Full length article

The effect of extensible and non-extensible lumbar belts on trunk postural balance in subjects with low back pain and healthy controls

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ABSTRACT

Background: Previous findings suggest that wearing a lumbar belt may benefit some patients with low back pain; however, the mechanisms of action are not yet fully understood.
Research question: The effect of wearing two flexible (extensible and non-extensible) lumbar belts on trunk postural control was investigated during an unstable sitting task.
Methods: Healthy subjects and subjects with LBP sat on a wobbling chair, with and without the lumbar belts. Chair rotation was measured in the sagittal and frontal planes, and 10 linear and nonlinear measures of balance were computed to assess the quantity (3 measures) and quality (7 measures) of the movements.
Results: Both lumbar belts induced similar changes in specific measures of trunk postural control, for both subject groups, generally indicative of more instability and less controllability, but with low effect sizes (0.14 and 0.40). Subjects with LBP also showed lower entropy (complexity; effect size 0.93) and higher determinism (predictability; effect size 0.56) than healthy controls, under all test conditions. These findings indicate that the subjects with LBP used a less complex, more predictable trunk postural control strategy, suggestive of impaired adaptability and responsiveness to dynamic trunk postural control demands. The findings also suggest other factors related to dynamic adaptability may be impaired by lumbar belt use.
Significance: The effects of the lumbar belts on trunk postural control were small, however, their practical implications for the management of LBP remain to be determined in relation to other effects of lumbar belts (e.g. increased mechanical stiffness).

1. Introduction

While current evidence indicates that wearing a lumbar belt (LB) cannot prevent a first episode of low back pain (LBP) [1], the potential role for LB in the treatment of LBP remains unclear [2]. Low quality and insufficient evidence means that no clear guidelines exist for the use of LB for any subgroups of patients with LBP [1,2]. There is a need, therefore, for research examining the effect of LBs on biomechanical and motor control mechanisms with individuals with LBP.

One previous study on airline baggage handlers [3] is frequently cited to raise concerns about the use of LBs. A marginally significant increased injury incidence was noted in non-compliant workers who discontinued LB use during the study. One hypothesis is that trunk muscle weakness gradually developed because of the mechanical support provided by the LB. This hypothesis, however, remains

controversial [4]. Another possibility is that the biomechanical support from the LB triggered changes in neuromuscular control mechanisms (proprioception, anticipatory postural adjustments, and reflex responses) responsible for lumbar spine mechanical stability. Cholewicki, Shah [5] studied the effect of using LBs for three hours a day over three weeks on 14 healthy subjects; findings related to lumbar proprioception were inconsistent, precluding any clear conclusion. Results related to trunk neuromuscular responses following trunk perturbations did not reveal detrimental changes [6].

Trunk postural control (TPC) during unstable sitting provides a more "functional" test of the capacity of the central nervous system (CNS) to integrate the motor control processes essential for mechanical and postural stability. Previous studies have found no immediate effect of LB on the mean velocity of the center of pressure (CoP) during an unstable sitting tasks in asymptomatic individuals, [7,8]. Other postural

sway measures, however, are not correlated with mean CoP velocity [9], and may provide further and complementary information. Consequently, the immediate effect of LB use on trunk postural balance needs to be revisited, with the use of a more comprehensive set of measures, in healthy subjects and in subjects with LBP.

Extensible and non-extensible belts (EB and NEB) are two types of LBs that provide adequate comfort and functionality for use during activities of daily living and in the workplace. EB are both flexible and elastic. NEB are flexible but not elastic, and do not expand with the outward expansion of the belly during lumbar movements. Consequently, NEB might be more prone to increase two intrinsically linked phenomena - intra-abdominal pressure and lumbar stiffness [10,11] - which in turn may differentially affect TPC. One previous study did find that NEB produce more lumbar stiffness than EB [12], although our previous study showed no difference [13].

