THE ANTICIPATORY AND COMPENSATORY ADJUSTMENTS
DURING TRUNK EXTENSION IN CHILDREN

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Abstract

Postural control in children involves anticipatory and compensatory postural adjustments. OBJECTIVE: The aim of the study was to further investigate these two components of postural control in typically developing children (N=12, main age 9.4±1.3 years old, main weight 31.7±5.5 kg and mean height 1.40±0.10 m) using the task of the trunk extension. METHODS: Electrical activity of the four lower extremity muscles (biceps femoris, rectus femoris, tibialis anterior, and gastrocnemius lateralis) as well as changes in the angular position of the hip joint were recorded and analyzed during the anticipatory and compensatory phases of the bending. RESULTS: Higher EMG during compensatory postural adjustments for all muscles. CONCLUSION: The larger co-activation of ankle muscles and the decrease anticipatory activity due to age suggest how children choose an efficient postural pattern to stabilize the posture.

Key words: posture, motor control, EMG.

Resumo

Controle postural em crianças envolve os ajustes posturais antecipatórios e compensatórios. OBJETIVO: O objetivo deste estudo foi analisar esses dois componentes do controle postural em crianças com desenvolvimento saudável (n=12, idade 9.4±1.3 anos, peso 31.7±5.5 kg e estatura 1.40±0.10 m) que realizaram a tarefa de extensão do tronco. MÉTODO: A atividade elétrica de quatro músculos dos membros inferiores (biceps femoral, reto femoral, tibial anterior e gastrocnêmio lateral) e a mudança angular da articulação do quadril foram adquiridas e analisadas durante as fases de antecipação e compensação do controle postural. RESULTADOS: Foi observado alta atividade eletromigráfica durante o ajuste postural compensatório. CONCLUSÃO: A grande coativação dos músculos tibial anterior e gastrocnêmio lateral e a diminuição da atividade antecipatória com o aumento da idade, o que sugere que as crianças escolheram um padrão eficiente para a estabilidade postural.

Palavras chaves: postura, controle motor e EMG.
INTRODUCTION

The feature of a motor action depends on the body movements performance, the adequate postural control, the integration of sensory information [vestibular, somatosensory and visual] about kinesthesia and proprioception, and the environment (physical constraints) and the task (required kinetics and kinematics). A mechanical perturbation to the body may provoke motor control responses which will try to stabilize the posture and balance. Those postural responses anticipate the perturbation, the anticipatory postural adjustment (APA) or they try to restore the imbalance condition, the compensatory postural adjustment (CPA). The problem of degrees of freedom is the question about how the central nervous system (CNS) chooses the combination of joint and muscles for a motor action. One answer is the CNS coordinates the muscles and joints into a synergy that controls the posture and the movement. A motor synergy coordinates how a muscle pair (agonist and its antagonist) of each joint is controlled by the co-contraction and the reciprocal inhibition.

The postural control is affected by development. The development and biological maturation of the whole body and its internal systems, such as the nervous system, affect the existence and the quality of the postural adjustments in the child. The APA depends on the child age; thus, for example, a two-years-old-child usually does not use APA for its balance control.

Based on those observations: what does happen when a child moves its trunk? Is the postural response to a trunk imbalance is age-related? The aim of this paper is to analyze the APA and CPA during trunk extension and the relation of those postural responses with aging.

METHOD

Participants

Twelve healthy typically developing children (main age 9.4±1.3 years old, main weight 31.7±5.5 kg and mean height 1.40±0.10 m) participated into the study. The inclusion criteria were: a) overweight or obesity (BMI > 0.22); b) practicing gymnastics, judo, roller skating, dancing or any other sport activity with emphasis in balance control, and c) Reporting the first menstrual period (girls only). The study protocol was approved by the university ethical committee. The parents of each child gave their written consent allowing their child to participate in the study.

