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Trunk coordination in healthy and chronic nonspecific low back pain subjects during repetitive flexion–extension tasks: Effects of movement asymmetry, velocity and load

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ABSTRACT

Multiple joint interactions are critical to produce stable coordinated movements and can be influenced by low back pain and task conditions. Inter-segmental coordination pattern and variability were assessed in subjects with and without chronic nonspecific low back pain (CNSLBP). Kinematic data were collected from 22 CNSLBP and 22 healthy volunteers during repeated trunk flexion–extension in various conditions of symmetry, velocity, and loading; each at two levels. Sagittal plane angular data were time normalized and used to calculate continuous relative phase for each data point. Mean absolute relative phase (MARP) and deviation phase (DP) were derived to quantify lumbar–pelvis and pelvis–thigh coordination patterns and variability. Statistical analysis revealed more in-phase coordination pattern in CNSLBP ($p = 0.005$). There was less adaptation in the DP for the CNSLBP group, as shown by interactions of Group by Load ($p = .008$) and Group by Symmetry by Velocity ($p = .03$) for the DP of pelvis–thigh and lumbar–pelvis couplings, respectively. Asymmetric ($p < 0.001$) and loaded ($p = 0.04$) conditions caused less in-phase coordination. Coordination variability was higher during asymmetric and low velocity conditions ($p < 0.001$). In conclusion, coordination pattern and variability could be influenced by trunk flexion–extension conditions. CNSLBP subjects demonstrated less adaptability of movement pattern to the demands of the flexion–extension task.

1. Introduction

Repetitive sagittal trunk movement is accomplished by the coordinated rotation of the pelvis and lumbar spine (Gracovetsky et al., 1995; Granata & Sanford, 2000; Nelson, Walmsley, & Stevenson, 1995). Aberrant patterns of lumbar–pelvis–hip coordination have been reported in research studies and have been used to discriminate normal subjects from

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individuals with mechanical low back pain (LBP)(Esola, McClure, Fitzgerald, & Siegler, 1996; McClure, Esola, Schreier, & Siegles, 1997; Porter & Wilkison, 1998). However, these findings are not consistent because a decrease (Paquet, Malouin, & Richards, 1994), increase (Esola et al., 1996; Porter & Wilkison, 1998), and no change (Wong & Lee, 2004) of the contributions of the lumbar spine to forward bending have been reported in previous studies.

The ratio of segment rotations at discrete points within flexion–extension cycles has been considered as a measure of coordination in several studies (Esola et al., 1996; Lariviere, Gagnon, & Loisel, 2000; McClure et al., 1997; Nelson et al., 1995; Porter & Wilkison, 1998). However, these discrete measures only consider couplings at single occurrences during flexion–extension cycles. Therefore, important events may be ignored between discrete points during cycles. Thus, discrete measures do not account for continuous dynamic interactions between trunk segments throughout entire cycles, and this may provide more information about control mechanisms underlying neuromuscular impairments in individuals with LBP.

To our knowledge, a single study has addressed lumbar–hip coordination using the continuous method of cross-correlation during three-plane trunk bending in patients with LBP (Wong & Lee, 2004). No significant difference was reported in continuous measures of lumbar–hip coordination during sagittal trunk movements between LBP and healthy subjects in this study. However, reduced trunk velocity and acceleration in people with LBP have been reported in several studies (Marras & Wongsam, 1986; Marras et al., 1993; McIntyre, Glover, Conino, Seeds, & Levene, 1991; Wong & Lee, 2004). Thus, to improve the accuracy of the current data, a detailed analysis of behavior using higher dimensional variables that incorporate both spatial and temporal information is necessary.

Motor variability is fundamental to human movement and is essential to musculoskeletal health over the span of a working life (Srinivasan & Mathiassen, 2012). Because most functional movements are complex and involve multiple segments, coordination variability provides more relevant information about motor variability which reflects the consistency of the inter-segmental relationship across repeated trials. Decreased coordination variability has been considered as a factor that increases mechanical stress and overuse situations (Heiderscheit, Hamill, & van Emmerik, 2002). Few studies, which have quantified variability of trunk kinematics during repeated lifting exertions, have considered the trunk as one segment (Granata, Marras, & Davis, 1999; Mirka & Baker, 1996). However, considering that trunk sagittal movements involve multiple segments, coordination variability can provide more data about the variability of trunk kinematics.

