MODELING OF PELVIS AND THORAX ROTATIONS IN HEALTHY AND PATHOLOGICAL GAIT

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INTRODUCTION

During gait the pelvis and thorax rotate in the transverse plane in a near sinusoidal pattern [1]. With changes in gait velocity, the relation between these rotations changes, especially in terms of the relative timing. Whereas at low velocities the rotations are almost in phase, phase lead of the pelvis increases at increasing velocities up to around 2.5 radians (140 degrees; Figure 1). In several pathological conditions, among which low back pain [1] and pregnancy-related pelvic girdle pain (PPP) [2] this increase in phase difference has been shown to be less pronounced (Figure 1).

The out-of-phase relationship between pelvis and thorax rotation in healthy gait has been interpreted as a coordinative strategy to reduce body angular momentum around the vertical axis [3]. However, since stride frequency increases with gait velocity, it may be the case that this phase relationship emerges from second order dynamics of the system without any active coordination. The reduced phase difference in patients with disorders such as low back pain could then be accounted for by an increased stiffness, consequent to increased cocontraction [4]. Thus, we set out to model the relative rotations of pelvis and thorax in healthy and pathological gait as second order linear dynamics.

METHODS

Data were derived from an earlier study on healthy nulliparous women, healthy pregnant women, and pregnant women with PPP [2]. Relations between pelvis and thorax rotations in the transverse plane were characterized as group averaged frequency responses (gain and phase as function of stride frequency).

Analytical solution of a linear second order system with harmonic position forcing was used to express gain and phase as function of frequency, inertia (of the thorax), stiffness and damping. Thorax inertia was estimated based on literature data [5]. First, this model was fitted to the experimental frequency response by optimizing a constant stiffness and gain. Then, a second model was developed in which stiffness and damping were modeled as sigmoidal functions of stride frequency.

RESULTS AND DISCUSSION

The model with constant stiffness and damping did not permit an acceptable description of the experimental data.

The second model adequately described the data of all three groups (Figure 1). The model predicted stiffness and damping to decline above stride frequencies of 0.65 Hz. The declining stiffness and damping might be due to reduced activity of muscles, for example of left rotating muscles active when the trunk is right rotated (stiffness) or rotating to the right (damping). The stiffness, however, declines below values expected on the basis of passive trunk stiffness [6], which implies that at higher velocities active counter rotation is required to obtain the kinematics observed. This can be explained by increased activity of muscles producing for example left rotation when the trunk is already left rotated. For damping no reference data are available, but similarly the decreased damping could be a consequence of increased activity of left rotators when the trunk is rotating to the left and vice versa. The PPP patients differ from the healthy controls mostly in that the damping at higher stride frequencies is reduced less than in the controls.

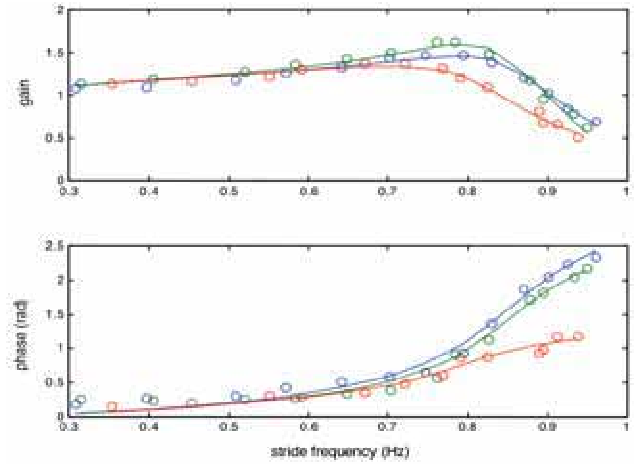

Figure 1: Actual relations between transverse pelvis and thorax rotation (circles) during gait in healthy nulliparous (blue) pregnant (green) and pregnant women with PPP (red) modeled as the frequency responses of second order systems (lines) with stiffness and damping declining with frequency.

CONCLUSIONS

Relative transverse rotation between pelvis and thorax during gait can not be modeled as a passive second order system. With increasing stride frequency stiffness and damping are reduced, which suggests that counter rotation of the thorax is actively coordinated. This counter rotation is less pronounced in subjects with PPP than in healthy controls.

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