ELSEVIER

Brain Research Bulletin 67 (2005) 30–39

BRAIN RESEARCH BULLETIN

www.elsevier.com/locate/brainresbull

Maintenance of upright standing posture during trunk rotation elicited by rapid and asymmetrical movements of the arms

Yoshihiko Yamazaki [a,*], Masataka Suzuki [b], Tetsuo Ohkuwa [a], Hiroshi Itoh [c]

[a] Department of Computer Science and Engineering, Graduate School of Engineering, Nagoya Institute of Technology, Nagoya 466-8555, Japan
[b] Department of Psychology, Kinjo Gakuin University, Nagoya 463-0021, Japan
[c] Department of Material Science and Engineering, Graduate School of Engineering, Nagoya Institute of Technology, Nagoya 466-8555, Japan

Received 5 July 2004; accepted 16 May 2005
Available online 20 June 2005

Abstract

Nine healthy subjects standing upright, initiated small, medium and large (S, M and L conditions, respectively) forward movements of their right (Rt) arm together with backward movements of their left (Lt) arm. They also performed medium-size movements while holding a 3 kg dumbbell in each hand (D condition). Movements started with the arm hanging alongside the body and ended when the shoulder reached a desired orientation. The arm and trunk movements were videotaped and recorded by accelerometers taped to the wrists, shoulders, and hips bilaterally. The torque around the vertical axis was measured using a force-plate on which the subjects stood. EMGs were recorded with surface electrodes bilaterally from the shoulder, trunk, and thigh muscles. Trajectories of the center of foot pressure were measured in additional experiments.

In association with arm movements, there was a small counterclockwise (ccw: the Rt shoulder forward and the Lt backward) rotation of the trunk, followed by large alternate rotations of the trunk, first clockwise (cw) and subsequently ccw. The intervals from the hand acceleration to the shoulder and hip accelerations were, respectively, 0 ± 15 ms (mean and S.D. for all subjects) and -17 ± 15 ms. The force-plate showed initial cw and later ccw torques 63 ± 41 ms after hand acceleration. The EMGs of the Rt hamstrings (Ham) and Lt rectus femoris (RFem) were followed by those of the Lt Ham and Rt RFem which, respectively preceded the alternate trunk rotations. The integrated EMGs and torques increased with increasing amplitude of arm movement and load. The integrated torques increased in the order of S, M, L, and D conditions. The integrated EMGs of the thigh muscles correlated with the integrated torques (medians: $r = 0.880$, 0.696, 0.785, and 0.688, respectively, in the Rt Ham, Lt Ham, Rt RFem, and Lt RFem). The trajectories of the center of foot pressure showed variations, initially toward the Rt side and then the Lt side which, respectively coincided with the initial and later phases of the trunk rotations and the muscle activation. The trunk muscles were generally coactivated between the Rt and Lt muscles, and the integrated EMGs increased with increasing the integrated torques.

Our results showed that alternate rotations of the upper trunk, produced by rapid arm movements, were transmitted to the hip in part due to cocontraction of trunk muscles, and each pair of hip joint muscles contributed to the maintenance of the standing posture by stabilizing the hip joints against alternating trunk rotations.

Keywords: Rapid arm movement; Standing posture; Trunk rotation; EMG; Anticipatory postural adjustments

1. Introduction

In the pioneering work of Belen'kii et al., during a rapid flexion of the arm while standing, several of the leg and trunk muscles were activated prior to the prime mover of the anterior deltoid muscle [3], which is considered to serve to maintain postural equilibrium against the disturbance due to reaction forces produced by arm movement and the displacement of the center of mass caused by a change in body configuration [18]. They also showed that both the biceps femoris muscles of the contralateral side to the arm moved, and the rectus femoris muscles of the ipsilateral side were activated late after the onset of the anterior deltoid muscle. Many

* Corresponding author. Tel.: +81 52 735 5195.
E-mail address: yamazaki.yoshihiko@nitech.ac.jp (Y. Yamazaki).

0361-9230/$ – see front matter © 2005 Elsevier Inc. All rights reserved.
doi:10.1016/j.brainresbull.2005.05.015

investigations focused on components preceding the prime mover [5,6,10,11,14,16], while later components remain unstudied.

