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Lumbar contribution to the trunk forward bending and backward return; age-related differences

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ABSTRACT

Age-related differences in lumbar contribution to the trunk motion in the sagittal plane were investigated. Sixty individuals between 20–70 years old in five gender-balanced age groups performed forward bending and backward return with slow and fast paces. Individuals older than 50 years old, irrespective of the gender or pace, had smaller lumbar contribution than those younger than this age. The lumbar contribution to trunk motion was also smaller in female participants than male participants, and under fast pace than under the slow pace. Age-related differences in lumbar contributions suggest the synergy between the active and passive lower back tissues is different between those above and under 50 years old, differences that are likely to affect the lower back mechanics. Therefore, detailed modelling should be conducted in future to find the age-related differences in the lower back mechanics for tasks involving large trunk motion.

Practitioner Summary: Lumbar contribution to the sagittal trunk motion was observed to be smaller in individuals above 50 years old than those below this age. This could be an indication of a likely change in the synergy between the active and passive lower back tissues, which may disturb the lower back mechanics.

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KEYWORDS
Lumbopelvic coordination; ageing; spinal loading; low back pain; range of motion

Introduction

Low back pain (LBP) is a major health problem, which affects about two-thirds of the adult population for at least once in life. As the second most frequent reason for visiting a physician (Deyo and Weinstein 2001; Deyo, Mirza, and Martin 2006), and a significant cause of disability (Frymoyer et al. 1983; Buchbinder et al. 2013), the prevalence of LBP has been increasing over the past three decades (Hoy et al. 2012). This disorder is also associated with a substantial economic burden (Maetzel and Li 2002; Bakker et al. 2009), as the total direct and indirect costs of low back injuries and related pain were estimated to be $25–95 billion per year (Cats-Baril and Frymoyer 1991). Ageing is known to be an important risk factor for LBP (Burdorf and Sorock 1997; Manchikanti 2000; Kopec, Sayre, and Esdaile 2004; Cassidy et al. 2005; Deyo, Mirza, and Martin 2006; Dionne, Dunn, and Croft 2006; Johannes et al. 2010; Hoy et al. 2012, 2014). The population of older workers has been predicted to be growing from 19.5% (total = ~30 million) in 2010 to 25% (total = ~41 million) in 2020 (Toossi 2012), highlighting the importance of research to find out the relationship between ageing and LBP.

Abnormal mechanics of the lower back, specifically excessive stress and strain imposed on the lower back tissues, have been suggested to play an important causal role in the development of LBP (Adams, Burton, and Bogduk 2006). Such a harmful mechanical environment may result either from large muscle forces in response to equilibrium requirements of the spine while performing highly demanding tasks, or from large tissue deformations due to spinal instability while performing activities of daily living. Although earlier studies have reported age-related differences in tissue properties and function (Buckwalter 1995; Adams, McNally, and Dolan 1996; Iida et al. 2002; Shao, Rompe, and Schiltenwolf 2002; Galbusera et al. 2014) that can be associated with age-related differences in lower back loading, no study has yet directly assessed such a relationship. The major challenges in evaluation of age-related differences in lower back mechanics are the difficulties associated with experimental-based measurement as well as modelling-based estimation of the lower back loading. In other research areas related to lower back mechanics, such a limitation has been tackled using indirect measures. In particular, measures related to the lumbopelvic

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coordination have been extensively used to investigate the relationship between exposure to LBP risk factors and changes in the lower back mechanics (Granata and Sanford 2000; Larivière, Gagnon, and Loisel 2000; Thomas and Gibson 2007; Hu, Ning, and Nussbaum 2014; Phillips, Bazrgari, and Shapiro 2014; Hu and Ning 2015a; Pries et al. 2015), as well as differences in the lower back mechanics of people with versus without LBP (Paquet, Malouin, and Richards 1994; Porter and Wilkinson 1997; Larivière, Gagnon, and Loisel 2000; van Wingerden, Vleeming, and Ronchetti 2008; Kim et al. 2013; Hasebe et al. 2014; Jandre Reis and Macedo 2015).

