Acta of Bioengineering and Biomechanics
Vol. 25, No. 1, 2023

Original paper
DOI: 10.37190/ABB-02211-2023-03

Relationship of lumbar-hip kinematics during trunk flexion and sex, body mass index, and self-reported energy expenditure: a cross-sectional analysis

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Purpose: Physical activity (PA) is a well-known, simple and effective preventive and therapeutic intervention for low back pain (LBP). In spite of the growing interest in active lifestyles and its benefits, more needs to be known about the relationship between energy expenditure, body mass and lumbar-pelvic kinematics during the forward bending movement in a group of young asymptomatic people who met PA guidelines. Young people can be identified as a future risk group of civilisation diseases and lumbar-hip kinematics can be considered as a predictor of LBP occurrence. The aim of this study was to identify the association of gender, self-reported energy expenditure, body mass index, and lumbar-hip kinematics in young people. *Methods*: Sixty-four students at pre-employment stage participated in the study. They declared moderate-to-high PA and activity-induced energy expenditure (AEE) was self-reported. Kinematic data of the lumbar spine, pelvis and hip were collected during forward bending using a 3D motion capture system. *Results*: Sex was found to be associated with pelvis ($\beta = -0.38$ $p = 0.002$) and lumbar mobility ($\beta = 0.49$, $p < 0.001$) during forward bending and BMI was related only to lumbar mobility ($\beta = -0.41$, $p = 0.001$). Recreation AEE significantly predicted hip flexion mobility ($\beta = 0.38$, $p = 0.002$). *Conclusions*: This study showed that among a sample of physically active young people, BMI, self-reported AEE and sex can partially predict lumbar-hip kinematics during trunk flexion. Recreational PA can be regarded as improving hip mobility and thus making forward bending more effective and less prone to injury.

Key words: *lumbar-pelvic movement, physical activity, body mass index, kinematics, hip, motion capture*

1. Introduction

Physical activity (PA) is a well-known, simple and effective preventive and therapeutic intervention for low back pain (LBP) [12]. Examination tools of PA included self-reported questionnaires, e.g., International Physical Activity Questionnaire (IPAQ), accelerometers, and pedometers. One of the most popular low-cost methods is assessing the self-reported PA and estimating on this basis the activity-induced energy expenditure (AEE)[14]. Energy is expended during a variety of human activities. PA defined as leisure, recreational activity, transporting, occupational activity or housekeeping duties results in an elevation of energy expenditure above resting levels. The metabolic equivalent (MET) system is widely used by researchers, clinicians and practitioners for the estimation of AEE. For example, MET is used in IPAQ, which is a common, easy to administer and complete questionnaire for evaluation of self-reported PA [14]. One MET is generally expressed in terms of oxygen uptake per unit of body mass: 1 MET = ~ 3.5 ml $O_2 \times kg^{-1} \times min^{-1}$ [14]. However, increasing evidence suggests that estimates of AEE using the MET may be inaccurate across individuals of different body mass or body composi-

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Received: March 7th, 2023
Accepted for publication: May 18th, 2023

tion. PA estimates based on MET are reliable sources of information only when an individual's recall recorded in questionnaires is accurate. Thus, the MET system is sensitive for intentional or unintentional misreporting of PA and may not be sufficient for heterogeneous groups of large body mass range [14], [36]. Body mass has been linked with various leisure activities including PA, due to the fact that decreased in PA level is considered as a risk factor in getting overweight [23]. On the other hand, a seemingly homogeneous group of people who declare a high level of PA can significantly differ in terms of AEE due to the fact that there is no upper limit in this group.

Body mass index (BMI) has also been shown to affect spine mobility. It has been previously reported that obese female adults were characterised by reduced mobility of the spine flexion at both pelvic and thoracic level [33]. Spine flexion motion, particularly during forward bending, seems to be one of the most relevant movements to evaluate in healthy individuals and patients with LBP and is one of the most common movements in daily activities, sport and occupational work [10], [20]. It is a fast and simple non-invasive test to examine the quality (pace, coordination, spine curve and ribcage shape) and range of motion (ROM) of the spine [8]. Nevertheless, the relation between PA and flexion during forward bending has not been extensively investigated so far, despite the fact that both can be related to LBP [37]. The research revealed that spinal flexion ROM measurements have a relation with the disability in LBP probably due to the fact that forward flexion dominates in almost all human functional tasks and may have a major impact on the daily activities [1]. In work related situations, spinal flexion can occur in both intellectual and physical work, due to the fact that sedentary workers flexed their posture during sitting and physical workers flexed spine during lifting/lowering tasks.