The current study aims to examine the effects of EB and NEB on TPC during an unstable sitting task, in healthy controls and subjects with LBP. Ten linear and nonlinear TPC measures, quantifying the quantity and quality of movement respectively (see methods), were used. It was hypothesized that both linear and nonlinear TPC measures would change in response to wearing LBs, and that the changes would be more pronounced with the NEB and in subjects with LBP.

2. Methods

2.1. Subjects

Twenty healthy controls and 40 subjects with LBP, aged 18–65, and equally divided by sex, participated in the experiments (Table 1). The subjects were recruited through newspaper advertisement and from physiotherapy clinics in Montreal, Quebec, Canada. General inclusion criteria were: mastery of French or English; being currently employed, or, for subjects with LBP, having been employed before the current episode of LBP. The inclusion criteria for the LBP group were: lumbar or lumbosacral pain (with or without radicular pain) for at least 4 weeks (non-acute phase); no radicular pain below the knees. General exclusion criteria were: pelvic or spinal surgery; specific lumbar pathology (fracture, infection or tumor); scoliosis; systemic or degenerative disease; body mass index $> 30 \, kg/m^2$; high blood pressure (systolic > 140 mmHg and/or diastolic > 90 mmHg); history of neurological condition other than those related to back pain; anxiolytic, anticonvulsant, antidepressant, or other medication which can influence neuronal excitability (antispasmodic, anti-inflammatory and analgesic medications were accepted); sacroiliac pain as identified with five clinical tests [14]; and pending litigation over a compensation. Additional exclusion criteria for healthy subjects were the presence of back pain in the last year, or having a history of back pain lasting more than

a week. All subjects were informed about the experimental protocol and potential risks, and signed written consent before participation. The ethics committee of the Center for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR) approved the study and the consent form.

2.2. Lumbar belts

Two models of LB were chosen by consultation with an orthotist, based on functionality of use at work (flexibility and comfort) as well as affordability and durability. Both types of LB consisted of two layers of straps, secured with Velcro material (Fig. 1). Initial adjustment and placement of the LB was carried out with the inner layer, while the final tension was adjusted with the external layer, which was an elastic material for the extensible LB (EB) (model LumboLux, Hope Orthopedic) and non-extensible nylon straps for the non-extensible LB (NEB) (model 582, MBrace). The EB also allowed for insertion of dorsal and ventral panels that were not used in the present study. Both LBs are commercially available in seven lengths, with standard abdominal and dorsal heights of 6 and 10 in., respectively. The 6-inch front, which is typical of most "low-profile" LBs on the market, is regarded as being less restrictive of trunk flexion.

Each LB was positioned over a T-shirt, with the subject sitting, such that the lower edge of the LB covered the antero-superior iliac spines without touching the thighs. The tension of the LB was then adjusted, with the subject in quiet standing, before recording any experimental condition. LB tension was standardized to produce a contact pressure of 60 mmHg (8.0 kPa), recorded from a FSR sensor (Force Sensing Resistor; Interlink Electronics; model FSR400) attached on the skin between the lateral aspect of the left iliac crest and the 12th rib.

2.3. Seated balance task and experimental conditions

A detailed description of the wobble chair and its calibration is available elsewhere [15] (Fig. 2). Briefly, adjustable springs allow for modulation of task difficulty and for calibration of the system in order to circumvent the confounding effect of subject size on performance. The subjects crossed their arms while their lower limbs were fixed to the wobble chair, thus requiring subjects to use their trunk to control sitting balance. An inertial 3D-motion-capture sensor (sampling rate of 100 Hz; Xsens Motion Technologies, Enschede, Netherlands), attached to the back of the chair), recorded the chair's anteroposterior (AP) and mid-lateral (ML) rotation. An additional sensor, attached at the subject's C7 level, was removed after the initial calibration. Following two 30-s (eyes open, eyes closed) and one 60-s (eyes closed) familiarization trials, the three belt conditions (eyes closed) were performed in random order. For each belt condition, three consecutive 60-s test trials,

Table 1
Demographic characteristics of the healthy subjects and subjects with LBP volunteered in this study.