The suggested premise behind the study of lumbopelvic coordination is that any change in the lumbopelvic coordination could be an indication of alteration in the synergy between active and passive contributions of the lower back tissues to trunk motion. Such changes could in turn alter the load (forces and deformations) distribution within the lower back tissues. The amount of *lumbar contribution (LC) to the trunk motion* has been used as a measure of lumbopelvic coordination in previous studies. Presence of external load and muscle fatigue has been separately shown to increase the LC (Hu, Ning, and Nussbaum 2014; Hu and Ning 2015b), whereas increasing the pace of trunk motion, as another identified LBP risk factor, has been shown to decrease the LC (Thomas and Gibson 2007). While increasing the external load and pace of trunk motion is both associated with an increase in equilibrium demand of the task on the spine, the reported differences in LC suggest different levels of active versus passive contributions from the lower back tissues to fulfil such an increase in equilibrium requirement. Specifically, for a given fixed level of equilibrium demand, a larger LC is an indication of larger passive involvement of lower back tissues, whereas a smaller LC suggests more active contribution to offset the equilibrium demand of the spine (Tafazzol et al. 2014).

While the exact relationship between the changes in lumbopelvic coordination and alterations in the lower back loading is not yet known, investigation of age-related differences in the lumbopelvic coordination may help us identify ages above which substantial changes in the lower back loading, when performing activities of daily living, should be expected. At present, such knowledge is not offered by the few studies that have reported differences in lumbar range of motion (ROM) between older and younger populations (Gracovetsky et al. 1995; Pries et al. 2015). Thus, the main objective of this study was to determine the starting age for occurrence of a significant change in LC to the trunk motion in the sagittal plane. This was achieved by assessing LC over the entire as well as each quartile of bending and return phases of trunk motion among 60 gender-balanced asymptomatic individuals between 20 and 70 years old. The effects of gender and pace of trunk motion on the age-related differences in LC were also investigated. The lumbar ROM has been suggested to be significantly smaller in the older age groups than the younger age groups. Such an age-related difference has been reported to be consistent in both males and females, but to be more pronounced after the age of 40 in males and age of 50 in females (Intolo et al. 2009). Accordingly, significant reductions in both total and quartile LCs to trunk motion in the sagittal plane were hypothesised to occur after the age of 40, reductions that were not expected to be affected by gender. Increasing pace of trunk motion has been reported to be associated with decreased lumbar ROM in young asymptomatic individuals (Thomas and Gibson 2007). Whether increasing the pace of trunk motion would add to the expected age-related reduction in LC was not clear and left to be the exploratory objective of this study.

Methods

Study design and participants

A cross-sectional study was designed wherein 60 individuals were recruited to form five equal-sized and gender-balanced age groups, each representing a decade of an individual's working life between 20 and 70 years. To increase the chance of identifying any potential differences in our outcome measures, particularly between the adjacent age groups, two years from the ends of each decade were cut off, resulting in the age groups of 22–28, 32–38, 42–48, 52–58 and 62–68 years of age. All vvolunteers completed a consenting procedure which had been approved by the Institutional Review Board of the University of Kentucky, and were then screened for the following exclusion criteria: (1) back pain within the last year, (2) spinal deformity, surgery or any other musculoskeletal abnormality in the trunk, (3) a history of work in physically demanding occupations (eg frequent lifting,

Table 1. General characteristics of the participants.

Age range (years)	22–28	32–38	42–48	52–58	62–68
Number and Gender	6 M*, 6 F*	6 M, 6 F	6 M, 6 F	6 M, 6 F	6 M, 6 F
Stature (cm)	171.4 (8.6)	170.2 (6.6)	173.1 (8.7)	172.2 (11.8)	170.6 (10.8)
Body mass (kg)	70.0 (10.4)	73.0 (13.2)	79.3 (14.6)	78.1 (12.2)	72.4 (16.8)

*M: Male; F: Female; Stature and body mass are given as mean (SD).

twisting, bending and/or driving) and (4) BMI < 20 or > 30. These exclusion criteria were adopted to minimise their confounding effects on our outcome measures. Univariate analysis of variance (ANOVA) indicated no significant differences in stature (p = 0.808) or body mass (p = 0.095) between the five age groups (Table 1).