In spite of the growing interest in active lifestyles and its benefits, more needs to be known about the relationship between energy expenditure, body mass and lumbar-pelvic kinematics during the forward bending movement in a group of young asymptomatic people who met PA guidelines. Young people can be identified as a future risk group of civilisation diseases and lumbar-hip kinematics can be considered as a predictor of LBP occurrence [38]. On the other hand, meeting PA guidelines can result in greater productivity and fewer sickness absences [21]. However, we believe that research interest in physically active people in this area is not sufficient. When occupational load and work environment are in the spotlight, leisure activities, household chores or active transport behaviour (walking, cycling) are less studied [24], [29]. Nevertheless, they are basic human activities and a part of AEE [24], [34], [35]. Ergonomic applications focused on non-occupational activities have emerged and developed more recently [19], [25], [29].

Based on this background, the aim of this study was framed to investigate the relationship between sex, BMI, self-reported energy expenditure and lumbar-hip kinematics during trunk forward flexion in young adults. We hypothesised that all the above-mentioned factors can be related to pattern alternation in lumbar-hip kinematics.

2. Materials and methods

2.1. Participants

Initially, 85 young adults (professionally inactive university students) volunteered to take part in this study and were examined by the physical therapist (first author). The ethics committee (KE-0254/322/2018) approved the procedures of the study and the experiments were carried out according to Declaration of Helsinki. Written informed consent was obtained from all participants. Nineteen subjects were excluded due to meeting exclusion criteria and 2 records were excluded due to technical errors. The main inclusion criterion was at least moderate level of PA measured using the International Physical Activity Questionnaire (IPAQ). Participants were excluded if they had any musculoskeletal or orthopedic injury in the year previous to the study, lower limb pain or apparent advanced postural defects. Back pain or neurological symptoms, like radiation to the feet or numbness, were also identified as exclusion criteria. Sixty-four subjects (23 females and 41 males) who met the PA guidelines (13 participants declared moderate PA level and 51 declared high PA level) were finally included in the investigation. The number of participants with moderate and high PA level in males and females did not differ statistically (chi squared = 1.98, $p = 0.16$).

The average age was 20.73 years (SD = 0.99), the average body weight was 70.37 kg (SD = 13.47 kg) , the average body height was 1.75 m (SD = 0.09 m) and the average BMI was 22.72 kg/m^2 (SD = 2.88 kg/m^2) (Table 1). The changes in hip, spine and pelvic angles during the normalised time of forward bending (separately for males and females) are shown in Figs. 1–3.

Table 1. Descriptive statistics

	Female (F) Male (M)	Mean	CI –95.00%	CI +95.00%	SD	*t*	*p*
Age[years]	F	20.31	20.10	20.51	0.47	2.71	**0.01**
	M	20.99	20.62	21.33	1.13		
Body mass [kg]	F	59.31	56.23	62.40	7.14	6.23	**<0.001**
	M	76.58	72.74	80.40	12.13		
Height [m]	F	1.66	1.64	1.69	0.06	8.72	**<0.001**
	M	1.80	1.79	1.82	0.06		
BMI [kg/m^2]	F	21.42	20.61	22.23	1.87	2.87	**0.006**
	M	23.46	22.48	24.44	3.10		
Total AEE [METmin/week]	F	6059.74	4963.06	7156.42	2536.08	2.10	**0.04**
	M	4612.25	3758.92	5465.59	2703.525		
ROM pelvis [deg]	F	44.84	38.62	51.06	14.38	3.19	**0.002**
	M	34.41	30.81	38.00	11.41		
ROM lumbar spine [deg]	F	66.14	60.45	71.83	13.16	2.91	**0.005**
	M	74.22	71.39	77.05	8.97		
ROM hip [deg]	F	55.78	51.04	60.52	10.96	1.04	0.30
	M	53.04	49.98	56.09	9.67		
Forward bending depth [%]	F	39.60	36.30	43.00	7.70	1.30	0.20
	M	37.10	34.80	39.40	7.30		

AEE – activity-induced energy expenditure, ROM – range of motion.