Table 1: Description of the experimental sample. BMI is the body mass index.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age (year)</th>
<th>Mass (kg)</th>
<th>Height (m)</th>
<th>BMI (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>24.0</td>
<td>1.23</td>
<td>15.9</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>25.2</td>
<td>1.25</td>
<td>16.1</td>
</tr>
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<td>3</td>
<td>8</td>
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<td>1.25</td>
<td>16.5</td>
</tr>
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<td>4</td>
<td>9</td>
<td>28.2</td>
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<td>16.3</td>
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<tr>
<td>7</td>
<td>10</td>
<td>31.6</td>
<td>1.38</td>
<td>16.5</td>
</tr>
<tr>
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<td>10</td>
<td>34.5</td>
<td>1.39</td>
<td>17.9</td>
</tr>
<tr>
<td>9</td>
<td>10</td>
<td>36.2</td>
<td>1.42</td>
<td>18.0</td>
</tr>
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<td>10</td>
<td>11</td>
<td>37.3</td>
<td>1.45</td>
<td>17.7</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>38.3</td>
<td>1.44</td>
<td>18.5</td>
</tr>
<tr>
<td>12</td>
<td>11</td>
<td>40.5</td>
<td>1.46</td>
<td>19.0</td>
</tr>
</tbody>
</table>

Mean 9.4 ± 5.5  Sample size 12

Experimental Setup

The electromyographic signals (EMG) were recorded with Myosystem 1400 system (Noraxon Inc. USA) using surface electrodes positioned on the biceps femoris (BF), rectus femoris (RF), tibialis anterior (TA) and gastrocnemius lateralis (GL) muscles. The pairs of electrodes were placed over the right side of the subject’s body over the muscle bellies, spaced 1 cm apart. Prior to the placement of the electrodes, the skin area was cleaned with alcohol. The changes in the angular position of the right hip joint were recorded with a flexible electrogoniometer (Noraxon. Inc USA). The position of the electrogoniometer was aligned to the center of hip rotation, which was found by a palpation. All data were collected using a microcomputer via an AD converter board. All signals were sampled at 1 kHz with a 16-bit resolution.

Procedure

The subjects were standing upright, barefoot with feet positioned shoulder with apart, parallel to each other, and with the arms along the trunk. The subjects were required to look straight ahead at the target positioned at the eye level 3 m away in front of them. Then the subject was requested...
to bent the trunk forward by moving flexing the hip so the trunk is bent 45 degrees of flexion. This bent posture was maintained for 2-5 sec. After receiving the “go” signal (a bip) the subject was required to extend the trunk as fast as possible by moving the hip and the lower back to the upright position. The subjects were required to perform the task in a self-paced motion (Figure 1). Each subject performed the task 10 times. Prior to that the subjects performed 1-2 practice trails to familiarize themselves with the task.

Figure 1: Motor task. 1- initial position: trunk bending 2. final position: trunk extension

Data Processing

The signal from the goniometer was used to define the initiation of the trunk bending. The EMG data were amplified 1000 times and band-pass filtered (10-200 Hz) using a 4th order Butterworth filter. The angular position data were low-pass filtered (20 Hz) using a 4th order Butterworth filter. The filtered EMG was then full-wave rectified. The integrated EMGs (iEMG) were calculated for each muscle at two time windows each 200 ms in duration. For APA (equation 1), the window begins 200 ms before the initiation of movement and ends 50 ms after it. For CPA (equation 2), the integration window starts at 50 ms after movement initiation and lasts to 300 ms after it. Both the iEMG for each muscle were corrected by this muscle iEMG of baseline activity obtained during the time interval -400 ms to – 200ms before the start of the movement. The times defining both APA and CPA integrals were derived from previous literature (Bigongiari et al., 2011).

\[
\begin{align*}
iEMG_{APA} &= \int_{-0.2}^{0.05} EMGdt - \int_{-0.15}^{0.25} EMGdt \quad \text{Equation 1} \\
iEMG_{CPA} &= \int_{-0.2}^{0.05} EMGdt - \int_{-0.4}^{0.4} EMGdt \quad \text{Equation 2}
\end{align*}
\]

Additionally the following variables were calculated:

a) The intensity of muscular activation: the iEMG calculated during the APA and the CPA for the selected muscles.

