UPPER TRUNK-PELVIS AXIAL ROTATION COORDINATION DURING TREADMILL RUNNING

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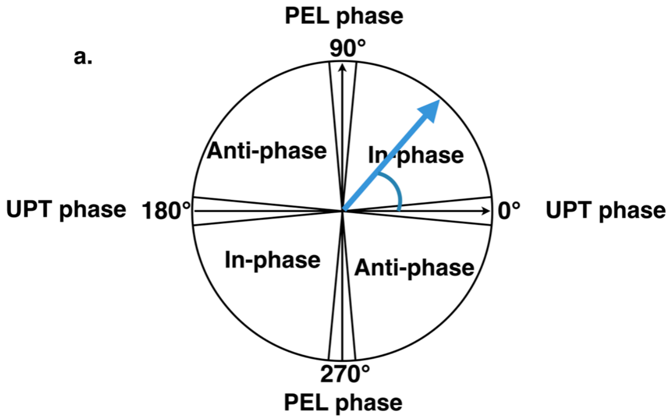
The purpose of our study was to assess the effect of running speed on upper trunk-pelvis coordination of axial rotation during running. A 7-camera Vicon system (120 Hz) was used to capture motions of 20 participants running on a treadmill at three speeds. Upper trunk and pelvis segmental angles were calculated and used in cross-correlation analysis and vector coding methodology to quantify upper trunk-pelvis phase lag and coordination patterns, respectively. Multilevel modeling was used to test running speed effect on those variables. Upper trunk motion preceded pelvic motion and the phase lag increased with running speed. Running speed could also contribute to changes in coordination pattern. Knowledge of upper trunk-pelvis coordination may potentially change our understanding of the roles of axial motions during running.

KEYWORDS: trunk, running technique, vector coding.

INTRODUCTION: Using an anti-phase (two segments rotating in opposite direction) coordination pattern between the pelvis (PEL) and upper trunk (UTP) for axial rotation during human locomotion is thought to control the transverse plane angular momentum in order to maintain postural stability (Herr & Popovic, 2008). Hence, during gait, UPT-PEL coordination shifts from in-phase (rotating in the same direction) to anti-phase coordination as walking speed increases (Lamoth, Beek, & Meijer, 2002). The inability to shift to greater time spent in anti-phase at higher speeds by patients with low back pain (Seay, Van Emmerik, & Hamill, 2011b; Selles, Wagenaarb, Smit, & Wuismane, 2001) suggests that this coordination can be adversely affected. The UPT-PEL coordination patterns used during running are not agreed upon. Understanding the effects of running speed on coordination patterns can help elucidate the purposes of different coordination patterns used within a running stride. In turn, this understanding may improve our understanding of effective running technique and to begin to comprehend the consequences of atypical trunk coordination. Therefore, the purpose of the study is to assess the speed effect on UPT-PEL coordination in running for healthy participants. We hypothesized that more phase lag between PEL and UPT and longer time spent in anti-phase would be demonstrated as running speed increases.

METHODS: 20 participants (age = 22.4 ± 3.0 yr, mass = 67.4 ± 12.9 kg, height = 1.7 ± 0.1 m, moderate to vigorous physical activity = 6 ± 3 hrs/wk) ran on a treadmill at three self selected speeds: natural (range: 2.2 – 4.2 m/s), 110% of natural (2.5 – 4.7 m/s) and submaximal speed (2.9 – 5.4 m/s). Locations of 24 reflective markers placed on the upper trunk (C7 – T8), pelvis and lower extremity were captured by a 7-camera Vicon system (120 Hz) for 10 strides. Segmental axial rotation angles for the UPT and PEL were calculated and used in cross-correlation analyses to determine phase lag between the two segments. Coordination was quantified using the vector coding method (Chang, Van Emmerik, & Hamill, 2008) to generate the coupling angle (CPA, 0° to 360°), defined as the vector orientation between two adjacent data points in time on the UPT-PEL angle-angle diagram relative to the right horizontal (shown in Fig. 1 & 3). Time spent in each of four coordination patterns during each stride were identified based on the CPA: in-phase, anti-phase, UPT phase (UPT rotates, negligible PEL motion) and PEL phase (pelvis rotates, negligible UPT) (Fig. 1). Phase lag and time spent in each coordination pattern were scaled to % stride time (% ST) and analyzed using multilevel modeling (MLM) (HLM7®; SSI, Skokie, IL). In MLM, phase lag and time spent in each coordination pattern were outcome measures with level 1 (individual trial level, n = 60) and level 2 (participant level, n = 20) and with running speed as the predictor. MLM finds the best linear fit to the outcome measures and accounts for the intercept and slope of each participant (i.e., the between-subject variability).