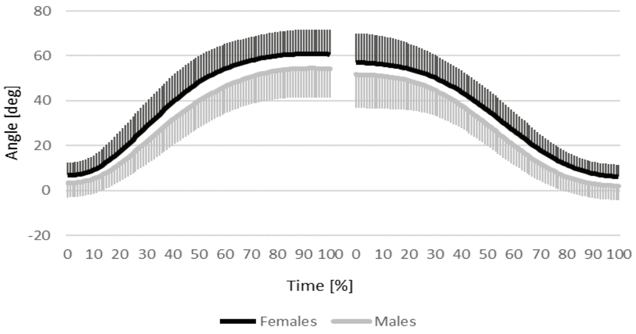

Fig. 1. Mean sagittal angular displacement of hip during forward bending (deg ± SD in single-sided error bars)

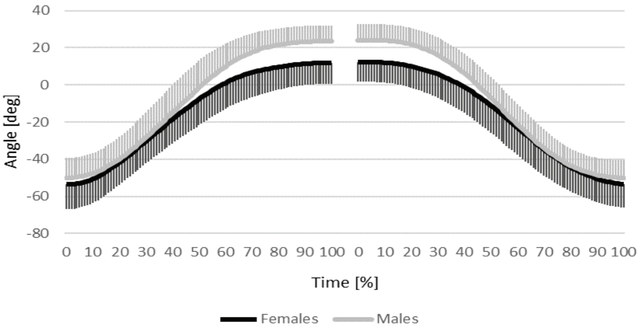

Fig. 2. Mean sagittal angular displacement of lumbar spine during forward bending (deg ± SD in single-sided error bars)

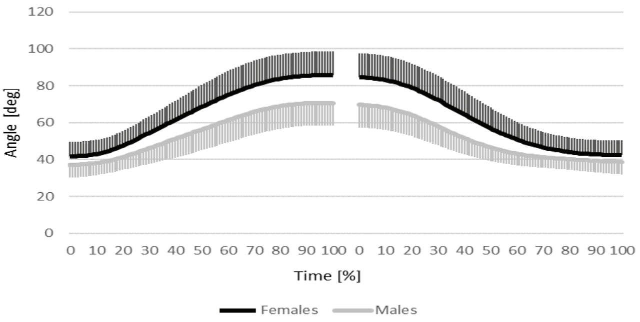

Fig. 3. Mean sagittal angular displacement of pelvis during forward bending (deg ± SD in single-sided error bars)

2.1. Experiment design

Participants were asked to perform five trials of forward bending (Fig. 4). Each participant was also permitted three practice attempts before data collection. The initial position was standing looking straight ahead. On command, participants flexed their arms forward, parallel to the floor. Movement execution was verbally explained and demonstrated as forward bending with straightened knees. The pace of forward bending was self-selected, however, participants were instructed not to do ballistic or rapid movements. Participants were asked to bend forward as far as they could. After three seconds of final flexed position, participants were asked

