adults as well as in children. The purpose of the study was to delineate significant EMG and muscle length differences during gait, observed between age groups in a large pediatric database and in adults.

II. Method

A. Subjects

63 healthy children, divided in 5 age groups (from 3 to 4 (N=12), 5 to 6 (N=10), 7 to 8 (N=14), 9 to 11 (N=14) and 16 to 17 years (N=13)), as well as 13 adults, underwent a full body 3D gait analysis. Kinematic and kinetic data were collected using an 8 camera VICON system (612) and 3 AMTI forceplates (Advanced Mechanical Technology Inc., Watertown, Massachetts). Muscle activity of 8 lower extremity muscle groups were obtained bilaterally, using a surface EMG system (L-Lab, Biometrics, AD Almere, The Netherlands, with high-pass filter, cut-off at 20 Hz, 18 dB/oct.).

B. Data collection

For each subject, EMG on/offset determination was performed by visual evaluation of the EMG traces, (definition of detectible rise in EMG activity above the steady state with 2 SD from the rest phase signal as a reference for steady state), for 3 gait trials bilaterally at self-selected speed. The activity patterns were averaged per limb. The muscle lengths of Gastrocnemius, Soleus, Tibialis Anterior, Rectus Femoris, Vastus Lateralis, Biceps Femoris, Semitendinosis and Gluteus Medius were estimated using a 4 segment musculoskeletal model (1) with 3D lower limb segment and joint kinematics as input for the model. Each muscle length was expressed as a percentage of the length that the muscle would have if the subject were in the anatomical position, where all joint angles are 0. For each age group, frequency of different activity profiles (timing and duration of on/off phases), as well as muscle length patterns (shortening, lengthening or isometric condition) were described and compared to normal adults. The linear envelopes (window of 20ms), normalized to the mean of the subject ensemble average, were averaged per activity patterns and per age groups.

C. Data collection

Differences in frequency distributions of patterns between age groups were defined by chi-squared tests. Between group differences of activity profiles and duration of activity were compared by Kruskal-Wallis and post-hoc Wilcoxon rank tests. A regression analysis was performed for each significant parameter to determine how the variance of muscle activity parameters (f.i. duration of muscle activity in stance) could be predicted by age. Finally, ANOVA and post hoc Tuckey tests were used to evaluate the differences between non-dimensional walking velocity (normalized to body dimensions) (2) of the different activity patterns per muscle.

III. Results

The total duration of activity significantly decreased with increasing age in the Lateral Hamstrings, but increased with increasing age in the Rectus Femoris, the Vastus Lateralis and the Gastrocnemius ($P<0.001$).

The overall averaged linear envelope of Rectus Femoris showed one major and one minor activity burst, with a peak value respectively at 4% and 62% of the gait cycle. Three patterns were recognized (Fig. 1): 61.3% of the subjects showed pattern one with a short stance phase activity (ending on average at 12.1% of the gait cycle), 5.3% of the subjects showed pattern two, characterized by a prolonged stance phase activity (on average until 45.8% of the gait cycle) and 33.3% of the subject presented with a third pattern, characterized by two activity phases in stance (during loading response and around toe-off). Significant developments with age were found for duration of the stance phase activity, the starting time of the second phase in pattern three and for the onset of swing phase activity. The main contraction modality for Rectus Femoris was eccentric for all subjects, starting at the end of swing phase, preceded by a period of concentric activity in mid-terminal swing. The results of ANOVA indicated that pattern three was typically seen for subjects walking at a high non-dimensional walking velocity ($P<0.0001$).

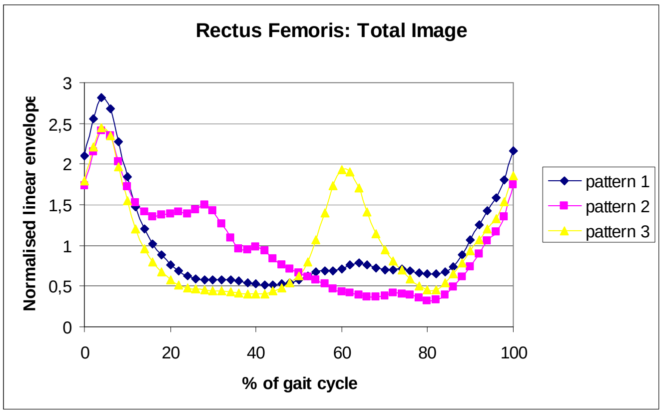

Figure 1: Linear envelopes of the different patterns of the Rectus Femoris

The Vastus Lateralis showed one major peak of activity around weight acceptance (4% of the gait cycle). The activity gradually increased starting at 80% of the gait cycle, with a peak at 4%. The linear envelope than decreased again until 20% of the gait cycle. Also three activity patterns could be recognized (short, prolonged and two-phasic stance phase activity), with only minor differences between age groups.

