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Effects of coupled upper limbs movements on postural stabilisation

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ABSTRACT

The preference for in-phase association of coupled cyclic limbs movements is well described (mirror-symmetrical patterns) and this is demonstrated by the ease of performing in-phase movements compared to anti-phase ones. The hypothesis of this study is that the easiest movement patterns are those with minor postural activity. The aim of this study was to describe postural activity in standing subjects in the sagittal and frontal planes during the execution of three upper limbs tasks (single arm, in-phase, anti-phase) at four different frequencies (from 0.6 to 1.2 Hz).

We employed six infrared cameras for recording kinematics information, a force platform for measuring forces exerted on the ground, and a system for surface electromyography (SEMG). Outcome measures were: upper limb range of movement and relative-phase, centre of pressure displacement (COP), screw torque (T_z) exerted on the ground, and SEMG recordings of postural muscles (adductor longus, gluteus medius, rectus femoris, and biceps femoris).

Our results show that in both the planes the in-phase task resulted in less COP displacement, torque production, and postural muscles involvement than the anti-phase and single arm tasks. This reduced need of postural control could explain the ease of performing in-phase coupled limb movements compared with anti-phase movements.

1. Introduction

Executing a voluntary movement involves the use of muscles with both agonist and postural roles (Massion, 1992). Postural intervention is necessary to counteract mechanical perturbations of the body produced by movement. Depending on the mechanical characteristics of the movement, all muscles can have either an agonist or postural role. The postural role has two objectives: to fix the body segments and to manage the body's centre of gravity sway by anticipatory postural adjustments (APAs) during movements that could provoke its unwanted displacement (Belenkii et al., 1967; Cordo and Nashner, 1982; Bouisset and Zattara, 1987; Clement et al., 1984). The characteristics of the postural component of the movement (muscles involved, their activation intensity, and their sequence of activation) are determined by the mechanical characteristics of the tasks. Precisely, the involvement of the postural component depends on the amount of muscular forces, body segments weight and moments of inertia involved in the task. For this reason, the movement of two upper limbs should require greater involvement of the postural component in comparison with moving one upper limb (Viviani et al., 1976).

Moreover, when two upper limbs are simultaneously moved in order to perform a coordination task, the central nervous system determines a constraint to the freedom of movement, which facilitates the execution of a mirror-symmetrical pattern (De Rugy et al., 2008; Schöner et al., 1986; Zanone and Kelso, 1992; Haken et al., 1985; Kelso and Jeka, 1992). For example, moving both hands in the horizontal plane is easier when they move in opposite directions (mirror symmetrically) performing the same joint movement (Scholz and Kelso, 1989, 1990; Swinnen et al., 1998).

Similarly, when two segments of the same body side are simultaneously moved in the same plane, the execution is facilitated in the same angular direction. This phenomenon has been described for several situations including cyclic movements of fingers and hands in the transverse plane (Schöner et al., 1986; Zanone and Kelso, 1992; Haken et al., 1985), elbow and knee flexion–extension in the sagittal plane (Kelso and Jeka, 1992) and hand and foot flexion and extension in the sagittal plane (Baldissera et al., 1998).

Mirror-symmetrical patterns and movements performed in the same angular direction are termed "in-phase" and all the studies cited above concluded that in-phase coupling is easier to perform in comparison with anti-phase one. Other authors described that these movements are more stable and accurate, also when new

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motor patterns are being learned (Salesse et al., 2005b; Franz et al., 1991; Gatti et al., 2011). Moreover, in-phase movements characteristics are independent on the muscle group involved: in the sagittal plane, coupled hand and foot movement of the same body side is easier if the forearm is in either the prone or supine position (Salesse et al., 2005a).

Some cognitive constraints can also explain a greater difficulty for anti-phase movement. In particular if compared with in-phase movement the anti-phase one implies a more difficult representation of the task goal (Spencer et al., 2006) and requires a greater activation of brain networks related to attention (Wu et al., 2010).

Synthetically, it can be assumed that the coupled movement of both upper limbs requires: (1) the activation of muscles with a postural role, (2) the control of many kind of constraints involved in the task.

Esposti et al. (2010) interpreted the easiness of executing in-phase coupled hand movement with the concept of "energy saving". They speculated that the reason for the preferred movement pattern could be its minor postural and energetic involvement.

We predict that the interpretation presented by Esposti and colleagues is a general rule regarding the coupled movement of two body segments, whereby the easiest patterns of movement are those with minor postural activity that require lower metabolic cost.

According to this prediction, the hypothesis of this study is that the in-phase movement of two body segments (e.g. upper limbs) could require minor postural activity than the anti-phase movement of the same segments or the movement of a single segment.

Therefore, the aim of the present study was to describe the biomechanics of postural activity during in-phase and anti-phase coupled movement of both upper limbs executed at different frequencies in two planes of motion.