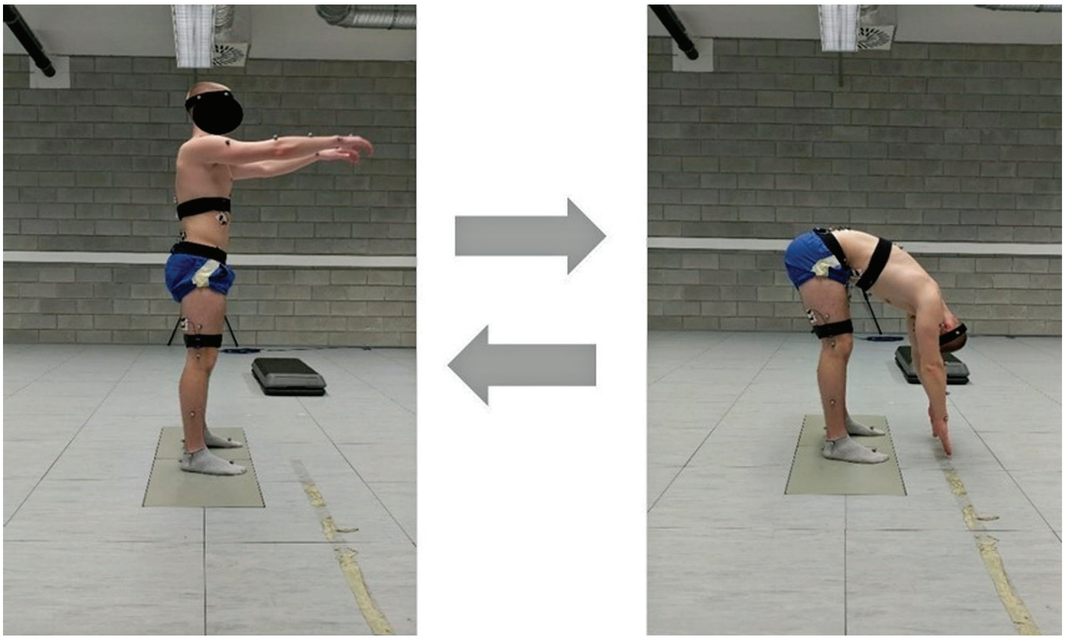

Fig. 4. Execution of forward bending

to extend and return to their initial positions at a similar pace. An average of three middle trials (without the 1st and 5th to avoid unpreparedness and learning effect) were analysed.

2.2. Measurements and data analysis

Data collection occurred in one session during morning hours (between 8 am and 12 am). Kinematic data (100 Hz) were collected using an 8-camera, 3D motion capture system (Vicon Oxford, UK). The system registered three-dimensional trajectories of passive markers. Spherical reflective markers were placed on specific anatomical landmarks. A full plug-in-gait model was created and for modelling purposes, spine, pelvic and hip markers attached to the following places were used: tenth and twelfth thoracic spinous process (Th10, Th12), posterior and anterior superior iliac spine, second and third sacral spinous process (S2, S3), seventh cervical spinous process (C7), lateral femoral condyle (39). Filtered marker trajectories were used to compute a three-dimensional segment (trunk and pelvis) and joint kinematics using

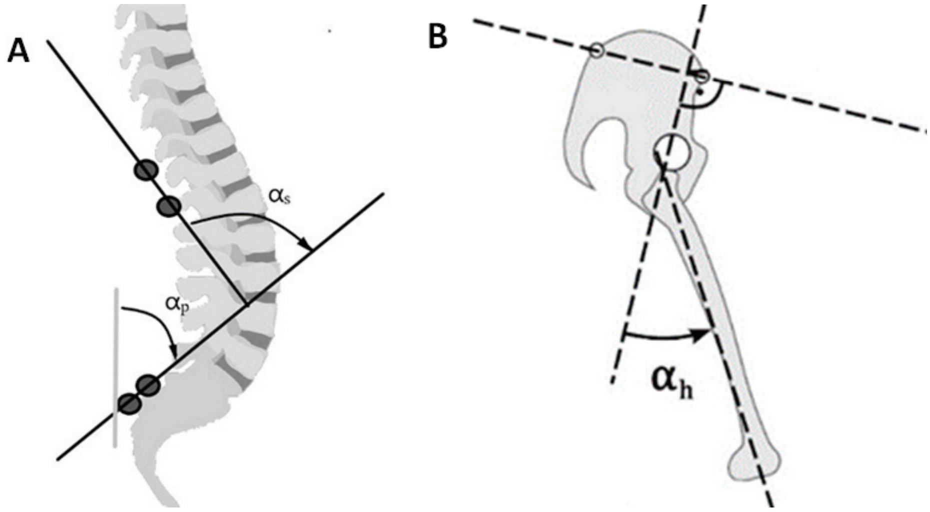

Fig. 5. Kinematic measurements: the pelvis anterior tilt angle (α_p) was the angle between the line connecting markers S2 and S3 and the gravity direction axis in the global coordinate system (A); the lumbar spine angle (α_s) was defined as the angle between the line connecting Th10 and Th12 and the line connecting S2 and S3 (the relative motion of the thorax with respect to the pelvis) (A); hip flexion angle was defined as the angle of the pelvis relative to the thigh (α_h) (B)