The dynamical systems theory (DST) approach offers techniques to characterize coordination pattern and variability (Kelso, 1995; Kurz & Stergiou, 2004). Continuous relative phase (CRP) and deviation phase (DP) are used as techniques to quantify coordination patterns and variability in the DST approach. CRP can provide both temporal and spatial information continuously throughout the cycle. In this method, coordination patterns between two segments are measured using relative phase (RP) that is calculated continuously from the differences between the position-velocity phase planes of the oscillating movement of two body segments. In this way, coordination dynamics is calculated using higher order variables incorporating both joint position and velocity in the analysis. Variation in the organization of the neuromuscular system is quantified by the DP that is the measure of magnitude of variability and reflects how the relationships between two segments are consistent in repeated trials. Higher DP values indicate more coordination variability or less coordination stability (Hamill, van Emmerik, Heiderscheit, & Li, 1999; Stergiou, 2004).

Several studies have demonstrated aberrant coordination patterns and variability in patients with LBP during dynamic movements such as walking, running (Lamoth, Meijer, Daffertshofer, Wuisman, & Beek, 2006; Seay, van Emmerik, & Hamill, 2011, 2014), forward reaching (Silfies, Bhattacharya, Biely, Smith, & Giszter, 2009), and axial rotation (Sung, 2014), using CRP and DP methods. Results from these studies suggest these measurements are useful techniques to determine neuromuscular impairments and clinical assessments of this population.

Asymmetric, high velocity and loaded flexion–extension movements have been associated with the risk of low back injury (Fathallah, Marras, & Parnianpour, 1998; Marras, Lavender, & Leurgans, 1995). The higher level of muscle co-activation during these highly demanding movements increases compression, shear, and torsional spinal loads (Gardner-Morse & Stokes, 1998; Granata & Orishimo, 2001). However, conditions of load, symmetry, and velocity of flexion–extension movements can affect lumbar–pelvis coordination by altering trunk muscle length and lumbar curvature (Granata & Sanford, 2000; Lariviere et al., 2000; Nelson et al., 1995). Moreover, coordination variability may also be influenced by the aforementioned conditions. In this way, reduced coordination variability can further increase the risk of loaded, high velocity, and asymmetric flexion–extension movements and predict low back injuries associated with these highly demanding movements (Heiderscheit et al., 2002; Yen, Gutierrez, Ling, Magill, & McDonough, 2012). Several studies have measured the effects of load and velocity on the coordination variability of the trunk during walking (LaFiandra, Wagenaar, Holt, & Obusek, 2003; Lamoth et al., 2006; Yen et al., 2012), forward reaching (Silfies et al., 2009). To our knowledge, no study has assessed the effects of the conditions of load, symmetry, and velocity on variability features of trunk coordination during flexion–extension movements in individuals with and without LBP.

The purpose of the present study was to compare coordination patterns and coordination variability between individuals with chronic nonspecific low back pain (CNSLBP) and healthy control subjects during repeated trunk flexion–extension movements. Impaired neuromuscular control mechanisms have been frequently reported in individuals with LBP (Graham, Oikawa, & Ross, 2014; O'Sullivan et al., 2003; Radebold, Cholewicki, Polzhofer, & Greene, 2001; Ross, Mavor, Brown, & Graham, 2015; Van Dieën, Selen, & Cholewicki, 2003; VanDieën, Cholewicki, & Radebold, 2003; Willigenburg, Kingma, Hoozemans, & vanDieën, 2013). Altered trunk muscle recruitment patterns have been reported as a means to enhance lumbar–pelvis stability in patients with LBP (Van Dieën, Selen, & Cholewicki, 2003; VanDieën, Kingma, & Van der Bug, 2003; vanDieën et al., 2003); thus, we expected a more in-phase and less variable (more stable) coordination pattern