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Differences in lumbopelvic rhythm between trunk flexion and extension

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ABSTRACT

Background: Trunk flexion and extension have already been found to have different characteristics, such as those in lumbopelvic rhythm. Although a more advanced method of quantifying such rhythm, lumbopelvic continuous relative phase and phase variability have not been used to explore the differences between trunk flexion and extension motions. This information is important since abnormal lumbopelvic coordination patterns increase the risk of low back pain. The current study investigated the differences in lumbopelvic rhythm between trunk flexion and extension, and how the rhythm changed within each of the two motions.
Methods: Thirteen subjects performed pace-controlled trunk flexion/extension motions in the sagittal plane while lumbar and pelvis kinematics data were recorded, such that the lumbopelvic continuous relative phase and phase variability could be calculated to quantify lumbopelvic rhythm.
Findings: Trunk extension motion had significantly smaller lumbopelvic continuous relative phase and phase variability than flexion motion, which indicated a more in-phase and stable rhythm. Additionally, the lumbopelvic rhythm within trunk extension motion changed from a more in-phase and stable pattern to a more out-of-phase and unstable pattern; by contrast, the opposite change (from out-of-phase and unstable to in-phase and stable) was observed in trunk flexion.
Interpretation: Findings of the current study provided important information about the differences in lumbopelvic rhythm between trunk flexion and extension motions. Quantifying these patterns provides the means for identifying abnormal patterns in a clinical setting, and could serve as normative benchmarks during low back pain rehabilitation plans.

1. Introduction

As recently reported in the literature, low back pain (LBP) continues to be one of the most serious global health problems, with the global point prevalence of 9.4% (Driscoll et al., 2014; Hoy et al., 2013). LBP causes not only personal suffering but also tremendous economic costs (Druss et al., 2002; Lambeek et al., 2011). In the United States, over 100 billion dollars was spent annually because of LBP, including both direct (e.g. medical cost) and indirect cost (e.g. lost productivity) (Dagenais et al., 2008; Ma et al., 2014). Consequently, it is important to identify risk factors of LBP, such that control strategies can be developed (Kerr et al., 2001). Repetitive or prolonged trunk flexion/extension has been reported by previous epidemiological studies to be a major contributory factor to LBP (Hoogendoorn et al., 2000; Punnett et al., 1991; Wai et al., 2010).

As essential components of trunk flexion/extension motion, lumbar and pelvis rotations occur simultaneously during trunk motion (Cailliet, 1988; Nelson et al., 1995). Lumbopelvic rhythm describes the relative contributions of the two interactive segments to the total trunk motion. It is a major influential factor in spinal loading (Arjmand et al., 2011; Granata and Sanford, 2000) since multi-segment movement is affected by the coordination pattern of each individual segment (Qu et al., 2012; Schöner et al., 1990). A more in-phase or out-of-phase lumbopelvic rhythm indicates a synchronous or asynchronous coordination pattern between lumbar and pelvis, respectively (Chow et al., 2014). In several previous investigations of lumbopelvic rhythm, it has been demonstrated that LBP patients showed a more in-phase coordination pattern and a decreased coordination variability compared with a non-symptomatic population when performing running, walking, and sit-to-stand tasks (Esola et al., 1996; Porter and Wilkinson, 1997; Seay et al., 2011; Shum et al., 2005). Chow and colleagues investigated the effect of backpack carriage on lumbopelvic rhythm and found a more out-of-phase coordination pattern and increased variability when carrying heavier backpacks (10% and 15% of bodyweight) and when performing forward reaching tasks (Chow et al., 2014). Lumbar muscle fatigue was also

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reported to affect lumbopelvic rhythm during stoop lifting, and a more in-phase coordination pattern was observed with the presence of muscle fatigue (Hu and Ning, 2015).

Some differences between trunk flexion and extension motions have already been reported in previous studies. Several studies found different timing in muscle activation between trunk flexion and extension (Hashemirad et al., 2009; McGorry et al., 2001; Tanti and Masuda, 1985), and it was reported that in trunk flexion, relaxation of the erector spinae muscle (flexion relaxation phenomenon) occurred at a smaller lumbar angle than during reactivation of the muscle during trunk extension motion (Hashemirad et al., 2009; Tanti and Masuda, 1985), which indicated that trunk extension was initiated by trunk extensor muscles (McGorry et al., 2001). The muscle co-contraction pattern was also found to be different between trunk flexion and extension (Granata et al., 2005; Marras, 2008). Granata and colleagues revealed that, compared with trunk extension, approximately twice the amount of co-contraction was observed in trunk flexion (Granata et al., 2005), which resulted in 50% greater spinal compression force (Granata et al., 2005; Marras, 2008). Only a few previous studies compared the kinematics patterns of trunk flexion and extension motions (Nelson et al., 1995; Tafazzol et al., 2014). Nelson and associates examined the relationship between lumbar and pelvic motion during trunk flexion and extension, attempting to understand if lumbar and pelvic motion occurred simultaneously or sequentially. Their findings suggested that simultaneous lumbar and pelvic motion patterns were observed in both trunk flexion and extension motion (Nelson et al., 1995). These results were supported by a more recent study, which demonstrated that the simultaneous lumbar and pelvic motion pattern was adopted because it could help reduce spinal loading (Tafazzol et al., 2014). Despite the previous findings, the differences in lumbopelvic rhythm, especially lumbopelvic continuous relative phase (CRP) and CRP variability between trunk flexion and extension motion, has not been investigated. Lumbopelvic CRP is a more advanced way of examining the relative coordination pattern between lumbar and pelvis. Compared with traditional methods (e.g., lumbar-pelvic rotation ratio, discrete relative phase), which only examined displacements of segments in a static manner (Nelson et al., 1995; Tafazzol et al., 2014), CRP analyzes both displacements and velocities of intersegmental motions from a dynamical systems perspective (Chow et al., 2014; Kurz and Stergiou, 2004; Peters et al., 2003; Stergiou, 2004). Furthermore, CRP also provides quantitative information on how lumbopelvic rhythm changes during the motion. This information is critical since abnormal coordination patterns lead to greater spinal loading and thus increase the risk of LBP (Arjmand et al., 2011; Cailliet, 1988; Granata and Sanford, 2000).