the modelling software (Vicon, Nexus; Oxford Metrics). The total range of motion of pelvis segment, lumbar spine and hip was defined as the difference between the maximal and minimal angle in the sagittal plane during the forward bending movement. Forward bending depth was the quotient of (1) the height difference between the marker C7 height in the standing position and its height in the maximal forward bend and (2) the initial marker height [39].

$$\Delta h = \frac{h_{\max} - h_{\min}}{h_{\max}} \times 100\%,$$

where:

Δh – forward bending depth,

$h_{\max}$ – position of C7 marker in standing,

$h_{\min}$ – position of C7 marker in maximal forward bending position.

In Figure 5 a scheme of the kinematic measurements taken into account in this study.

PA was investigated using the national version of IPAQ [3], [4]. The long version of the IPAQ consists questions about the amount of walking undertaken and participation in moderate and vigorous activities at work, in transportation, in domestic and garden activities, and in leisure time [5]. The questionnaire describes physical activity in METs. This unit is used to estimate the metabolic cost of PA (energy expenditure as reflected by oxygen consumption), e.g., one MET is equal to approx. 3.5 ml of oxygen per kilogram of body weight per minute. Total PA was defined as sum of all forms of activities (walking, moderate and vigorous activities). Total PA was categorised as low (<600 MET min/week), moderate (600–3000 MET min/week), or high (>3000 MET min/week) physical activity [18].

2.3. Statistical analysis

Statistical analysis was performed using Statistica Software (Tibco, 13.3). The normality of variables was assessed via a Shaphiro–Wilk test. The proportions of highly/moderately active participants and males/females in subgroups were compared using the Chi-squared test. A significance limit of $\alpha = 0.05$ was chosen. A series of multiple linear regression analyses were performed, with the lumbar, pelvis and hip ROM during forward bending and total trunk forward bending depth as the dependent variables. The independent variables included in the first model: sex (males coded as 1 and females coded as 0), total energy expenditure, BMI. Additionally we have split total energy expenditure into particular activities (leisure, recreational activity, transporting or housekeeping duties) and built a second regression model. Additionally, backward stepwise linear regression was used to identify possible predictors of the outcome (lumbar, pelvis and hip ROM) out of the above-mentioned candidate variables. The normal probability plot showed that the dependent variable is roughly normally distributed overall. The effect size (ES) for multiple regression analysis is estimated by the Cohen effect size parameter f^2 and should be interpreted as: 0.02 = small, 0.15 = medium, 0.35 = large [7].

3. Results

3.1. Pelvis anterior tilt

The overall regression first model with 3 independent variables was statistically significant ($R^2 = 0.19$, $F(3.60) = 4.81$, $p = 0.005$, ES = 0.23). It was found that sex significantly predicted pelvis anterior mobility during forward bending ($\beta = -0.37$ $p = 0.01$). The predictors explained 19.39% of the variance in the dependent variable. Moreover, in the backward stepwise regression model, the female sex was included as a predictor of grater pelvis ROM during forward bending ($\beta = -0.38$ $p = 0.002$). Adding specific activities into the second model does not change much the overall results of regression (Table 2).

3.2. Spine flexion

The results of the regression indicated that the predictors explained 26.85% of the dependent variable variance ($R^2 = 0.27$, $F(3.60) = 7.34$, $p < 0.001$, ES = 0.36). It was found that sex significantly predicted lumbar flexion ROM ($\beta = 0.50$, $p < 0.001$), as did BMI ($\beta = -0.40$, $p = 0.001$). Moreover, the backward stepwise regression model selected male sex ($\beta = 0.49$, $p < 0.001$) and lower BMI ($\beta = -0.41$, $p = 0.001$) as predictors of greater lumbar spine ROM during forward bending. Adding specific activities into the second model does not change much the overall results of regression (Table 3).