Variable	Healthy group (n = 20)				LBP group (n = 40)				P-value (ANOVA)	
	Male (n = 10)		Female (n = 10)		Male (n = 20)		Female (n = 20)		Group	Sex
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)		
Age (year)	41	(14)	40	(14)	39	(10)	46	(11)	0.258	0.344
Height (m)	1.76	(0.07)	1.65	(0.05)	1.75	(0.05)	1.62	(0.08)	0.432	**< 0.001**
Mass (kg)	77	(10)	62	(8)	77	(9)	64	(11)	0.663	**< 0.001**
BMI (kg/m^2)	24.7	(2.1)	23.0	(2.8)	24.9	(2.9)	24.3	(2.9)	0.291	<u>0.067</u>
NPRS (/10)					4.1	(1.7)	4.0	(1.1)		0.957
RMDQ – day 1 (/24)					6.1	(3.8)	3.7	(2.5)		0.100

The p-values ≤ 0.05 are identified in bold characters while the trends with 0.05 < p < 0.1 are underlined.
BMI: Body mass index.
NPRS: Eleven-point (0–10) numeric pain rating scale corresponding to to assess the current, best and worst levels of pain intensity during the last week, so as to average the three ratings [41].
RMDQ: Roland-Morris disability questionnaire [42].

Fig. 1. (A) extensible lumbar belt (the 2 tissue layers are elastic) and (B) non-extensible lumbar belt (the 2 nylon straps prevent extensibility).

separated by 2-min rest, were executed.

2.4. Data processing and statistical analyses

Only the signals from the last 55 s of each 60-s trial were processed, as detailed elsewhere [15]. Twelve TPC measures were selected, based on an earlier reliability study [15] and with the consideration that TPC measures based on linear and non-linear analyses should be considered as complementary (Table 2). Effectively, while linear analyses measure the quantity of movement, they are not sensitive enough to reflect the dynamic characteristics of movement [16,17]. Non-linear analyses and chaos theory [17,18], however, reveal the characteristics of the underlying dynamics by quantifying the variability and complexity of the movement dynamics [19–21]. Many diseases and disorders are characterized by less complex dynamic behavior, indicating less flexibility of the involved systems for adaptation to the demands of a constantly changing environment [22]. Among many nonlinear measures (see Table 2), only DETERMINISM and ENTROPY were analyzed and reported in this study, as they are the most reliable ones among the recurrence quantification analysis (RQA) metrics [23,24].

NCSS statistical software (version 8.0 for windows) was used for the statistical analyses, with the significance level set at P < 0.05. Because some variables showed abnormal distributions, we elected to systematically transform all variables [25] to normalize their distributions, as verified with the Wilk-Shapiro test. Please note, however, that mean values reported in the tables are the untransformed values. Two-way ANOVAs (2 GROUP [LBP vs control] × 3 CONDITION [no belt (NB) vs extensible belt (EB) vs non-extensible belt (NEB)]) was carried out, with CONDITION treated as a repeated-measures factor. Significant interactions or main effects were further analyzed using a post-hoc Tukey-Kramer test. Only the double interactions were interpreted. Effect sizes corresponding to effects detected for between-subjects (GROUP) and within-subjects (CONDITION) factors were computed using the Hedges's g_s and Hedges's g_{av} formulations, respectively [26], using means, standard deviations (SD) and sample sizes. These formulations allow for the comparison of the effects across within and between-subjects designs. These g scores are, basically, unbiased (sample size correction) Cohen's d scores, and can be interpreted the same way: g around 0.2 is interpreted as "low", 0.5 as "average" and 0.8 as "strong".

