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Low back pain affects trunk as well as lower limb movements during walking and running

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ABSTRACT

Up to now, most gait analyses on low back pain concentrate on changes in trunk coordination during walking on a treadmill. Locomotion on uneven ground as well as lower limb changes receives little attention in association with low back pain. The present study focuses on how chronic non-specific low back pain causes modifications in lower limb and trunk movements, in level and uneven walking and running.

We found that trunk as well as lower limb movement was influenced by chronic non-specific low back pain. A consistent finding across all gaits and ground level changes is that patients with chronic non-specific low back pain show less pelvis and unchanged thorax rotation as compared to healthy controls. Furthermore, in chronic non-specific low back pain patients the trunk rotation decreased only during level and uneven running whereas the sagittal trunk inclination at touchdown increased only during uneven walking as compared to healthy controls. Besides significant changes in the upper body, in chronic non-specific low back pain patients the knee joint angle at touchdown was more extended during level walking but also during uneven walking and running as compared to healthy controls.

We assume that trunk movements interact with lower limb movements or vice versa. Therefore, we recommend that further investigations on low back pain should consider both trunk (primarily pelvis) and lower limb (primarily knee) movements.

1. Introduction

Low back pain (LBP) is often accompanied by changes in gait (Keefe and Hill, 1985; Lamoth, Meijer, et al., 2002; Spenkelink et al., 2002; van der Hulst et al., 2010). A consistent finding is that people with LBP tend to walk slower than healthy control subjects. It is suggested that slower walking reflects the presence of pain and/ or avoidance behaviour associated with pain.

At lower walking speeds, in healthy subjects horizontal thorax and pelvis rotations are more or less in phase (synchronous pelvis and thorax rotation in the same direction), but at higher speeds, the phase difference increases and tends toward anti-phase (Bruijn et al., 2008; Lamoth, Beek, et al., 2002; Selles et al., 2001; Wu et al., 2014). Subjects with chronic LBP encounter problems in adjusting pelvis–thorax coordination and the thorax and pelvis move less out of phase at higher walking speeds (Lamoth et al., 2006; Lamoth et al., 2002; Seay et al., 2011; van den Hoorn et al., 2012). Also, during running LBP patients showed more in-phase coordination and reduced transverse plane coordination variability when compared to healthy subjects (Seay et al., 2011).

One interpretation of the reduced variability is that the trunk's stiffness increased in LBP (van den Hoorn et al., 2012). When avoiding unplanned movements between pelvis and thorax during walking, patients with chronic LBP alter trunk stiffness while increasing superficial lumbar muscle activity (van Dieen et al., 2003). More precisely, muscle activity of the *M. erector spinae* and *M. rectus abdominis* increase (Arendt-Nielsen et al., 1996; Lamoth et al., 2006; Vogt et al., 2003) and the activity of the *M. obliquus externus* remains unchanged (van der Hulst et al., 2010). These changes in muscle activity suggest increased stiffness.

Stiffening of the trunk in healthy subjects (while contracting their abdominal muscles, or wearing an orthopaedic brace that limits trunk motions) led to similar changes in thorax–pelvis coordination as observed in LBP patients, but to different changes in pelvis–leg coordination, with the pelvis remaining more out of phase with the legs (Wu et al., 2014). These results may suggest that LBP patients do not simply stiffen their spine during gait.

Until now, lower limb movements receive little attention in association with LBP. In healthy subjects, during slow walking hamstring activity at the end of the swing phase (before touchdown) decreased as walking speed decreased and the knees were

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significantly more extended at touchdown (Hanlon and Anderson, 2006; Murray et al., 1984). As mentioned previously, people with LBP tend to walk slower and thus, we assume with more extended knees and reduced hamstring activity at the instant of touchdown. Nevertheless, a more extended knee joint at touchdown leads to increased vertical forces and minor shock-absorption (Murray et al., 1984; Podraza and White, 2010). Furthermore, patients with chronic LBP showed increased (and no decreased) hamstring activation at the end of the swing phase and in the early stance phase (Vogt et al., 2003). However, until now it is not known how LBP influences lower limb movements.

The available literature shows that chronic LBP primarily affects trunk movement during level walking. In daily living, frequently changes of level are necessary (such as when crossing a road and stepping on the sidewalk, mounting doorsteps entering stores, or climbing stairs). These situations require adaptations in muscle recruitment and more effort than level walking. To better understand how chronic LBP affects movement, we here investigate whether chronic non-specific LBP causes modifications in lower limb and trunk movements and how it influences the different strategies of locomotion on level and uneven ground. We hypothesised that CNLBP patients show lower limb and trunk movements that differ from healthy control subjects, in level and uneven walking and running.

2. Methods

2.1. Subjects

Eleven patients with chronic non-specific low back pain (CNLBP) diagnosed by a physician and 11 healthy control participants took part in this study (Table 1). Both groups were gender, age, height and weight matched. Informed written consent was obtained from each volunteer. The experiment was approved by the local ethics committee (University of Jena, 2917-09/10) and in accordance to the Declaration of Helsinki.

2.2. Measurements

At the beginning of the investigation, CNLBP patients indicated their current level of low back pain on a visual analogue scale that ranged from “no pain” (0) to “maximum pain” (10). Afterwards, all subjects were instructed first to walk and second to run along a 17 m walkway with two consecutive force plates in its centre (Fig. 1; the walkway was adapted to a previous study described in (Müller et al., 2014)). Subjects were allowed to choose their walking and running speed ad libitum but had to make sure that they moved naturally with constant speed and centred their right foot on the first and left foot on the second force plate (1. and 2. contact; Fig. 1).