According to the previous findings (Nelson et al., 1995; Tafazzol et al., 2014), it is believed that significantly different lumbopelvic CRP and CRP variability can be observed between trunk flexion and extension motion. Therefore, the objective of the current study is to compare the lumbopelvic rhythms of trunk flexion and extension motion by quantifying lumbopelvic CRP and CRP variability. It is hypothesized that trunk extension motion would have significantly smaller lumbopelvic CRP and CRP variability compared with trunk flexion motion, which indicates a more in-phase and stable motion pattern. Additionally, it is hypothesized that during trunk extension motion, lumbopelvic rhythm changes from a more in-phase (smaller CRP) to a more out-of-phase pattern (larger CRP), while the variability also becomes larger, and also that the change from a more out-of-phase (larger CRP) to a more in-phase pattern (smaller CRP), as well as a decreasing variability, could be generated during trunk flexion motion.

2. Methods

2.1. Subjects

Thirteen male subjects were recruited from the local student community with mean (standard deviation) age, body mass, and body height of 24.2 (3.4) years, 75.2 (5.9) kg, and 175.1 (5.3) cm, respectively. Those who have a previous injury in the trunk or lower extremities were not included in the current study. The experimental protocol was approved by the West Virginia University's Institutional Review Board.

2.2. Equipment

Lumbar and pelvic kinematics were captured using a magnetic-field-based 3D motion tracking system (Motion Star, Ascension, Burlington, VT, USA). Two magnetic sensors were placed on the skin surface and aligned with the spinous processes of the first lumbar (L1) and first sacral (S1) spinal vertebrae, respectively. Lumbar flexion angle was defined as the angular difference between L1 and S1 sensors in the sagittal plane, and pelvic rotation angle was defined as the angular rotation of S1 sensor in the sagittal plane (Fig. 1). A metronome was used to help subjects keep a consistent pace (velocity) across all trunk motion tasks.

2.3. Experiment design

The independent variable was trunk motion direction (DIRECTION), which included two different conditions: flexion and extension. The two dependent variables were lumbopelvic continuous relative phase (CRP) and the CRP variability. CRP was defined as the absolute value of angular difference in the relative phases between lumbar and pelvis during trunk flexion/extension motion, and CRP variability was defined as the standard deviation of the CRP in each task. The details about lumbopelvic CRP calculation are explained in the below "Data processing" session.

To investigate how lumbopelvic rhythm changes within each of the two DIRECTION conditions, the total trunk motion was split into two parts with respect to range of motion (SEQUENCE): the first and second halves of the motion. In addition to DIRECTION, the effects of SEQUENCE, and the interaction between DIRECTION and SEQUENCE on lumbopelvic CRP and the CRP variability were also examined.

2.4. Procedure

Upon arrival, the subjects were given an explanation of the experimental procedures and signed an informed consent form. Two motion sensors were then placed on the skin surface of the L1 and S1 spinous processes after completing a five-minute warm-up session. Subjects performed 3 repetitions of pace-controlled trunk flexion/extension

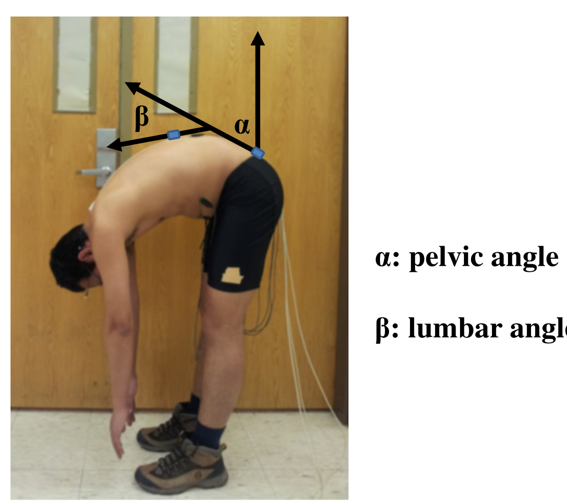

Fig. 1. Definition of lumbar angle and pelvic angles.