For the Hamstrings activity, again three patterns were defined, with a large similarity between the medial and lateral hamstrings. The first pattern was characterised by a stance phase activity which continued on average until 9% of the gait cycle. In pattern two, stance phase lasted longer then in pattern one (on average until 35.9% of the gait cycle). In pattern three, two activity phases in stance could be recognised. The first phase ended on average at 10% of the gait cycle, the second phase started on average at 27% and continued until 43% of the gait cycle. At initial contact and during loading response, activity was recognised in all ages. For the youngest children (three until eleven years old) an extra activity peak around 22% of the gait cycle could be recognized (mid stance). At terminal swing there was a peak activity for all ages. The timing of the peak activity in swing was similar for all ages. (Fig. 2).

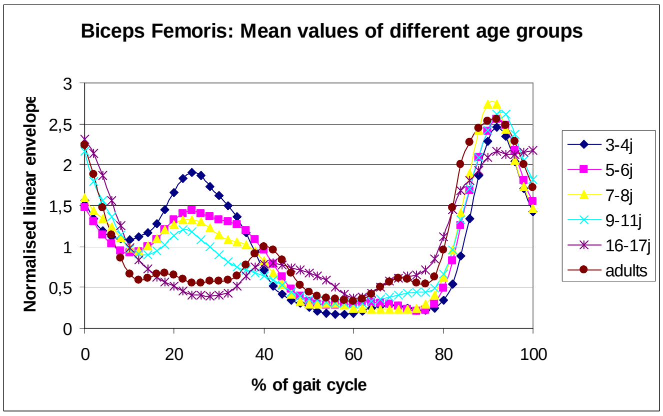

Figure 2: Mean values of the different age groups for the Lateral Hamstrings.

Terminal swing showed isometric co-contraction patterns for Rectus Femoris and Hamstrings in all subjects.

The overall averaged Gastrocnemius activity gradually increased at 20% of the gait cycle, with a peak value at 40%. After the peak value, the activity decreased until 58% of the gait cycle. A high similarity could be found between the age groups, however with a slightly increased duration of activity for the youngest children. Triceps activity in terminal swing was frequently observed, especially in the 3 to 4 years old children. The onset of Gastrocnemius activity, expressed in % in the gait cycle, gradually delayed with increasing age until age of 16 years ($P<0.005$). The most common contraction modality was eccentric contraction of gastrocnemius (lengthening) until 46% of the gait cycle, usually followed by a short period of concentric contraction (shortening of Gastrocnemius). However, concentric contraction at terminal stance was not recognized for 38.1% of the children of the 3-6y group, 16.1% of the 7-11y group and 7.7% for 16y-adults, which may be related to the electro-mechanical delay. Similar patterns were found for the Soleus.

Tibialis Anterior activity was characterized by two peaks: a major peak during loading response (at 2% of the gait cycle), gradually decreasing in midstance and a second peak in swing (at 70% of the gait cycle). Young children more frequently show prolonged eccentric activity of Tibialis Anterior in stance (46.5% of the children for 3-6y group, 32.1% for 7-11 y group, and 26.9% in the 16y-adult). Tibialis Anterior activity and contraction modalities in swing were similar for the different age groups, starting with 5% eccentric, followed by 20% concentric activity, a period of variable muscle length, and finally eccentric activity at the end of swing. Terminal swing is characterized by cocontraction of Tibialis Anterior and Gastrocnemius.

The Gluteus Medius activity started in late swing, with a peak during weight acceptance (at 5% of the gait cycle), and then gradually declined during mid stance. No major differences could be found between the age groups. The contraction modality was characterized by a large intra- and inter-subject variability.

IV. Discussion

Lower limb EMG activity, as well as muscle length patterns were estimated for a large group of healthy growing children and for adults.

Different EMG profiles were recognized for each muscle group, and some of these patterns could be related to results previously described in literature. We discovered some significant evolutions with age in the timing of certain activity phases. Differences between age groups were mainly found in stance. The influence on walking velocity on the defined EMG profiles has been recognized for Rectus Femoris. Unexpected muscle length patterns during gait were mainly seen for bi-articular muscles, especially at the transition from swing to stance or vice versa. However, except for the triceps, the contraction modalities (lengthening, shortening, isometric) were mature at 3 years of age. It can be concluded that in the clinical decision making process based on gait analysis data, individual pathological EMG profiles should be compared to different EMG patterns per muscles of age related normal subjects.

References

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