Testing procedure

The participants were instrumented with two magnetic inertial motion trackers (MT) (Xsens MTw, Xsens Technologies, Enschede, Netherlands) strapped around the thorax at the level of T10 and pelvis to measure the thoracic and pelvic rotations according to earlier studies (Bazrgari et al. 2011; Hendershot et al. 2011). A computer recorded the three-dimensional orientation of the MTs as rotation matrices at the sampling rate of 50 Hz, after utilising a Kalman filter to minimise any potential effect of noise on the data (Xsens 2012) (Figure 1).

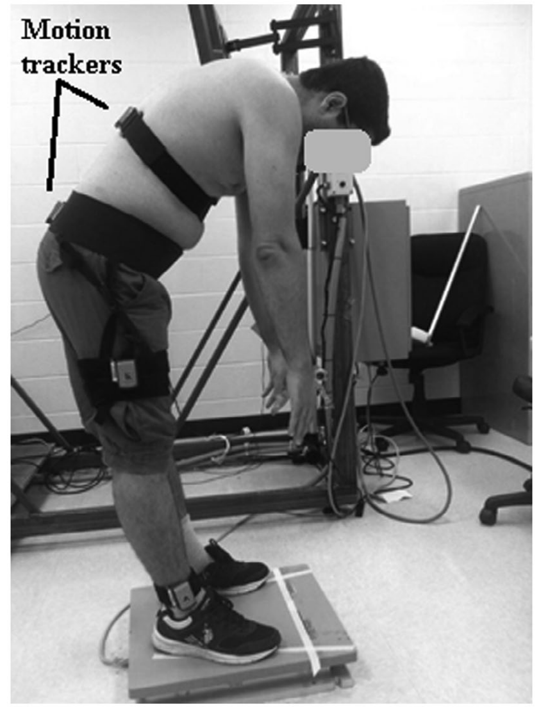

Figure 1. Participant instrumentation set-up.

Each participant completed two sessions of data collection, taking place in the morning to minimise the diurnal and occupational effects on the results, with at least 48 h in between. During each session, participants completed two trunk bending return (BR) tests: "slow BR" and "fast BR" tests. In the slow BR test, from an upright standing posture, participants bent their trunk at a self-selected pace to reach their maximum forward bending posture without any abdominal muscle efforts at the end. They waited for five seconds at their maximum bent posture (ie guided by examiner counting the seconds out load), and then returned to the upright posture, again using a self-selected pace. The fast BR test was performed similarly except the participants performed the test as fast as possible, and without a wait period at the maximum bent posture. Each of these tests was repeated three times. To reduce measurement variance due to placement of the MT sensors, while the participant was in standard anatomical position, the height of MT sensors from the lab floor was recorded in the first session and was then used for placement of the sensor during the second session.

Data analysis

The MTs' rotation matrices were used to calculate the rotations of the thorax and pelvis in the sagittal plane by considering the standing posture as the reference posture. Lumbar flexion at each time point was calculated as the difference between the thoracic and pelvic rotations. The thoracic ROM during each BR test was calculated as the difference in the respective recorded rotations between the starting and the ending time points of the bending phase of the test. The starting and ending time points of the bending phase of each BR test were the times when the thoracic rotations were, respectively, 5% and 95% of the maximum recorded thoracic rotation during that test. To calculate the LC, the bending and return phases of each test were divided into quarters of equal thoracic rotation. The total/quartile LC was calculated as the ratio of the total/quartile range of lumbar flexion/extension to the total/quartile range of thoracic rotation. Therefore, the LC can range from 0 to 1 representing 0% to 100% contribution to the trunk motion.

Statistical analysis

The dependent variables including the thoracic ROM and the total and quartile LCs were analysed using three-way repeated measures analysis of variance (ANOVA) by SPSS (IBM SPSS Statistics 22, Armonk, NY, USA), considering the age group and gender as between-subject factors and the pace of test (ie slow and fast) as a within-subject factor. Whenever appropriate, *post hoc* analyses were conducted on the age groups using the Tukey test. The minimum p value to accept the significance was set to 0.05. Prior to statistical analyses, conformity of our data to the required ANOVA assumptions was verified. In the case of a significant three-way interaction, univariate ANOVAs with two between-subject factors (ie age and gender) were used to investigate whether the simple two-way interaction of gender*age was significant separately at each level of the pace. Statistical significance of a simple two-way interaction was accepted at a Bonferroni-adjusted alpha level of 0.025.