The ground reaction forces were sampled at 2000 Hz by using one variable–height force plate at the site of the first contact (9281B, Kistler, Winterthur, Switzerland) and one ground-level force plate at second contact (9287BA, Kistler). After walking and running on the unperturbed flat track, the setup was changed. The variable–height force plate at first contact was set up to an elevation of 10 cm and the subjects were instructed again first to walk and second to run along the uneven walkway (Fig. 1). All subjects were visually aware of the walkway and had to accomplish at least five successful trials per experimental setup and gait. A trial was successful when the subjects centred both touchdowns on the corresponding force platforms without losing any reflective joint markers. The markers (19 mm) were placed on the tip of the toe, *lateral malleolus*, *epicondylus lateralis* and *trochanter major* on both lower limbs as well as on *acromion*, *L5* and *C7 proc. spinosus*. All trials were recorded with eight cameras (240 Hz) by a 3D infrared system (MCU 1000, Qualisys, Gothenburg, Sweden) and synchronized by using the trigger of the Kistler soft- and hardware.

2.3. Data processing

Kinetic and kinematic data were analysed using custom written Matlab code (The Mathworks, Inc., Natick, MA, USA). For kinetic analysis the ground reaction force was normalised to subject body weight (*bw*). A vertical ground reaction force threshold of 0.02*bw* was used to determine the instants of touchdown and take-off at first and second contact. The raw kinematic data were filtered with a third-order low-pass Butterworth filter at 50 Hz cut-off frequency (Müller and Blickhan, 2010). The main parameters used for the kinematic analysis in the transverse plane were the rotational amplitudes (calculated as max–min between 200 ms before touchdown and 100 ms after touchdown) of: thorax rotation (calculated as the rotation of the *acromion* markers, projected on the global transverse plane, around the vertical axis of *C7 proc. spinosus*), pelvis rotation (calculated as the rotation of the *trochanter major* markers, projected on the global transverse plane, around the vertical axis of *L5*), and trunk rotation (calculated by subtracting thorax rotation from pelvis rotation; described in (van den Hoorn et al., 2012)). The main parameters in the sagittal plane were: trunk inclination at the instant of touchdown (the line joining the *C7 proc. spinosus* to the *L5* with respect to the vertical) and inner angles at the knee and ankle joint at the instant of touchdown (Fig. 1).

Table 1
Characteristics of the subjects.

Subject	Sex	Age [years]	Height [cm]	Weight [kg]	BMI
CNLBP 1	f	58	162	54	20.6
CNLBP 2	m	27	180	74	22.8
CNLBP 3	f	22	174	63	20.8
CNLBP 4	f	21	172	64	21.6
CNLBP 5	f	56	172	67	22.6
CNLBP 6	f	50	162	54	20.6
CNLBP 7	m	37	177	91	29.0
CNLBP 8	m	28	177	90	28.7
CNLBP 9	f	46	166	61	22.1
CNLBP 10	m	48	170	72	24.9
CNLB 11	m	27	171	63	21.5
mean (sd)		**38.2 (13.9)**	**171.2 (5.9)**	**68.5 (12.5)**	**23.2 (3.1)**
control 1	f	54	163	61	23.0
control 2	m	30	182	74	22.3
control 3	f	23	164	55	20.4
control 4	f	24	177	60	19.2
control 5	f	50	167	70	25.1
control 6	f	52	159	52	20.6
control 7	m	38	180	87	26.9
control 8	m	34	172	75	25.4
control 9	f	46	161	58	22.4
control 10	m	48	169	84	29.4
control 11	m	24	172	67	22.6
mean (sd)		**38.5 (12.1)**	**169.6 (7.7)**	**67.6 (11.6)**	**23.4 (3.0)**

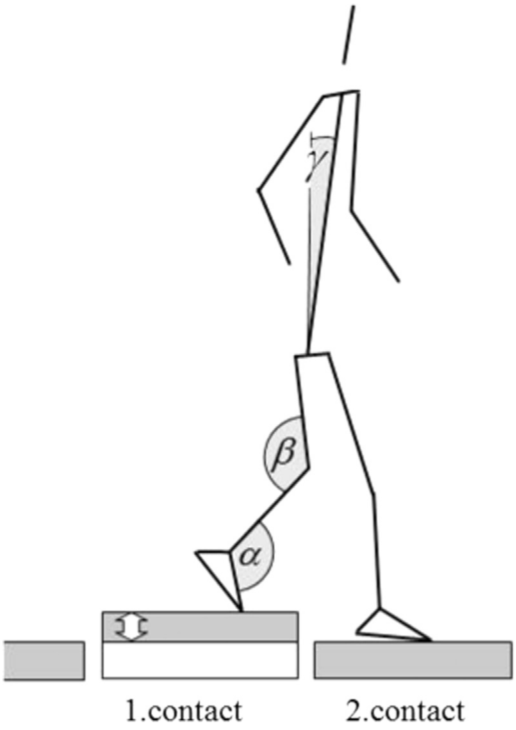

Fig. 1. Side view of the instrumented walkway with two consecutive force plates in its centre. The first force plate (1. contact) was set at two different elevations: 0 cm (level ground) and 10 cm (uneven ground). In the sagittal plane, we calculated the trunk inclination with respect to the vertical (γ) and the inner angles at the knee (β) and ankle joints (α). The figure exemplifies walking across uneven ground.