b) The intensity of reciprocal inhibition of muscles surrounding the ankle and knee joints (R-index) was computed by subtracting the iEMG activity of the dorsal muscles (GL, BF) from the iEMG activity of ventral muscles (TA, RF) (Equation 3 and 5).

c) The intensity of co-contraction (C-index) was computed by adding the iEMG activity of the GL-TA and BF-RF muscle pairs (Equation 4 and 6).

\[
\begin{align*}
R_{\text{knee}} &= iEMG_{\text{BF}} - iEMG_{\text{RF}} & \text{Equation 3} \\
C_{\text{knee}} &= iEMG_{\text{BF}} + iEMG_{\text{RF}} & \text{Equation 4} \\
R_{\text{ankle}} &= iEMG_{\text{TA}} - iEMG_{\text{GL}} & \text{Equation 5} \\
C_{\text{ankle}} &= iEMG_{\text{TA}} + iEMG_{\text{GL}} & \text{Equation 6}
\end{align*}
\]

Statistical analysis

The Analysis of Variance (ANOVA) was applied to verify the effect of postural adjustment (APA and CPA) and joint (ankle and knee). Tukey’s HSD was applied for post-hoc comparisons where appropriate. The linear regression analysis was applied to test the relationship between the iEMG of the lower limb muscles and age.

RESULTS

The mean iEMG, R-index and C-index are presented in tables 2 and 3. We ran one-way ANOVA to check the effect of postural adjustments (APA and CPA) in the iEMG of each muscle. The type of postural adjustment affected the level of activity of all muscles (RF, BF, TA, GL: F(1,479) ≥ 83, p<0.0001). The Tukey HSD test showed that the iEMG of all muscles were higher during CPA (RF, BF, TA, GL: p<0.0001).

For the second analysis, we run a one-way ANOVA to check the effect of postural adjustments (APA and CPA) in the R-index and C-index. The type of postural adjustment affected the R and C indexes (R_{\text{knee}} C_{\text{knee}} R_{\text{ankle}} C_{\text{ankle}}: F(1,479) ≥ 121, p<0.0001). The R and C indexes were higher during CPA (R_{\text{knee}} C_{\text{knee}} R_{\text{ankle}} C_{\text{ankle}}: p<0.0001).

For each postural adjustment, we analyzed the effect of joint in the intensity of R-index and C-index. For APA, the R-index and C-index were
not affected by the joint (F(1,47.9)=2.8, p<0.5). For CPA, the joint affected the R-index (F(1,47.9)=18.6, p=0.0001) but not the C-index (F(1,47.9)=0.6, p=0.43). The post hoc test showed that the Rknee was higher than the Rsole (p<0.001).

The last analysis evaluated the relation between iEMG of each muscle during APA and aging (figure 4) running a linear regression analysis. The RF iEMG presented a linear relation to aging (R=-0.78, R²=0.61, p=0.002). The other muscles did not show any linear relation to aging.

Table 2: Mean values of the integral of the EMG signal (iEMG) in percentage of maximum (%) of the rectus femoral (RF), biceps femoral (BF), tibialis anterior (TA) and gastrocnemius lateralis (GL) during the anticipatory postural adjustment (APA) and compensatory postural adjustment (PCA).

<table>
<thead>
<tr>
<th>Muscle</th>
<th>APA</th>
<th>CPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF</td>
<td>0.70±1.06</td>
<td>2.52±3.39</td>
</tr>
<tr>
<td>BF</td>
<td>2.62±3.84</td>
<td>6.54±5.47</td>
</tr>
<tr>
<td>TA</td>
<td>1.93±2.69</td>
<td>4.11±3.78</td>
</tr>
<tr>
<td>GL</td>
<td>2.19±3.80</td>
<td>5.46±5.41</td>
</tr>
</tbody>
</table>

Table 3: Mean values of the integral of the EMG signal (iEMG) in percentage of maximum (%) of the rectus femoral muscle pairs - biceps femoral (RF-BF) and tibialis anterior - lateral gastrocnemius (TA-GL) for the parameters coactivation (C-index) and reciprocal inhibition (R) during the anticipatory postural adjustment (APA) and compensatory postural adjustment (PCA).