3.3. Hip flexion

The results of the regression indicated the predictors explained 16,10% of the variability of the dependent

Table 2. Regression summary for dependent variable – pelvis ROM during forward bending

First model	β	SE β	B	SE B	t	p-value	R	R^2	Adjusted R^2
Intercept	–	–	25.26	13.33	1.89	0.06	0.44	0.19	0.15
Sex	–0.37	0.13	–10.23	3.51	–2.91	0.01			
BMI	0.13	0.12	0.62	0.58	1.08	0.28			
AEE	0.21	0.12	0.001	<0.001	1.72	0.09			
Result of regression analysis with backward stepwise elimination procedure: variables left in the model									
Sex	–0.38	0.12	–10.43	3.27	–3.19	0.002	0.38	0.14	0.13
Second model									
Intercept			28.30	13.17	2.15	0.04	0.46	0.22	0.15
Sexr	–0.35	0.13	–9.79	3.66	–2.67	0.01			
BMI	0.12	0.12	0.54	0.58	0.93	0.36			
Transportation EE	–0.05	0.12	<0.001	0.001	–0.41	0.68			
Housework EE	0.18	0.13	0.003	0.002	1.40	0.17			
Recreational PA EE	0.17	0.12	0.001	0.001	1.43	0.16			

SE – standardised error, B – non-standardised coefficient value, R – multiple correlation coefficient, R^2 – coefficient of determination, AEE – activity-induced energy expenditure, PA – physical activity, EE – energy expenditure.

Table 3. Regression summary for dependent variable – spine ROM during forward bending

First model	β	ES β	B	ES B	t	p-value	R	R^2	Adjusted R^2
Intercept	–	–	99.02	10.65	9.29	<0.001	0.52	0.27	0.23
Sex	0.50	0.12	11.55	2.81	4.11	<0.001			
BMI	–0.40	0.12	–1.58	0.46	–3.44	0.001			
AEE	0.04	0.11	<0.001	<0.001	0.36	0.72			
Result of regression analysis with backward stepwise elimination procedure: variables left in the model									
BMI	–0.41	0.12	–1.59	0.46	–3.49	0.001	0.52	0.27	0.24
Sex	0.49	0.12	11.33	2.72	4.17	<0.001			
Second model									
Intercept			97.82	10.46	9.35	<0.001	0.54	0.30	0.24
Sex	0.46	0.12	10.79	2.91	3.71	<0.001			
BMI	–0.39	0.12	–1.54	0.46	–3.35	0.001			
Transportation EE	0.04	0.11	<0.001	0.001	0.35	0.73			
Housework EE	–0.09	0.12	0.001	0.001	–0.78	0.44			
Recreational PA EE	0.15	0.11	0.001	0.001	1.39	0.17			

SE – standardised error, B – non-standardised coefficient value, R – multiple correlation coefficient, R^2 – coefficient of determination; AEE – activity-induced energy expenditure; PA – physical activity; EE – energy expenditure

variable ($R^2 = 0.16$, $F(3.60) = 3.84$, $p < 0.01$, ES = 0.19). It was found that AEE significantly predicted hip flexion ROM ($\beta = 0.39$, $p = 0.002$). The backward stepwise regression model selected AEE as a predictor of greater hip ROM during forward bending Adding specific activities into the model shows that EE related to housework and recreation significantly predict hip mobility during forward bending ($\beta = 0.27$, $p = 0.03$ and $\beta = 0.35$, $p = 0.003$, respectively). However, backward stepwise regression analysis includes in a model only recreational PA EE as predictor of greater hip ROM during forward bending ($\beta = 0.38$, $p = 0.002$) (Table 4).

3.4. Forward bending depth

The overall regression was statistically significant ($R^2 = 0.14$, $F(3.60) = 3.14$, $p = 0.03$). It was found that AEE significantly predicted forward bending depth ($\beta = 0.30$ $p = 0.02$, ES = 0.16). The predictors explained 13.56% of the variance in the dependent variable. When specific activities were added into the model, only the EE related to recreation significantly predicted forward bending depth ($\beta = 0.31$, $p = 0.01$). However, backward stepwise regression analysis removed all variables from the regression equation (Table 5).

