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Comparison of the trunk-pelvis and lower extremities sagittal plane inter-segmental coordination and variability during walking in persons with and without chronic low back pain

Samaneh Ebrahimi [a,b,c], Fahimeh Kamali [b,c,*], Mohsen Razeghi [b,c], Seyyed Arash Haghpanah [d]

[a] Student Research Committee, Shiraz University of Medical Sciences, Shiraz, Iran
[b] Department of Physical Therapy, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Shiraz, Iran
[c] Rehabilitation Sciences Research Center, Shiraz University of Medical Sciences, Shiraz, Iran
[d] School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran

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ABSTRACT

Inter-segmental coordination can be influenced by chronic low back pain (CLBP). The sagittal plane lower extremities inter-segmental coordination pattern and variability, in conjunction with the pelvis and trunk, were assessed in subjects with and without non-specific CLBP during free-speed walking. Kinematic data were collected from 10 non-specific CLBP and 10 non-CLBP control volunteers while the subjects were walking at their preferred speed. Sagittal plane time-normalized segmental angles and velocities were used to calculate continuous relative phase for each data point. Mean absolute relative phase (MARP) and deviation phase (DP) were derived to quantify the trunk-pelvis and bilateral pelvis-thigh, thigh-shank and shank-foot coordination pattern and variability over the stance and swing phases of gait. Mann-Whitney *U* test was employed to compare the means of DP and MARP values between two groups (same side comparison). Statistical analysis revealed more in-phase/less variable trunk-pelvis coordination in the CLBP group ($P < 0.05$). CLBP group demonstrated less variable right or left pelvis-thigh coordination pattern ($P < 0.05$). Moreover, the left thigh-shank and left shank-foot MARP values in the CLBP group, were more in-phase than left MARP values in the non-CLBP control group during the swing phase ($P < 0.05$). In conclusion, the sagittal plane lower extremities, pelvis and trunk coordination pattern and variability could be generally affected by CLBP during walking. These changes can be possible compensatory strategies of the motor control system which can be considered in the CLBP subjects.

1. Introduction

Chronic low back pain (CLBP) is a highly common musculoskeletal disorder affecting 70–85% of people at some point during their lifetime (Andersson, 1999). However, up to 85% of LBP cases are classified as non-specific LBP or LBP with unknown origin (White III & Gordon, 1982).

Since locomotion is one of the main functions in human life, the effects of CLBP on gait parameters have been investigated in many studies; Kinematics/kinetics assessments have shown decreased walking speed, swing time and step lengths in LBP

* Corresponding author at: School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Abiverdi 1 Ave., Chamran Blvd, Shiraz, Fars, Iran.
E-mail address: Fahimehkamali@hotmail.com (F. Kamali).

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patients (Keefe & Hill, 1985; Khodadadeh, Eisenstein, Summers, & Patrick, 1988). Moreover, Muller et al. showed decreased ground reaction force and pelvic rotation amplitude in CLBP patients during level walking. They also stated that the knee joint angles were significantly more extended at touch down in these subjects (Müller, Ertelt, & Blickhan, 2015). In addition, Agostini et al. revealed that LBP patients had a tendency to walk with extended knees during the load acceptance phase of gait (Agostini, Schieroni, Siccardi, Campagnoli, & Knaflitz, 2009). It has been also shown that CLBP subjects walked with anterior pelvis tilt and excessive hip flexion during walking as well as reduced knee flexion ability in the swing phase and limited ankle power generation at push-off (Vismara, Cimolin, Galli, Crivellini, & Capodaglio, 2009). Chronic LBP subjects are reported to have balance impairment (Ruhe, Fejer, & Walker, 2011), poor motor control (Etemadi, Salavati, Arab, & Ghanavati, 2016), altered control strategies (Lamoth, Meijer, Daffertshofer, Wuisman, & Beek, 2006) and altered trunk muscular activity (Lamoth, Meijer, et al., 2006).

Despite overall consistent results about the effects of CLBP on gait, the biomechanical strategies during walking are not well understood in these patients. The human gait is a sophisticated task with a high motor control demand for producing coordinated limb movements (Chiu, Osternig, & Chou, 2013). It has been stated that quantifying such movements with kinematic/kinetic parameters alone is difficult (Chiu, Lu, & Chou, 2010; Seay, 2008). Previous researchers stated that the complex movements are not created exclusively from the single joints movement summation (Cordo & Gurfinkel, 2004). Therefore, the spatial and temporal gait parameters or single joints kinematics/kinetics studies cannot be a good presenter of the pathology (Nematollahi et al., 2016) or accurately show alterations in neuromuscular control (Chiu & Chou, 2013).