RESULTS: The upper trunk preceded pelvis axial rotation (phase lag =1.5% – 34.0% ST) during a running stride (Fig. 2). Ranges of time spent in each of four coordination patterns (in-phase, anti-phase, UPT and PEL phase) were 27–88%, 4–63%, 1–26% and 0–5% ST, respectively. MLM indicated that running speed contributed some to changes in phase lag (slope coefficient = 1.23, R^2 = 16.06%, p = 0.005), and time spent in UPT phase (slope coefficient = -0.67, R^2 = 18.61%, p = 0.012). Every 0.45 m/s (about 1 mph) increase of running speed would increase the phase lag by 1.23% ST and decrease UPT time by 0.67% ST. Running speed displayed a tendency to contribute to increased time spent in anti-phase (slope coefficient = 1.19, R^2 = 12.17%, p = 0.100). No other coordination pattern variables associated with running speed significantly.



b.

Coordination pattern	Coupling angle (CPA) range
In-phase	5°< CPA< 85°; 185°< CPA< 265°
Anti-phase	95°< CPA< 175°; 275°< CPA< 355°
Upper trunk (UPT) phase	0°≤ CPA≤ 5°; 175°≤ CPA≤ 185°; 355°≤ CPA≤ 360°
Pelvis (PEL) phase	85°≤ CPA≤ 95°; 265°≤ CPA≤ 275°

Figure 1: Coordination pattern classification based on coupling angle (CPA): (a) shows a upper trunk (X axis) vs. pelvis (Y axis) angular displacement vector (blue) and the corresponding CPA; (b) indicates coupling angle ranges for each coordination pattern.

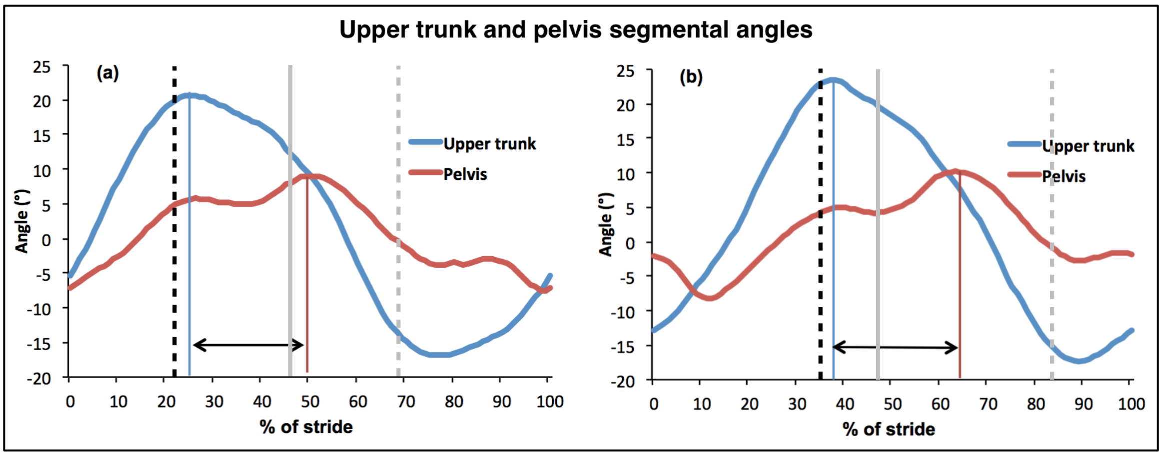


Figure 2: Upper trunk and pelvis segmental angles in axial rotation for a representative participant running at (a) 2.24 m/s and (b) 4.47 m/s during each % of the stride (0%= right foot touchdown). Vertical lines: black = right foot, gray = left foot; solid = touchdown, dashed = toe-off. The angles were averaged across 10 consecutive strides. Positive segmental angles indicate left rotation. The double-arrow indicates time lag between peak angles of upper trunk and pelvis.