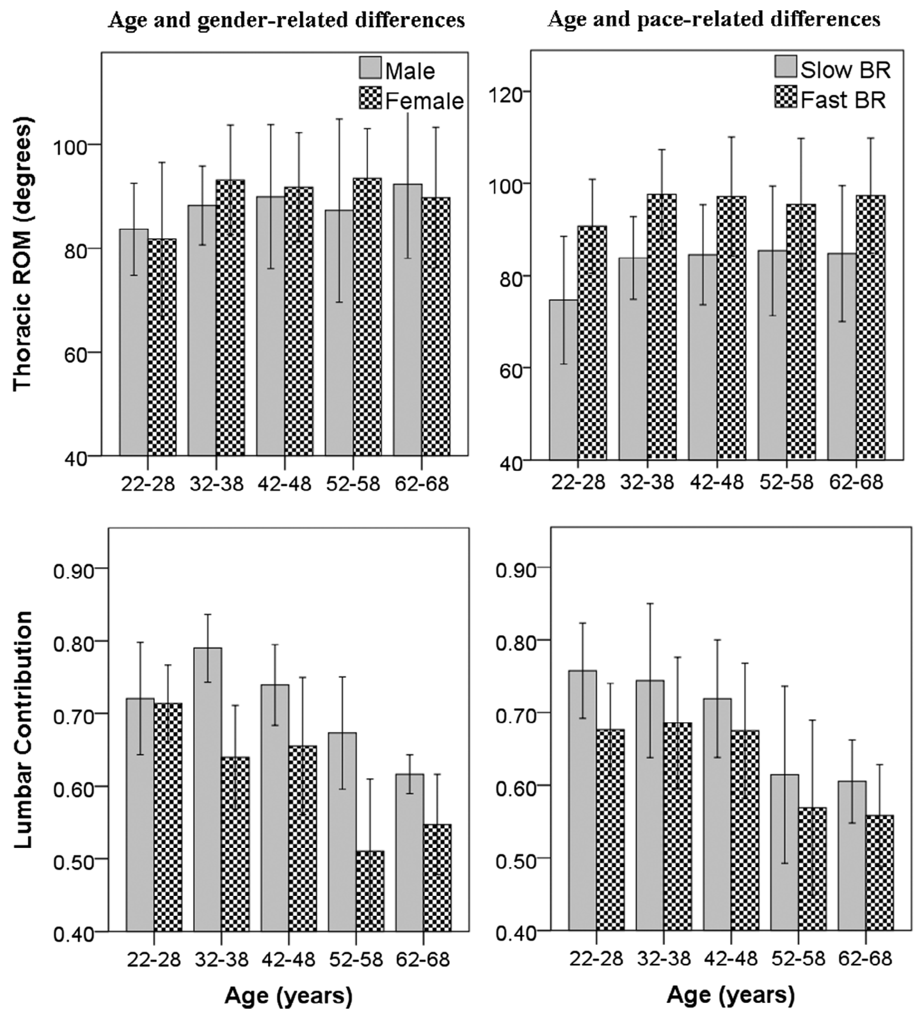

Figure 2. Age-related differences in the thoracic ROM (top row) and total LC to trunk motion (bottom row). The sub-figure on the left side of each row demonstrates age- and gender-related differences, whereas the right side sub-figure demonstrates age- and pace-related differences.

Table 2. ANOVA results for the thoracic range of motion and total lumbar contribution.

		Thoracic ROM		Total LC		Total LC (slow pace only)		Total LC (fast pace only)	
	df	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
Age	4	1.003	0.415	9.345	**<0.001**	12.066	**<0.001**	9.525	**<0.001**
Gender	1	0.281	0.599	21.578	**<0.001**	23.115	**<0.001**	28.999	**<0.001**
Gender*Age	4	0.300	0.876	2.988	**0.027**	2.639	0.045	2.074	0.098
Pace	1	313.528	**<0.001**	113.659	**<0.001**				
Pace*Age	4	1.760	0.152	10.423	**<0.001**				
Pace*Gender	1	0.173	0.679	4.356	**0.042**				
Pace*Gender*Age	4	0.783	0.541	3.142	**0.022**				

Note: Significant results are denoted iny bold font.