Recent improvements in non-linear dynamic field show that collective variables (higher-order variables), e.g. inter-segmental/inter-joint coordination (ISC/IJC) in contrast to conventional gait analysis (lower-order variables), e.g. kinematic/kinetic measures, can better capture the underlying coordination dynamics in motor tasks (Hamill, McDermott, & Haddad, 2000; Yen, Chen, Liu, Liu, & Lu, 2009). These measures are very useful to understand how the neuro-musculoskeletal system achieves an accurate and smooth functional activity through organizing the redundant joints degrees of freedom (Bernstein, 1967). ISC/IJC analysis describes the segments/joints spatio-temporal organization in relation to each other (inter-segmental/inter-joint coordination) to identify the movement patterns (Hutin et al., 2011). It is the ability to maintain accurate relationships between segments or joints in a limb to create a functional movement in an organized time/sequential manner (Ghanavati et al., 2014).

Based on the dynamic system theory approach, continuous relative phase (CRP) is a technique used for quantification of coordination pattern (Kelso, 1995). CRP can correlate both angular position and velocity information of two segments or joints continuously during the entire cycle (Hamill, van Emmerik, Heiderscheit, & Li, 1999). Moreover, CRP variability can quantify the variation in the organization of the neuromuscular system (Mokhtarinia, Sanjari, Chehrehrazi, Kahrizi, & Parnianpour, 2016). It has been declared that these parameters are more appropriate for determining motor control mechanisms involved in gait (Worster, Valvano, & Carollo, 2015). In the other word, the coordination pattern and variability have been considered as fundamental features of human movements that provide information about how motor control is changed in patients (Lamoth, Meijer, et al., 2006).

Lamoth et al. stated that the nature of many locomotion problems in patients with CLBP were coordinative (Lamoth, Daffertshofer, Meijer, & Beek, 2006). It has been reported that the evaluation of movement coordination in CLBP subjects during walking can improve the understanding of CLBP as a motor impairment (Lamoth et al., 2002) and determine how motor control is changed in CLBP (Lamoth, Meijer, et al., 2006). Various studies have shown abnormal coordination pattern and variability in individuals with CLBP during dynamic motions such as walking (Lamoth, Meijer, et al., 2006; Seay, Van Emmerik, & Hamill, 2011), running (Seay, Van Emmerik, & Hamill, 2014; Seay et al., 2011) or other tasks (Mokhtarinia et al., 2016; Seay, Sauer, Patel, & Roy, 2016). These studies demonstrated that CLBP mainly affects the trunk-pelvis coordination and stated that these patients generally have difficulty in adjusting the coordination at higher speeds or challenging tasks.

However, it has been declared that "the trunk is a part of a system, the human body" (Mientjes & Frank, 1999). Therefore, the spine should not be evaluated regardless of the lower extremities in CLBP patients (McGregor & Hukins, 2009). Song et al. stated that the movements of the lower limbs are substantial factors associated with the permanence or development of CLBP (Song, Jo, Sung, & Kim, 2012). Moreover Muller indicated that trunk and lower limb movements interact with each other (Müller et al., 2015). Therefore, as changes in the lumbo-pelvic control could affect the lower limbs (Lee, Ham, & Sung, 2012), it is very important to evaluate the possible effects of CLBP on the lower extremities movement patterns and coordination.

Based on the previous literature, although there are some studies that have shown differences in the lower limb biomechanical parameters in association with LBP during walking, but the lower limbs movement patterns have received relatively little attention. Moreover, to the best of our knowledge, no study has been conducted on the relationship between CLBP and lower limb coordination patterns and variability during gait. In order to address this issue, the aim of the present study was to investigate and compare the ISC and coordination variability of lower extremities in conjunction with pelvis and trunk in the sagittal plane during walking in non-specific CLBP patients and non-CLBP control subjects. We hypothesize that CLBP patients would demonstrate more in-phase ISC patterns with more stable patterns variability in the sagittal plane in some couples/phases of the gait cycle in comparison to non-CLBP control subjects.

The results of this study might be helpful for better understanding of CLBP associated problems in walking and considering those problems in treatment protocols to have more efficient and appropriate rehabilitation.