3. Results

No GROUP × CONDITION interaction was detected. Wearing the LBs, regardless of the type, significantly increased RmsDIST, but significantly decreased MeanFREQ and FractDim-CE (Table 3). The long-term Lyapunov exponent significantly increased with the EB only (Table 3). All effect sizes were low, ranging between 0.14 and 0.40.

While DETERMINISM was significantly larger (p = 0.026) in LBP group with an average effect size (g = 0.56), ENTROPY of subjects with LBP was significantly smaller (p = 0.041) with a strong effect size (g = 0.93) (Table 3). No other GROUP effect was detected.

4. Discussion

The immediate effect of wearing two flexible (extensible and non-extensible) LBs on TPC during unstable sitting was examined. It was found that: 1) both types of LB led to comparable findings; 2) linear TPC measures led to equivocal results but nonlinear measures more consistently deteriorated TPC and trunk stability; 3) while no GROUP effect was detected with the linear variables, significantly lower entropy and higher determinism were found in the subjects with LBP.

Fig. 2. Experimental set-up. In A, the wobble chair system is shown, comprising two parts: (1) a base having four springs that are adjustable radially (distance) from a low friction ball-and-socket pivot and (2) the chair that was adjusted so as to align its center on the pivot and the four springs in the rails to block rotation movements. In B, we see the whole setup where the subject is surrounded by a cushioned square structure for safety (from Ref. [15]).

Table 2

Abbreviations used to describe the summary measures for each category of analysis.

Summary measure	Description	Interpretation [43]	L/NL
Traditional postural sway summary measures [44]			
RmsDIST (°)[a]	RMS distance	Indicators of balance performance	L
MeanVELO (°/s)[a]	Mean velocity	Indicators of control demand	L
MeanFREQ (Hz)[a]	Mean frequency	Indicators of the relationship between control demand and balance performance	L
FD–CE	Fractal dimension based on the 95% confidence ellipse	Indicators of the relationship between control demand and balance performance. Larger FD indicates more complexity	NL
Hurst rescaled range analysis – HRRA [17]			
Hurst–AP	Slope of log–log plot of the RMS residual as a function of	> 0.5: higher complexity with persistent behavior; < 0.5: higher complexity with	NL
Hurst–ML	interval size in the AP or ML direction	anti-persistent behavior; $= 0.5$ Brownian motion	NL
Recurrence quantification analysis - RQA [18]			
DETERMINISM (%)	Percentage of determinism	Larger DETERMINISM indicates higher predictability	NL
ENTROPY	Shannon entropy: quantifies the complexity of the recurrence plot	Larger ENTROPY reflects higher complexity	NL
Maximum Lyapunov exponents [45]			
LyapunovS	Short-term Lyapunov exponents	Smaller LyapunovS or LyapunovL indicates better stability maintenance in,	NL
LyapunovL	Long-term Lyapunov exponents	respectively, a short or long period of time after perturbation	NL

AP: Antero-posterior; ML: Medio-lateral; RMS: root mean square; L: linear; NL: non-linear.

[a] These measures are computed based on spatial angle (R) or planar angles in sagittal (AP) and frontal (ML) planes from the origin (horizontal orientation of the seat in AP and ML planes).

4.1. Effect of LB extensibility on trunk postural control

The EB and NEB did not differentially impact TPC, which refutes our hypothesis that the NEB would produce a greater effect on TPC. This was based on previous reports that NEB increase lumbar stiffness more than EB [12]. However, as reported above, our previous study did not show any difference in lumbar stiffness for the EB and NEB used in the current study [13]. The description of the NEB in Cholewicki, Lee [12] suggests that it may be less flexible than their EB and our own LBs. A less flexible LB may have produced different results.

4.2. Effect of wearing LBs on trunk postural control

Both linear and nonlinear measures revealed changes in TPC with the use of LBs. The effects of both types of LB, however, were the same in both healthy and LBP groups (no GROUP × CONDITION interaction).