Results

Thoracic ROM and Total LC

Mean values of the thoracic ROM and total LC under slow and fast BR tests for different age and gender groups are depicted in Figure 2. The main and interaction effects of age, gender and test pace on the above set of outcome measures are summarised in Table 2. Although the thoracic ROM did not differ between the age and gender groups, the total LC was smaller in the older age groups than the younger age groups, and in females than males (except in the first age group). The thoracic ROM was larger, whereas the total LC was smaller in the fast pace than the slow pace in all age groups. Any possible interaction of independent

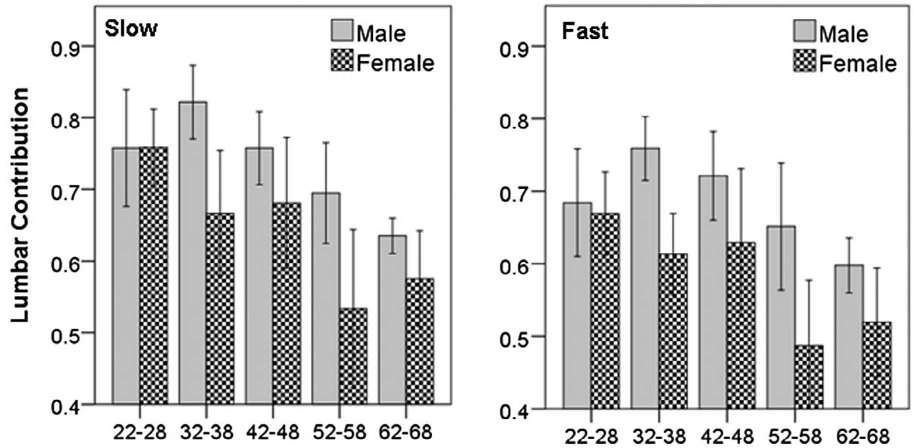

Figure 3. Age- by gender-related differences in the total LC for the results of slow (left) and fast (right) paces separately.

variables had a significant effect on the total LC. Particularly, a significant three-way interaction of pace*gender*age was found on total LC (Figure 3). Subsequent univariate ANOVAs on separate levels of pace revealed that the simple two-way interaction of gender*age was not significant for either of paces. Age and gender both had significant main effects on the total LC both for the slow and fast paces (Table 2).

Quartile LCs

Mean values of the quartile LCs (ie four LCs for each of bending and return phase of each test) for different age, gender and pace groups are depicted in Figure 4. The main and interaction effects of age, gender and test pace on the quartile LCs are summarised in Tables 3–5. Except during the fourth quarter of bending and first quarter of return, all other quartile LCs were smaller in the older age group than the younger age group. Females had a smaller LC during all quarters of bending and return phases than males. In general, the fast pace was associated with a smaller LC than the slow pace, except for the first quarter of bending where the fast pace had a larger LC.

Discussion

As a part of a larger project wherein age-related differences in lower back mechanics have been investigated, (Shojaei et al. 2015; Vazirian et al. 2016), the thoracic ROM, total and quartile lumbar contributions to the trunk motion were evaluated and compared among five gender-balanced age groups under slow and fast paces in this study. Although the thoracic ROM was not different among the age groups, the total LC and quartile LCs (except the fourth quarter of bending and first quarter of return) were smaller in individuals older than 50 years old than those younger than this age. Considering that a similar trend of age-related differences was observed in the total and quartile LCs, the following discussion materials apply to both the total and quartile LCs unless specifically stated otherwise. Our results confirmed the existence of a critical age (ie 50 years old) after which a significant reduction occurs in the LC, although it was not the hypothesised age of 40. In spite of significant gender by age interaction in the total LC, the LCs had the same trend (ie significant reduction after the age of 50) in both genders, supporting our hypothesis that age-related differences in the LC are not affected by gender. Moreover, despite a significant pace by age interaction in the total LC, as well as significant pace by age interactions in LC of the third and fourth quartiles of bending, it was shown that the same age-related trend existed in both paces. Therefore, it was concluded that the age-related differences in the LC are not affected also by the pace of trunk motion.