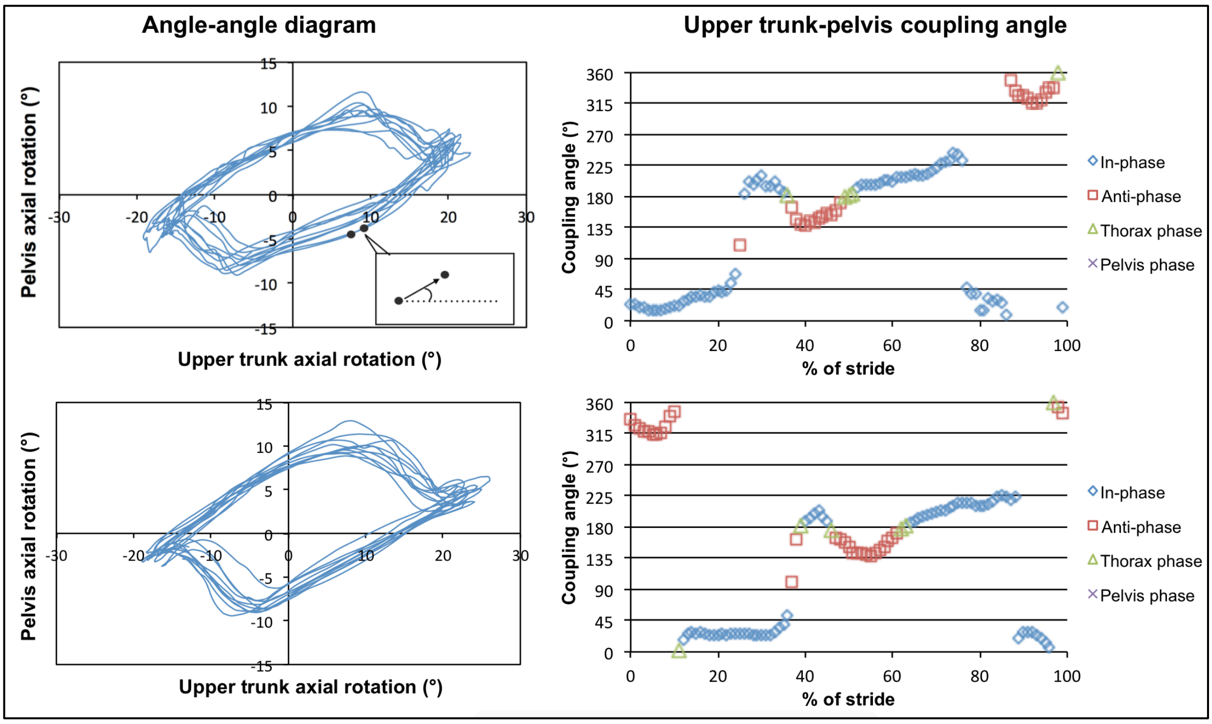


Figure 3: Upper trunk-pelvis angle-angle diagram (left column) and coupling angle (right column) for a representative participant running at 2.24 m/s (upper row) and 4.47 m/s (bottom row). Positive segmental angles indicate left rotation.