Previous studies have found that LBs induce no changes in MVELO in healthy subjects during a sitting balance task [7,8]. The present study replicated this finding (MVELO) for both healthy subjects and those

with LBP. MeanVELO results suggest that wearing a LB did not change the control demand (regulatory activities) of the neuromuscular system during the task.

Other measures of TPC were affected, however, generally indicating a decline in TPC with LB use. For linear measures of TPC, the findings were somewhat inconsistent. The significantly larger RmsDIST with LB use suggests worsening TPC, while the lower MeanFREQ score suggests an improvement. Both measures had small effect sizes (g range: 0.14 to 0.23), however, suggesting at most a very modest degradation of performance. Two nonlinear TPC measures, FD_CE and LyapunovL, both suggested a deterioration of TPC, with small (g: 0.20-0.21 for FD_CE) and average (g = 0.40 for LyapunovL) effect sizes. Special attention is needed when interpreting effect sizes in the presence of nonlinear phenomena, however, because the notion of proportionality no longer exists. The significantly smaller FractDim-CE scores emphasize less complex dynamics, suggesting less system adaptability to the dynamic environment [22,27]. The significantly higher long-term Lyapunov exponent (LyapunovL) scores (for EB only) indicate less postural stability over longer periods following perturbation.

Several factors may explain the deterioration of many measures of

Table 3

Descriptive statistics and P-values corresponding to GROUP (G) and CONDITION (C) main effects (ANOVA) along with post hoc analyses following a significant CONDITION effect.

Variable	GROUP				CONDITION				
	Mean (SD)		P-value	Post hoc analysis (g)	Mean (SD)			P-value	Post hoc analysis (g)
	Healthy	LBP			NB	EB	NEB		
Traditional postural sway summary measures [44]									
RmsDIST	5.63 (2.45)	6.12 (2.66)	0.580		5.66 (2.60)	6.04 (2.61)	6.17 (2.61)	0.001	NB < EB (0.14) ;NB < NEB (0.19)
MeanVELO	8.70 (4.15)	8.16 (3.37)	0.644		8.25 (3.73)	8.32 (3.53)	8.45 (3.71)	0.842	
MeanFREQ	0.28 (0.07)	0.25 (0.07)	0.181		0.27 (0.07)	0.26 (0.08)	0.26 (0.07)	< 0.001	NB > EB (0.18) ;NB > NEB (0.23)
FD_CE	1.62 (0.07)	1.58 (0.07)	0.116		1.61 (0.08)	1.59 (0.08)	1.59 (0.08)	0.001	NB > EB (0.20) ;NB > NEB (0.21)
Hurst rescaled range analysis – HRRA [17]									
Hurst–AP	0.88 (0.04)	0.89 (0.03)	0.414		0.88 (0.04)	0.89 (0.04)	0.88 (0.04)	0.375	
Hurst–ML	0.89 (0.04)	0.90 (0.04)	0.238		0.89 (0.04)	0.89 (0.04)	0.90 (0.04)	0.403	
Recurrence quantification analysis - RQA [18]									
DETERMINISM	0.96 (0.02)	0.98 (0.01)	0.026	Healthy < lBP (0.56)	0.97 (0.02)	0.97 (0.01)	0.97 (0.01)	0.109	
ENTROPY	2.53 (0.73)	1.35 (1.43)	0.041	Healthy > lBP (0.93)	1.72 (1.36)	1.77 (1.39)	1.72 (1.36)	0.704	
Maximum Lyapunov exponents [45]									
LyapunovS	5.26 (1.92)	5.03 (2.03)	0.521		4.83 (2.17)	5.29 (1.86)	5.20 (1.93)	0.124	
LyapunovL	0.00 (0.01)	0.00 (0.01)	0.458		1.82 (13.89)	7.77 (15.53)	5.52 (14.71)	0.004	NB < EB (0.40)