Smaller LC in the older individuals than the younger individuals under similar thoracic ROM indicates that the older individuals rely more on pelvic rotation than lumbar flexion to complete the trunk bending and return tasks. This finding is consistent with earlier reports of smaller lumbar ROM in older individuals than younger individuals (McGill, Yingling, and Peach 1999; Intolo et al. 2009; Dreischarf et al. 2014; Song and Qu 2014; Shojaei et al. 2015). Higher reliance on pelvic rotation with ageing, however, notably changes the mechanical demand of the task on the spine. Particularly, a larger pelvic rotation under similar thoracic rotation in the older individuals than the younger individuals was found to result in significant increase in the shearing demand of the bending task on the spine (Shojaei et al. 2015). Although the net moment demand of bending task (to be offset internally by spinal ligaments and muscles) was found not to be different between the older and younger individuals (Shojaei et al.

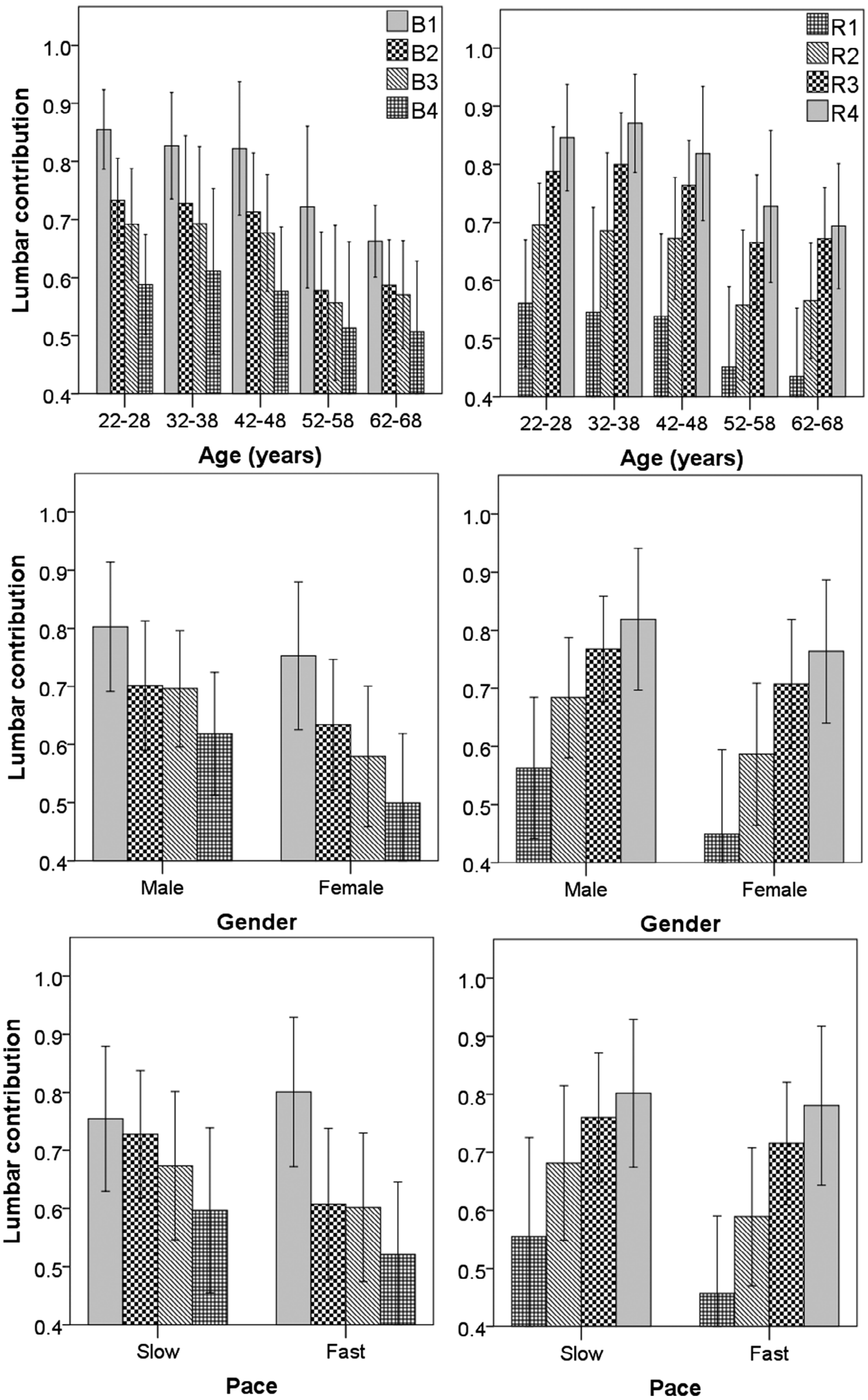

Figure 4. Age-related (top row), gender-related (middle row) and pace-related (bottom row) differences in quartile LCs during bending (left side) and return (right side) phases of tests.