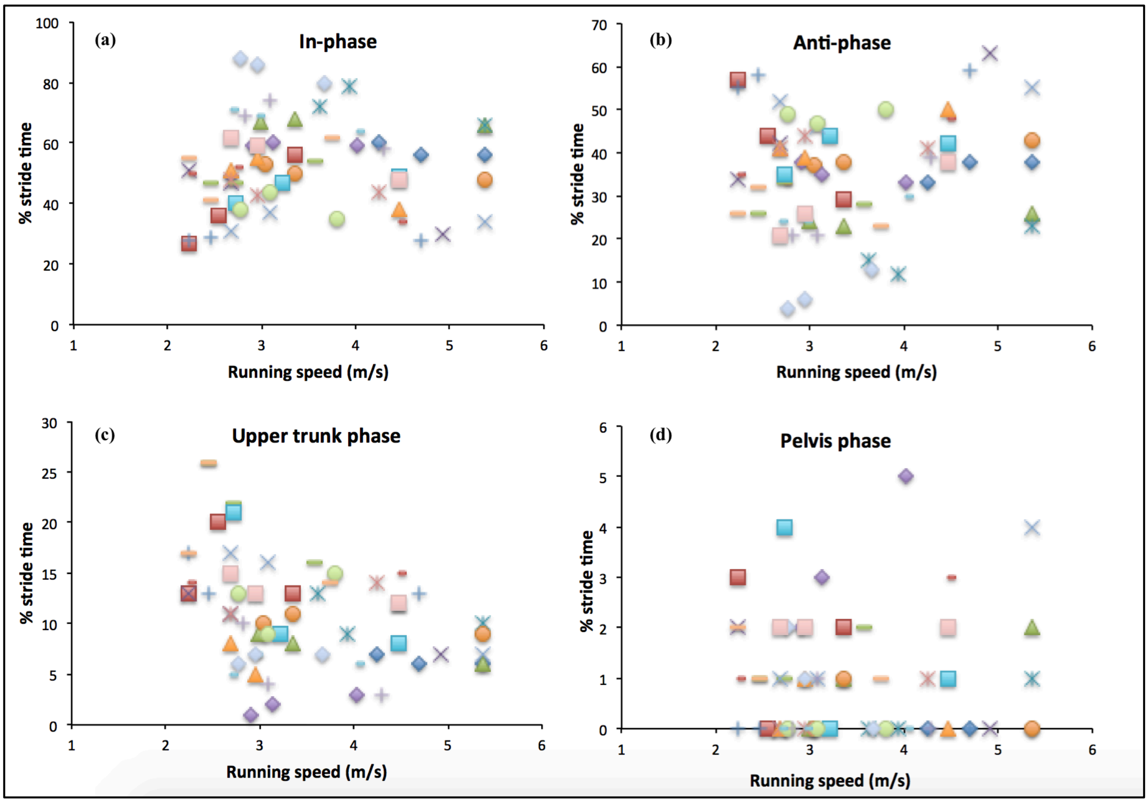


Figure 4: Scatter plot for time spent in each coordination pattern: (a) in-phase, (b) anti-phase, (c) upper trunk phase and (d) pelvis phase against running speed. Each participant is shown by different color and symbol.

DISCUSSION: Upper trunk axial rotation preceded pelvic motion during running at all speeds, which is consistent with previous walking (Bruijn, Meijer, van Dieën, Kingma, &

Lamoth, 2008) and running studies (Seay, Van Emmerik, & Hamill, 2011a). Moreover, the phase lag at higher running speeds increased possibly due to phase shift of pelvic rotation towards moving with the leg as suggested in walking (Bruijn et al., 2008). Informally, we observed a slight decrease of time in upper trunk phase as speed increased. Based on our initial observations, compared to the support phase, relatively little pelvic rotation occurred during the flight, thus accounting for when the UPT phase occurred during the stride. As running speed increased, more pelvic rotation possibly to control the postural stability was exhibited during the flight phase, hence, potentially reducing the UPT phase time. In walking, the increased UPT-PEL anti-phase time has been suggested to be the result of the pelvis rotating about the femur in order to increase step length at higher speeds, thus the PEL motion is decoupled from the UPT rotation (Bruijn et al., 2008). However, as we only observed a tendency ($p = 0.100$) to increase time spent in anti-phase at faster running speed and relatively low to modest coordination slope coefficients from the MLM, the behavioral relevance of running speed effects may be limited in the present study. One potential explanation for modest speed effects on coordination patterns is participant variation. It is evident (Fig. 4) that there was considerable individual participant variability for time spent in the coordination patterns and responses to increased speed. This variability likely includes natural variation in coordination patterns among humans, but also could be affected by participants' skill levels and running speeds.

CONCLUSION: Phase lag between the upper trunk and pelvis increased for axial rotation at higher speeds during treadmill running. We observed a tendency for increased time in anti-phase as speed increased similar to that in walking. However, possibly due to large participant and running speed variations, the speed effect was not statistically or clinically significant. The present study took an initial step towards understanding the mechanism of trunk and pelvis coordination in running. Further studies are still needed to provide more evidence on whether in-phase to anti-phase transition exists in running as speed increases and how it affects running technique.

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