In association with rapid and symmetrical movements of the bilateral arms during standing, the leg and trunk muscles are also activated alternately in the antagonistic muscles [11], which is analogous to the alternate activation of antagonistic muscles upon rapid movements of a single joint (e.g., [27]). The initial adjustments of standing posture with rapid arm movements, called anticipatory postural adjustments, are in the direction opposite to the reaction forces associated with the arm acceleration [6]. However, the arm(s) once accelerated must be decelerated towards the end of the arm movement, which generates reaction forces again but in an opposite direction. Hence, the standing posture should be adjusted to the reaction forces in the deceleration of the arm(s) as well as the acceleration. The later component in the study of Belen'kii et al. [3] was possibly related to the deceleration of the arm.

From a mechanical perspective, there are complex reaction forces at the shoulder during arm movements while standing, in which the force to rotate the trunk is included. However, adjustments of standing posture to trunk rotation associated with arm movements have not been studied specifically. Arm movements such as raising a single arm have a force component to rotate the upper trunk around a vertical axis. However, it is difficult to determine the effects on the trunk rotation, because in the arm movement the rotational force is moderate in magnitude, and the effects would be indistinguishable from those of the other forces. When both arms are moved simultaneously and asymmetrically in the sagittal plane, the trunk rotation is enhanced by the bilateral movements of the arms while minimizing the displacement of the center of gravity, which is deductive from the forces acting between the arms and trunk [6]. One such movement is to swing the arms in opposite directions, like the arm movement while walking in place.

The present study was designed to investigate how the trunk rotation, produced by the rapid and asymmetrical movement of the arms, is adjusted by contractions of the trunk and thigh muscles to maintain the upright standing posture, focusing on the termination of the arm movement as well as the initiation. Surface electromyograms (EMGs) of the trunk and thigh muscles were recorded simultaneously with the trunk movements and torque in the force-plate. The magnitude of the rotational force external to the trunk was manipulated by increasing the amplitude of the arm movement and by holding dumbbells in the hands.

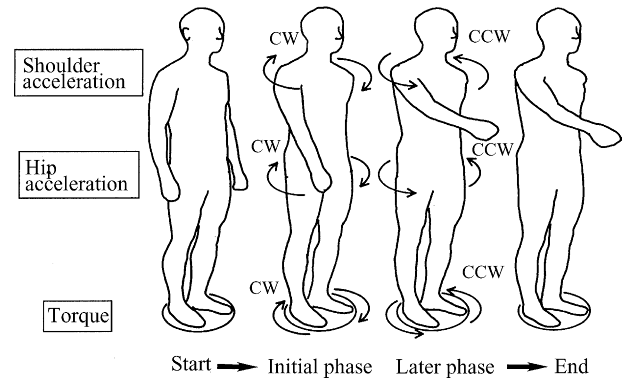

Fig. 1. Schematic drawings of task movement and resultant body rotations. Subjects made a rapid movement of arms while maintaining a standing posture, with the right arm flexed and the left one extended. Directions of trunk acceleration and torque in force-plate during arm movement are shown. Shoulders and hips were initially accelerated in clockwise (cw) direction, preceded by small counterclockwise (ccw) acceleration (not shown in figure), and later in ccw direction. Force-plate showed torques in initial cw and later ccw directions.

2. Methods

2.1. Subjects and task

Normal human subjects (nine subjects, aged 20–54) quietly stood on the center of a round aluminum plate (d: 35 cm) with arms hanging alongside the body, gazing at a visual target 3 m away. They were instructed to rapidly flex the right (Rt) arm and extend the left (Lt) one simultaneously, maintaining full elbow extension (asymmetrical arm movement: AAM; see Fig. 1). Target angles of the AAM were 5 (small: S condition), 20 (medium: M condition), or 40 (large: L condition) degrees from the initial position. The subjects also performed the M condition while holding a 3-kg dumbbell in each hand (D condition). The order of the four conditions was quasi-randomized among the subjects. The target angle was presented by four poles standing in front and back of the subjects. They initiated the AAM at the timing volitionally determined after maintaining the initial position for several seconds. They performed 11 trials for each experimental condition after practicing five times for each. During practice, the subjects learned the target angle confirming the final position of the arms. Once started, they completed the 11 trials unless the final position apparently under or overshot the target.

2.2. Measurements

The round plate on which the subjects stood could rotate on the vertical axis because it was supported by ball-bearings of a flat type. The plate was fixed to a base by a metal block on which strain-gauges were mounted to measure the torque. Accelerometers fixed to the bilateral shoulders on the acromions and both sides of the iliac crests measured rotational movements of the trunk. These four accelerometers were carefully attached to the skin using a special fixing device to be most sensitive to the rotation of the shoulders and hips on the vertical axis. Two accelerometers taped to the wrists recorded the tangential acceleration of the arms around the shoulder. In the recordings of the trunk accelerations and torque, clockwise (cw) and counterclockwise (ccw)