Table 4. Regression summary for dependent variable – hip ROM during forward bending

First model	β	ES β	B	ES B	t	p-value	R	R^2	Adjusted R^2
Intercept	–	–	40.24	10.28	3.91	<0.001	0.40	0.16	0.12
Sex	–0.06	0.13	–1.29	2.71	–0.47	0.64			
BMI	0.09	0.13	0.31	0.44	0.71	0.48			
AEE	0.39	0.12	0.001	<0.001	3.17	0.002			
Result of regression analysis with backward stepwise elimination procedure: variables left in the model									
AEE	0.39	0.12	0.001	<0.001	3.35	0.001	0.39	0.15	0.14
Second model									
Intercept			41.59	9.78	4.25	<0.001	0.49	0.24	0.18
Sex	–0.03	0.13	–0.65	2.72	–0.24	0.81			
BMI	0.07	0.12	0.23	0.43	0.55	0.59			
Transportation EE	0.08	0.12	0.001	0.001	0.65	0.52			
Housework EE	0.27	0.12	0.003	0.001	2.19	0.03			
Recreational PA EE	0.35	0.12	0.002	0.001	3.08	0.003			
Result of regression analysis with backward stepwise elimination procedure: variables left in the model									
Recreational PA EE	0.38	0.12	0.002	0.001	3.28	0.002	0.38	0.15	0.13

SE – standardised error, B – non-standardised coefficient value, R – multiple correlation coefficient, R^2 – coefficient of determination, AEE – activity-induced energy expenditure, PA – physical activity, EE – energy expenditure.

Table 5. Regression summary for dependent variable – forward bending depth

First model	β	ES β	B	ES B	t	p-value	R	R^2	Adjusted R^2
Intercept	–	–	0.43	0.08	5.56	<0.001	0.37	0.14	0.09
Sex	–0.04	0.13	–0.01	0.02	–0.27	0.79			
BMI	–0.15	0.13	–0.004	0.003	–1.16	0.25			
AEE	0.30	0.12	<0.001	<0.001	2.41	0.02			
Second model									
Intercept			0.45	0.08	5.89	<0.001	0.38	0.15	0.07
Sex	–0.09	0.14	–0.01	0.02	–0.64	0.52			
BMI	–0.15	0.13	–0.004	0.003	–1.19	0.24			
Transportation EE	0.03	0.12	<0.001	<0.001	0.20	0.84			
Housework EE	0.01	0.13	<0.001	<0.001	0.05	0.96			
Recreational PA EE	0.31	0.12	<0.001	<0.001	2.51	0.01			
Result of regression analysis with backward stepwise elimination procedure: all variables have been removed from the regression equation.									

SE – standardized error, B – non-standardised coefficient value, R – multiple correlation coefficient, R^2 – coefficient of determination, AEE – activity-induced energy expenditure, PA – physical activity, EE – energy expenditure.

4. Discussion

In this study, we have investigated the relationship between sex, BMI, self-reported energy expenditure and lumbar-hip kinematics in young adults. We hypothesised that all the above-mentioned factors can be related to pattern alternation in lumbar-hip kinematics. On the basis of the obtained results, we can conclude that the results of this study confirm the hypothesis. However, factors enabled us to predict the kinematics of the lumbar-hip complex in different ways.

