INFLUENCE OF VOLUNTARY POSTURE SELECTION ON ENDPOINT STIFFNESS

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INTRODUCTION

The endpoint stiffness of the human arm describes the relationship between postural perturbations applied at the hand and the steady-state forces generated in response to those displacements. As such, it characterizes the mechanical properties of the arm as seen at the point of contact with the environment and can be used to quantify limb stability. The stiffness properties of a limb are not fixed, but rather depend strongly on limb posture [1] and muscle activation [2]. It has been proposed that humans modulate limb stiffness to optimize the mechanical properties of a limb in a task-dependent manner [3]. However, most studies examining endpoint stiffness only have characterized 2D stiffness with the arm in the horizontal plane. Under these conditions, the direction of maximum stiffness is oriented approximately along the line connecting the shoulder and hand, and it appears that this orientation cannot easily be modified for a fixed arm posture. In contrast to these studies, functional tasks rarely are restricted to the horizontal plane. Hence, a more complete understanding of how endpoint stiffness is regulated during functional tasks requires an assessment 3D endpoint stiffness at self-selected arm postures. The purpose of this study is to quantify the 3D stiffness properties of the human arm and to examine if individuals voluntarily choose postures that optimize endpoint stiffness in a task-dependent manner.

METHODS

Endpoint stiffness was measured using a 3D robotic manipulator [HapticMaster; FCS Control Systems, The Netherlands], configured as a stiff position servo. The robot was used to apply random 3D displacements to the arm and to measure the 3D forces generated in response. Subjects were strapped into an adjustable height chair so that the trunk was fixed and positioned to that the hand was at shoulder height, approximately in front of the sternum. Although the shoulder and hand were fixed, the position of the elbow was free. In each trial subjects were instructed to exert a constant level of force against the robot and were assisted in this task by a 3D visual display of the force measured by the robot. Data were collected either with the arm positioned in the horizontal plane or positioned at a posture selected by the subject. The presented data focus on forces generated along the ±X-axis (Fig. 1), which corresponds pushing or pulling along the intersection of the sagittal and horizontal planes.

Endpoint stiffness was estimated from the measured endpoint displacements and forces using system identification techniques presented previously [2, 4].

RESULTS AND DISCUSSION

When the arm was kept in the horizontal plane, our 3D stiffness estimates were consistent with the 2D results that we and others have reported previously [1,2]. When allowed to self-select an arm posture, subjects always chose one in which the elbow was dropped below the horizontal plane connecting the shoulder and hand. Fig. 1 compares the stiffness estimated at two self-selected postures (purple) to those measured with the arm in the horizontal plane (green). Each ellipsoid represents the results of a separate endpoint force condition, indicated by the labels; the overlaid ellipsoids were collected at matched forces. The self-selected postures resulted in increased stiffness for forces along the –X axis, which tend to decrease limb stability [5], and increased stiffness for forces in the opposite direction, which tend to increase stability. Hence these postures may have been chosen to compensate for the effects of the constant forces applied at the hand.

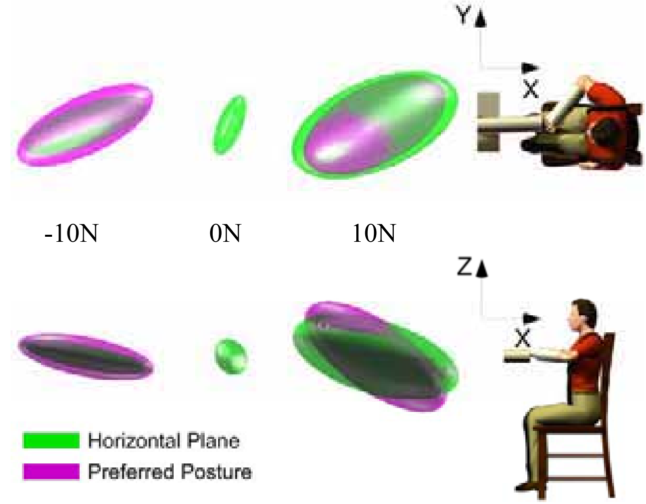

Figure 1: Endpoint stiffness measured at three different voluntary force levels along the X-axis.

CONCLUSIONS

These initial results demonstrate our ability to measure endpoint stiffness in the three degrees of freedom relevant to most functional tasks. In addition, they demonstrate that subjects often work outside of the horizontal plane characterized in most previous studies and that these alternate postures influence endpoint stiffness. We currently are examining how self-selected postures influence limb stiffness and stability in a variety of tasks.

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