2015), a smaller LC among the older participants suggests a decrease in the passive contribution of spinal ligaments and muscles (due to a smaller stretch) to offset the task demand on the spine. The associated smaller passive response of lower back tissues to the task demand with a smaller LC has been shown to result in a larger muscle response, therefore, leading to higher compression and shear forces at the lower spinal level (Tafazzol et al. 2014). Specifically, using a finite element model of the lumbar spine, Tafazzol et al. (2014) evaluated the compression and shear forces on the L5–S1 joint for angles of thoracic rotation ranging from 10 to 110 degrees with 10-degree

Table 3. ANOVA results for the quartile lumbar contributions in the bending phase of tests.

		1st quarter		2nd quarter		3rd quarter		4th quarter	
	Df	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*P*
Age	4	9.282	**<0.001**	10.206	**<0.001**	6.509	**<0.001**	2.365	0.065
Gender	1	4.315	**0.043**	9.546	**<0.001**	23.838	**<0.001**	19.294	**<0.001**
Gender*Age	4	2.171	0.086	2.392	0.063	1.917	0.122	1.825	0.139
Pace	1	27.253	**<0.001**	200.414	**<0.001**	111.651	**<0.001**	53.033	**<0.001**
Pace*Age	4	1.204	0.321	0.875	0.485	2.841	**0.034**	2.761	**0.038**
Pace*Gender	1	.621	0.434	0.677	0.414	1.111	0.297	0.023	0.881
Pace*Gender*Age	4	3.117	**0.023**	1.096	0.369	0.840	0.507	1.061	0.386

Note: Significant results are denoted in bold font.

Table 4. ANOVA results for the quartile lumbar contributions in the return phase of tests.

		1st quarter		2nd quarter		3rd quarter		4th quarter	
	Df	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*P*
Age	4	2.638	0.045	6.280	**<0.001**	7.091	**<0.001**	6.403	**<0.001**
Gender	1	12.434	**0.001**	16.176	**<0.001**	7.821	**0.007**	4.148	**0.047**
Gender*Age	4	1.634	0.180	2.353	0.066	1.613	0.186	0.785	0.541
Pace	1	79.077	**<0.001**	158.120	**<0.001**	45.737	**<0.001**	3.869	0.055
Pace*Age	4	2.395	0.063	1.950	0.117	1.131	0.353	0.808	0.526
Pace*Gender	1	3.183	0.080	1.287	0.262	0.625	0.433	0.016	0.900
Pace*Gender*Age	4	4.465	**0.004**	1.029	0.401	2.928	**0.030**	2.569	**0.049**

Note: Significant results are denoted in bold font.

Table 5. Tukey results on total and quartile lumbar contributions for age groups.

	Total LC	B1	B2	B3	B4	R1	R2	R3	R4
22–28	C	C	B	C	A	A	C	C	B, C
32–38	C	B, C	B	C	A	A	C	C	C
42–48	B, C	B, C	B	B, C	A	A	B, C	B, C	B, C
52–58	A, B	A, B	A	A	A	A	A	A	A, B
62–68	A	A	A	A, B	A	A	A, B	A, B	A

Notes: The column titles are coded as: B = bending, R = return and the quartile number. A, B and C show the homogenous subsets with the mean values increasing in order.

increments, under 11 total LC values ranging from 0.33 to 0.75 for each angle of thoracic rotation. They observed that in almost all the angles of thoracic rotation, both the compression and shear forces increase as the LC decreases. It should be, however, noted that smaller LC in the older individuals than the younger individuals may not result in the above-suggested increase in the spinal loads, when considering the age-related changes in passive behaviour of lower back tissues with ageing. We have recently quantified the lower back tissues' response to passive deformation for the same group of participants in this study. Those older than 50 years old were found to demonstrate a larger resistance to the passive deformation of lower back in the sagittal plane than those younger than this age (Shojaei, Allen-Bryant, and Bazrgari 2016). It should also be kept in mind that the reported changes in spinal load with LC by Tafazzol et al. only accounted for changes in contribution of muscles in spinal load and have neglected changes in spinal load due to increased tension in ligaments that have much smaller moment arm than trunk muscles. Therefore, the effects of age-related changes in LC on spinal load should be further investigated to account both for age-related changes in passive mechanical properties of lower back tissues as well as contribution of tension in spine ligaments on spinal loads.

