INTRODUCTION
The muscles involved in the postural component of a movement are determined by the mechanical characteristics of the motor task [1]. For example the movement of the two upper limbs should require a greater involvement of the postural component in comparison with the movement of only one upper limb. Moreover, when the two upper limbs are simultaneously moved in order to perform a coordination task, a constraint to the freedom of movement is experienced. For example Kelso and colleagues [2] studied some patterns of coordinative movement in which the two hands moved either in the same direction or in the opposite one. The author concluded that in-phase coupling (same direction) was easier to perform, and other authors confirmed this preference for in-phase coupling, describing its greater stability and accuracy, even when learning new motor patterns [3]. Summarizing, the coupled movement of the two upper limbs requires: 1) the activation of muscles with a postural role, 2) the control of the constraints involved in the task.

The present study analyses the biomechanics of the postural activity during the in-phase versus anti-phase coupled movement of the upper limbs.

METHODS
15 healthy subjects (7 females) from 20 to 25 years (mean 22.1) were enrolled. All the subjects signed an informed consent form. Subjects were told to perform cyclic movements of abduction/adduction (frontal plane, Fr) and flexion/extension (sagittal plane, Sa) from a position with the arms rest along the body to horizontal position. Limbs movements were coupled in three different coordination tasks: 1) only the right limb was moved (S), 2) both limbs were symmetrically moved (in-phase condition, P), 3) both limbs were anti-symmetrically moved (anti-phase condition, AP) (Figure 1).

Figure 1: Schematization of the three tasks executed standing on the force platform (S: single limb; P: in-phase; AP: anti-phase) performed on the 2 planes of movement (A: frontal; B: sagittal).

These movements were paced by a digital metronome at 0.6, 0.8, 1 and 1.2 Hertz (a, b, c, d on the figure). Sequences of 20 cyclic movements were performed for each tested frequency. On each plane both the frequency and the order of execution of the different tasks were randomized. A force platform (Kistler) was used for recording the centre of pressure (CoP) displacement and the value of the screw torque exerted on the ground on the vertical axes (Tz). Surface electromyographic activation (sEMG, TELEMG BTS) was recorded from two stabilization muscles, bilaterally recorded, among those involved in stabilizing the body segments during the movement of the upper limbs (frontal plane: Adductor Longus (Ad and Adq) and Gluteus Medius (Gm and Gq); sagittal plane: Rectus Femoris (RF and RFq) and Biceps Femoris (BF and BFq)). CoP displacement data were analyzed as: 1) variance of the displacement on the horizontal plane (VarX: lateral displacement; VarY: anterior-posterior displacement), 2) displacement track length (Lt) and 3) equivalent area of the track (Aeq). sEMG raw data were filtered, then rectified. The mean EMG amplitude was calculated over the whole acquisition time [4]. Data of CoP displacement and Tz were normalized and expressed as a percentage in the data collected during the task of abduction of the right arm alone on the frontal plane (S) at 0.6Hz; sEMG data were normalized and expressed as a percentage in the data collected during the task of in-phase abduction or flexion of both arms (P) at 0.6Hz. Statistical analysis was computed using the SPSS 14.0. Repeated measurement ANOVA (4 frequencies X 3 tasks) with repeated contrasts and the Bonferroni post-hoc test were applied for each plane of motion. The significance level was set at p<0.05.

RESULTS AND DISCUSSION
All the 15 subjects completed the experimental protocol. On the frontal plane, the CoP displacement significantly increased with frequency in all conditions except the anterior-posterior axes during the in-phase condition and the Lt during the single arm condition. Anyway in anti-phase conditions the CoP displacement were highest (p<0.01), followed by the single arm and the in-phase conditions. On the sagittal plane, CoP displacement significantly increased with frequency in all conditions except for VarY during the in-phase condition, Lt during the single arm condition, and Aeq during both in-phase and anti-phase conditions. Anyway in anti-phase conditions the CoP displacement were highest (p<0.01) followed by the single arm and the in-phase conditions. Only the VarX did not change significantly in different conditions. Both on the frontal (figure 2) and sagittal plane (figure 3), Tz significantly increased with frequency in single arm and anti-phase conditions, resulting always highest during
anti-phase conditions (except for lower frequencies on the frontal plane)

Figure 2: On the frontal plane, $T_z$ significantly increased with frequency, resulting highest during the anti-phase condition in higher frequencies and always lower during the in-phase condition (mean±1SE).

Figure 3: On the sagittal plane, $T_z$ significantly increased with frequency, resulting highest during the anti-phase condition and always lower during the in-phase condition (mean±1SE).

On the frontal plane the intensity of sEMG significantly increased with frequency in the anti-phase condition for Adr, Adl, Gr, and Gc. The intensity of sEMG also significantly increased with frequency in the in-phase condition for Adl and Gc and in the single arm condition for Gc. Anyway in the anti-phase condition, the activations of Adl and Gc were highest (p<0.01) in all the frequencies, while Adr and Gc were highest for frequencies of over 0.8Hz (p<0.05). In all the frequencies the sEMG activations of the stabilization muscles were lowest during the in-phase condition. On the sagittal plane, the amount of sEMG significantly increased with frequency during the anti-phase condition for RFr, RFs, BFr, and BFs, during the in-phase condition for BFs and during the single arm condition for RFs. In the anti-phase condition, the activities of RFs, BFr, and BFs were highest in all the frequencies, while RFs was highest at 1.2Hz. In all the frequencies the sEMG activations were lowest during the in-phase condition.

The results show that the anti-phase movement provokes major oscillation of the centre of pressure and screw torque exerted on the ground and requires the greatest postural activity, detected as sEMG activity of stabilizing muscles. Moreover moving only one limb could be more demanding than moving the two limbs in in-phase condition. The presented data could appear to conflict with those of the literature, reporting that the amount of postural activity derive from the dimension of the mass involved in the movement executed [5]. Data interpretation could be related to the kinesiology of the studied pattern of coordination. Esposti [6] has recently demonstrated that mirror symmetrical movements of the two hands performed on the transversal plane (in-phase conditions) produce a minor metabolic engagement as a consequence of minor neuromuscular involvement in maintaining the centre of mass stability. Indeed, during these movements the muscular activity involved in the movement helps to stabilize trunk displacement. Moreover our data not only indicate that the postural engagement was greater during the anti-phase condition than during the in-phase condition but that this last condition require less postural engagement that the movement of a single limb.

From our data, it could be speculated that the ease of execution of the in-phase coupling modality could be related to a concept of “energy saving modality.” The easiest patterns of movement are those with minor postural activity in which there is a minor metabolic cost. The biomechanics of movements could influence the internal neuromuscular constraints, leading the subjects to prefer one pattern over another because of its minor necessity for postural engagement.

CONCLUSION

When moving the two upper limbs on the frontal and sagittal plane, the in-phase coupling produces lower CoP displacement, torque and engagement of the stabilization muscles than during the anti-phase coupling, probably thanks to a self-stabilization of the body segments. The authors speculate that the described phenomena could be the origin of both the preference and the greater ability to perform in-phase movements.

REFERENCES