Introduction

Starting from an upright standing posture and reaching for a target that requires some forward bending of the trunk can be accomplished in many different configurations of the trunk and limb segments due to the large number of joints involved in these reaching tasks. Thus, there are more mechanical degrees of freedom than are strictly required to complete this task. In a previous paper we showed that the rotational excursion of each segment depends not only on target location, but also on speed and on subject preference (Thomas et al., 2003) the latter dependences are made possible by kinematic redundancy. The resolution of kinematic redundancy, when it does not entail freeing some of the degrees of freedom, calls for constraining relationships amongst them. Three authors proposed an inter-joint coordination rule (“linear synergy”) in which the CNS issues a single command which leads to torques of similar time course at each of the joints (Gottlieb et al., 1997; Gottlieb et al., 1996). This effect would simplify control of a multi-joint task. However, the experimental paradigm testing the linear synergy hypothesis have been limited to the shoulder and elbow torques in 2 and 3 degree freedom (DOF) pointing tasks. According to the linear synergy hypothesis (LSH), in two-joint reaching tasks, coordination of the shoulder and elbow is such that the peaks and zero crossings of the shoulder and elbow muscle torques are nearly coincident in time (Gottlieb et al., 1996). The purpose of this research was to test if the hypothesis generalizes beyond the shoulder and elbow joints in full body reaching tasks that require coordination of the postural joints of the arm, hip, knee and spine and the joints of the reaching arm (i.e. shoulder and elbow).

Methods

The time-series changes in orientation of the forearm, humerus, trunk, pelvis, thigh, and shank were measured in 20 healthy individuals (10 males and 10 females) performing whole-body reaching tasks. In this paradigm the targets were located around a clock face such that the subject could, in theory, reach them by flexing the hips 30° and 60° with the shoulder fixed 90° and the elbow extended. The target locations were chosen to create a task that progressively challenges the subject with larger excursions of the trunk. The segment orientation angles were measured in a counterclockwise direction as seen from the subject’s right side, starting with horizontal equal to zero degrees. Subjects reached for the targets at two speeds (self-selected and fast-paced) and were given no instructions on the limb-segment geometry to use while performing these reaching tasks.

The dynamic components of the joint torques were derived from a sagittal plane inverse dynamics analysis in which the gravitational components of the torques were excluded. A linked-segment model consisting of seven segments was used for the inverse-dynamics calculations. The seven segments were defined as follow: Segment 1: the left and right feet, Segment 2: the left and right shanks, Segment 3: the left and right thighs, Segment 4: the pelvis (iliac crests to greater trochanter to L3), Segment 5: the trunk (composed of the thorax from L3 to the first thoracic vertebrae, the head and neck, and the left humerus, forearm and hand), Segment 6: the right humerus, Segment 7: the right forearm and hand. The dynamic component of the joint torque was calculated for the following six joint amplitudes: ankle, knee, hip, lumbar, shoulder, and elbow.

Data Analysis

Sagittal plane dynamic joint torques of the elbow, shoulder, lumbar, hip, knee, and ankle were analyzed to determine the time of peak torque and zero crossing of each joint. The peak of torque and zero crossing of each joint was expressed as a latency relative to the ankle joint and analyzed using paired sample t-tests.

Results

Large differences in timing of the joint torques of the reaching arm (i.e. shoulder and elbow) and the postural joints (i.e. ankle, knee, hip and spine) are in conflict with the LSH. However, relatively small differences in timing of peak torque and zero crossing within the reaching arm (7 ms, 13 ms) and within the postural joints (136 ms, 154 ms) are consistent with the LSH. Overall the data suggest separate timing of relatively synchronized joint torques for the postural and reaching joints for full body reaching tasks.

Conclusions

DOES THE LINEAR SYNERGY HYPOTHESIS GENERALIZE BEYOND THE SHOULDER AND ELBOW IN MULTI-JOINT REACHING MOVEMENTS? James S. Thomas*, Daniel M Corcos†, and Ziaul Hasan†. School of Physical Therapy*, Ohio University, Athens OH. School of Kinesiology†, University of Illinois at Chicago, Chicago IL 767.13