Similar to the older versus younger participants, female participants had equal thoracic ROMs and smaller LCs compared to male participants (except in the 22–28-year-old age group). These differences in LC are consistent with the gender-related differences in the lumbar and pelvic ROMs reported in Pries et al. (2015). In contrast to the older versus younger individuals, resistance to the passive deformation of lower back is much smaller in females than males (Shojaei, Allen-Bryant, and Bazrgari 2016). Therefore, a smaller LC in female participants than male participants, during the bending and return phases of the task considered in this study, not only imposes higher shearing demand on the spine (Shojaei et al. 2015), but also is very likely to be associated with larger compression and shear forces at the L5–S1 spinal level (Tafazzol et al. 2014). This is an important observation, given the reported higher risk of LBP in females.

Our results were consistent with Thomas and Gibson (2007), who reported a decrease in LC with an increase in the pace of trunk motion. The mechanical demand of trunk bending and return tasks on the spine increases with increase in the task's pace due to the added inertial demand of the trunk mass. The observed larger thoracic ROM and smaller LCs (except during the first quarter of bending and fourth quarter of return) in the fast pace than the slow pace suggest additional increase in the mechanical demand of task on the lower back due to more reliance on pelvic rotation as discussed above (Shojaei et al. 2015). In an earlier modelling study (Bazrgari et al. 2008), we noted a substantial increase in the compression and shear forces on the spine under fast bending and return of the trunk, primarily due to the required large responses from the internal tissues (mainly trunk muscles) to offset such increased mechanical demand of the task. One potential explanation for the observed decrease in the LC, despite an increase in the task demand under the fast trunk motion, could be that the participants tended to keep their trunk muscles around a length (ie optimal length) associated with a higher force-generating capability of trunk muscles. Perhaps they could not achieve the faster motion under larger LCs that could markedly decrease the force-generating capability of their muscles (Delp et al. 2001).

Although our findings of age-related differences in the LC suggest changes in the lower back loading with ageing when performing a trunk bending and return task, the actual age-related differences in the spinal loading remain to be investigated. Future modelling studies that take into account the age-related differences in active and passive mechanical behaviour of the lower back tissues should be conducted to better compare the spinal loads between the age and gender groups under bending/return tasks. Furthermore, we only studied the magnitude of LC as a measure of lumbopelvic coordination. This measure, however, does not provide any insight related to the timing aspects of such a coordination (Scholz 1990), which plays a critical role in deciphering the motion synergy of multiple segments during task performance (Schöner, Jiang, and Kelso 1990). In our earlier modelling study (Bazrgari et al. 2008), it was noted that earlier lumbar contribution, rather than pelvic contribution, to trunk bending and return task under fast motion can considerably decrease the maximum loads experienced on the spine. Thus, the timing pattern of lumbopelvic coordination, as an independent aspect from the magnitude, should also be compared across the age groups in future studies.

In summary, our results suggested that the LC to trunk bending and return task is markedly different between those older than 50 years old than those younger. The observed age-related differences in LC during the trunk bending and return motion were similar to differences in LC between males and females, and between slow and fast paces of trunk motion. The prevalence of low back pain is higher among females than among males, and the risk of low back injury and pain increases under faster trunk motion (Norman et al. 1998; Davis and Marras 2000; Kingma et al. 2001). It has been reported that females experience 20% larger spinal load than males when performing similar manual material handing tasks (Marras, Davis, and Jorgensen 2002). Our earlier modelling studies similarly suggest an increase in spinal loads with an increase in motion pace (Bazrgari et al. 2008). Therefore, considering the increasing participation of older individuals at workplace, it is critical to evaluate the impact of age-related changes in the way individuals perform occupational tasks on mechanical loads experienced in their lower back.

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Disclosure statement

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