TPC with the use of LBs. First, a LB stiffens the spine in all degrees of freedom. This will affect the ability of the CNS to position the trunk center of mass, with respect to the position of the chair, in a timely manner (i.e. more passive resistance to postural adjustments). Second, constraining the lumbar spine degrees of freedom may increase the movement variability and, in consequence, the cost of control (effort and energy required for control) in the task-relevant directions, leading to declined control performance and error in achieving the goal (postural stability in this task). This is based on the theory of Todorov and Jordan [28], which suggests that the CNS allows movement variability in task-irrelevant directions (degrees of freedom) to decrease the cost of control in the task-relevant ones. Third, altered proprioceptive feedback due to the interaction of the belt and the skin might negatively affect TPC, although some (but not all) previous studies have suggested proprioceptive benefits from lumbar bracing [29,30]. Lumbar proprioception was measured in the subjects of the present study, but no effect was detected [31].

4.3. Between-group effects on trunk postural control

While linear TPC measures of movement quantity did not reveal any between-group effects, which concurs with previous findings produced in our lab [32], two nonlinear measures of movement quality - DETERMINISM and ENTROPY – did find differences between the healthy subjects and those with LBP.

Determinism (DETERMINISM) measures predictability. A system is predictable when it is not impacted by any random noise, and the chaotic dynamics of the system are deterministic (not stochastic). ENTROPY measures the complexity of the chaotic patterns of the motion dynamics. Dynamical complexity provides the variability necessary for the system to adapt to its continuously changing environment. The source of this complexity is the deterministic chaotic interaction of the dynamic components of a biological system [22,33]. Such complexity is developed as the biological system evolves toward maturity [34]. Complexity (ENTROPY) could decrease due to uncorrelated noise in the system, which decreases predictability and determinism (DETERMINISM). Conversely, complexity could decrease when the deterministic chaotic motion changes to a rigid non-varying periodic pattern, which increases predictability and determinism [35–37].

The current findings suggest that the latter may occur in the TPC strategy employed by subjects with LBP. This was characterized by a significantly lower ENTROPY (g = 0.93), or less complexity, and a significantly higher DETERMINISM (g = 0.56), or a more predictable rigid motion pattern. To our knowledge, ENTROPY has not been measured in previous studies of motor control in patient populations. Our findings for determinism, however, concur with studies showing higher determinism in standing body sway in subjects with knee osteoarthritis [38], and in spinal kinematics during repetitive lifting/lowering in subjects with LBP [39].

4.4. Potential implications for LB use in patients with LBP

The less complex, more predicable TPC strategy shown by the subjects with LBP suggests less adaptability to environmental demands. Our findings also indicate that wearing a LB may impair TPC by decreasing motion variability. While the effect of the LB on TPC appears to be similar for healthy individuals, the further impairment in the adaptability and responsiveness of the motor control system may be of greater consequence for individuals with LBP. A loss of movement variability and adaptability is central to a leading theory on maladaptive movement strategies associated with musculoskeletal pain and has been theorized to lead to relapses or to the perpetuation of LBP [40].

The immediate effects of the LBs on TPC were quite small, however, as such, we cannot imply that short-term use of a LB will lead to long-term maladaptive habituation of the CNS, or to impairment of motor control processes essential for trunk postural or mechanical stability.

This question remains to be examined.

5. Conclusion

The immediate effect of wearing two flexible (extensible and non-extensible) LBs was investigated on TPC during unstable sitting. Both belts produced deterioration in some measures of TPC, suggestive of reduced adaptability to environmental demands, with comparable effects for subjects with LBP and healthy controls. The subjects with LBP, however, demonstrated less complex, more predicable motion patterns under all conditions, which is also associated with reduced adaptability of motor control. The deleterious effects of LBs on TPC, therefore, may be of more consequence for individuals with LBP during complex movement tasks (e.g. in a dynamic manual work environment). Further study is required, however, to determine both the immediate and long-term implications of the negative changes in TPC produced by LBs. It must also be determined whether these TPC changes outweigh the potentially beneficial effects of the increased mechanical stiffness produced by LBs.

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