2. Methods

2.1. Subjects and experimental design

We recruited 15 healthy, right-handed subjects (8 males, 7 females; age 22 ± 1.8 years; weight 65.8 ± 8.6 kg, height 174 ± 8 cm; Edinburgh Handedness Inventory score 90.5 ± 5.8). None had history of previous neurological and/or orthopaedic diseases. All of them were university students that did not perform regular sports activity. All subjects signed an informed consent form prior to participation. The study was approved by the internal Ethical Committee of the San Raffaele Hospital and was conducted in the movement analysis laboratory of the Vita-Salute San Raffaele University in Milan.

Subjects stood barefoot on a force platform with their feet parallel to each other and 15 cm apart. During the test, they were told to perform cyclic upper limb movements of abduction/adduction (frontal plane) and flexion/extension (sagittal plane) while maintaining elbow extension and with their palms facing the ground. Upper limbs movements were coupled in three different coordination tasks: (1) only the right limb was moved, (2) both limbs were symmetrically moved (in-phase task), (3) both limbs were asymmetrically moved (anti-phase task) (Fig. 1).

Both abduction and flexion were executed by moving the arms from the rest position along the body to the horizontal position, parallel to the ground. These cyclic movements were paced by a digital metronome and performed at 0.6, 0.8, 1.0, and 1.2 Hz. (Russell and Baksh, 1994).

Each subject performed 20 cyclic oscillations for each tested frequency (total of movements: 20 $\times$ 4 frequencies $\times$ 3 coordination tasks $\times$ 2 planes). To exclude that a tasks sequence could affect the results, in each plane the frequency and the order of execution of the different tasks were pseudo-randomised in a balanced way so that the order of execution was different between the subjects and every possible order of the conditions was used.

Instructions given to the subjects explained: the starting and final positions of the arms, how to follow the digital metronome (one beat of the metronome for each complete movement cycle) and emphasised movement accuracy. In order to focalise the attention of the subjects on the accuracy of movement, they were asked to pay attention in maintaining elbows extended and to the correct frequency and range of movement, that will be monitored off-line thanks to the kinematic acquisition. There was a standing rest period of 1 min between two tasks.

Approximately 30 min before the test, subjects were allowed 5 min of practice to become confident with movements and frequencies.

2.2. Data acquisition

Kinematics information was acquired with six infrared cameras (Elite, BTS, Italy), a force platform was used to measure force exerted on the ground (Kistler mod. 9286A, CH), and a wireless electromyographic system was used to record surface electromyography (Freeemg 300, BTS, Italy). Eight channels of the SEMG acquisition system were used.

In order to collect upper limb kinematics, reflective markers were placed on the spinous process of C7 and on both acromions and epicondyles.

The force platform was used to record the displacement of the centre of pressure (COP) and the value of the screw torque exerted on the ground on the vertical axis (T_z). Acquisition sample frequency was set at 100 Hz.

Surface electromyographic activation (SEMG) of postural muscles was bilaterally recorded using bipolar surface electrodes (Ag/AgCl) placed 20 mm apart. The following muscles were bilaterally recorded: (r = right side; l = left side) the adductor longus (Ad_r and Ad_l) and gluteus medius (G_r and G_l) were recorded during the frontal plane tasks and the rectus femoris (RF_r and RF_l) and biceps femoris (BF_r and BF_l) were assessed during the sagittal plane tasks. Electrodes were placed in agreement with SENIAM guidelines (Hermens et al., 1999). SEMG signals were amplified (with a total gain of 1 k) and band-pass filtered (10–500 Hz, second order, dual-pass Butterworth filter). The acquisition sample frequency was 1000 Hz (digital resolution 16 bit; CMRR 92 dB; wireless transmission from probes to receiver unit: IEEE 802.15.4, from receiver unit to PC: IEEE 802.11b).

2.3. Data analysis

After filtering kinematic raw data (Butterworth lowpass dual pass filter with a cutoff frequency of 10 Hz), the range of motion (ROM) of the upper arms and their relative phase absolute error (RPerr), namely the degree of deviation from the target relative phase (0° for in-phase and 180° for anti-phase), was calculated and used for statistical analysis.

COP displacement data were analysed as displacement track length (L_t).

The screw torque (T_z) was detected by the force platform, rectified, and expressed as the mean and standard deviation during a sequence of 20 cyclic oscillations.

The mean rectified SEMG amplitude, included between the first and the last signal bursts, was calculated over the entire acquisition period (Viviani et al., 1976). To identify the beginning and end of activation, the threshold of the mean EMG intensity at rest plus two standard deviations was used (Soderberg and Knutson, 2000). The SEMG value for each postural muscle was expressed as the mean of the activations recorded bilaterally.