<table>
<thead>
<tr>
<th>Joint/Muscle pair</th>
<th>APA</th>
<th>CAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee/RF-BF</td>
<td>0.08±0.48</td>
<td>2.00±3.37</td>
</tr>
<tr>
<td>Ankle/TA-GL</td>
<td>4.12±2.66</td>
<td>1.64±2.58</td>
</tr>
</tbody>
</table>

Figure 2: Mean values and standard deviation of the integral electromyography signal (iEMG) and the straight line obtained by linear regression between the mean iEMG and ages of children for the m. rectus femoral (RF) during the anticipatory postural adjustment (APA).

**DISCUSSION**

Based on our results, we present the following answers for the research questions: 1) what does happen when a child extends its trunk? The postural control increased the muscle activity after the focal movement, that is, the postural control is based on CPA; 2) Is the postural response age-related? Yes, the anticipatory activity of the m. rectus femoris decreased with aging and suggests that the main concern for the postural control during childhood is to assist the performance of the focal movement.

We tested two hypotheses. The first hypothesis is that during the CPA the muscle activation will be the highest. Our results have confirmed this hypothesis. The postural strategy to control balance was to activate more the muscles after the beginning of the focal movement, enhancing the importance of feedback control not the forward control.

The trunk bending displaces the body center of mass (COM) about 4 cm forward. To move the trunk backward, to the upright position, the COM goes back; but, such a movement adds an angular momentum perturbation to the motor action. To counteract to both perturbations (COM backward displacement and angular momentum) an anticipatory activity assists the postural control to reduce the unbalance condition. A previous study showed that adults counterbalance those perturbations using the knee and the ankle. Odsson (1988) showed the anticipatory co-activation of the agonist and antagonist muscles at the ankle during the successful (not falling down) trunk bending in adults. This strategy had only a secondary importance for the postural control of the healthy children.

The importance of the reactive control is highlighted when the R and C indexes are described. Both co-activation and reciprocal inhibition indexes were higher during CPA. It suggests that the maintenance of the upright posture and the postural stability were mostly controlled after the beginning of the focal movement.

The muscle co-activation is a strategy to increase the joint stiffness. We found the increase of the ankle muscles co-activation and the decrease of the knee muscles co-activation, reinforcing that the knee and the ankle have different functions for balance control during the trunk bending task. The larger reciprocal inhibition at the knee muscles helps the knee flexion, which is part of the postural control strategy to stabilize the body.

The second hypothesis is the muscle activation during APA will increase as the children get older. For upper limbs movement, the APA increased with aging in healthy children. We found the opposite. The anticipatory activation of the rectus femoris muscle has decreased with aging. Although it contradicts our hypothesis, the change in the forward control of that muscle should be expected because the action of this
muscle decelerates the focal movement velocity, the pelvic and trunk extension. The negative linear relation between RF APA and aging suggests the improvement of the trunk extension task performance to the direction of the adult movement pattern. Furthermore, according Assaiante et al. (2012) the ontogenetic model of balance control show a gradual mastery of degrees of freedom of the various body joints. Therefore, not consistent forward control, or a large variability in APA, is the main cause of postural instability in children.

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The absence of another linear relation between APA and aging proposes the APA development in childhood is not monotonic. The development of the postural control is not a simple question of increases or decreases in muscle activation, but a matter of choosing the right synergy for the postural control.

Finally, the muscle co-activation at the ankle and the changes in APA with aging suggests that children first select the best way to stabilize the joints for the focal movement and then they try to use the anticipatory postural control.

CONCLUSION

The results in the study provide additional information on the organization of postural control in 7-to-11-years-old typically developing children. The compensatory postural control is the preferable strategy to stabilize the posture during trunk extension task; probably due to the slow anticipatory control maturation process during the childhood. Nevertheless, the reduction of APA in the m. rectus femoris with the increasing age suggests that an old child learns to select the most appropriate postural strategy, since the m. rectus femoris has involved to the focal movement. This result demonstrates the complexity to build the motor repertory in the childhood.

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