The pelvis during trunk forward bending is tilting anteriorly on the femur heads and positioning spine column [2], [6]. For this reason, the pelvis can be considered as a chain link connecting the lower limbs and trunk and transferring movement and forces. In the current study, only sex has been shown as a significant predictor of pelvis anterior mobility during forward bending. These findings mean that females shown greater pelvis ROM, which is consistent with previous findings [38]. Plamondon et al. [26], [27] previously observed that females showed different movement strategies than males when lifting boxes from the ground. These strategies with greater lumbar flexion and trunk inclination, stretched posterior passive tissues potentially leading to higher risk of injury. However, in this study, trunk flexion was not related with lifting and we have noticed that greater lumbar flexion may be more typical of males than females. According to Hoffman et al. [15], males demonstrated greater end-range lumbar flexion during slumped sitting and forward bending compared to females. Decreased mobility of hip flexion motion during forward bending encouraging greater lumbar flexion to compensate. Females in this study demonstrate greater pelvis mobility (motion is between the head of the femur and the acetabulum of the pelvis), thus do not require as much spine mobility for effective forward bending. Kinematic differences between males and females noted in pelvic motions can be a result of a wider female pelvis. It is apparent in other studies that males produce the greater loads on their spines during lifting and trunk sagittal angle is considered as one of the risk factors for occupationally related low back disorders [22]. In a previous study by Reis and Macedo [28] participants with LBP showed restriction in the pelvis and trunk flexion range of motion, but had higher amplitudes in the lumbar spine during forward bending. Despite the fact that the spine can be excessively flexed during sitting and lifting tasks, less spine mobility was also observed in people with LBP in other research, which can be related to different LBP subtypes [16], [17]. The occurrence of LBP is probably related to the nature and intensity of the physical activities undertaken. In general, engaging in regular sports activities is considered an indicator of a healthy lifestyle and is not associated with back problems [13], [32]. However, in this study, lumbar flexion was not related to AEE.

BMI has been identified in current study as a factor predicting lumbar mobility. Regression model showed that greater BMI contributes to smaller lumbar spine ROM during forward bending. This finding supports the previous reports indicating that with increasing BMI, thoracolumbar spine range of motion during seated and standing forward flexion was decreased [11]. Standing forward flexion may be difficult to perform owing to decreased forward stability due to abdominal fatness and static postural adaptation with an increased anterior pelvic tilt [11]. However, greater BMI can also be related to increased muscle mass as an effect of resistance training. A systematic and continuous exercise can influence sagittal spinal curvature especially among young people. More research is needed to investigate whether reduced lumbar extensor strength and reduced lumbar lordosis can lead to greater lumbar spine flexion in young adults. Increased BMI is a risk factor for back pain in Americans and adolescent Norwegian [30], [31]. However, other studies do not support a causal direct relationship between obesity and chronic LBP [9].

In our study, AEE was a statistically significant predictor for hip ROM and forward bending depth. Regarding hip mobility, short hamstrings and limited hip flexion have been previously linked to the LBP [30], [38]. Immobility of lower limb joints as a result of limitation in the posterior myofascial chain could lead to decreased forward bending depth or excessive spinal motion as a compensation [38]. Despite the fact that in the current study we did not investigate hamstring shortness or any other lower limb joints except the hip, housework and especially recreational PA may provide activities that improve whole posterior myofascial chain extensibility and result in better hip mobility. The increased mobility of all parts of the functional myofascial chain probably translates into deeper forward bending and enhances effectiveness of this movement.

Limitation of the study

Our study has a few limitations. Probably the main limitation is reliance on a single test of forward bending. We consider hamstring flexibility as the main cause of small hip mobility during forward bending, but, in fact, we did not investigate hamstring length using any other tests. Moreover, the previous studies showed that the variability of the trunk forward bending in standing activities during work and leisure time can significantly differ [32]. Thus, it would also be beneficial to perform measurements on blue-collar workers to investigate how occupational AEE can influence lumbar-pelvic kinematics. Another issue is the limited sample size in our study. However, the motion capture portion of this study is an enormous time commitment, and participation in the study was voluntary.

5. Conclusions

This study showed that, among a sample of physically active young people, BMI, self-reported AEE and sex can partially predict lumbar-hip kinematics during trunk flexion. Sex was related to pelvis and spine mobility during flexion, BMI was related to spine mobility only, and AEE was related to hip mobility. Looking closer at the AEE, it can be noticed that recreational activity influenced forward bending kinematics the most. Therefore, we recommend that, when performing a clinical examination of forward bending, gender, BMI and AEE should be considered as a potentially modifying factors. Especially recreational PA should be taken into account as an improving mobility of the hip and thus making forward bending more effective. Finally, the results of this research support the idea that an analysis of relationship between selective factors and lumbar-pelvic kinematics may provide new insight into the prediction of LBP, especially regarding to repeated forward bending motion.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

References

[1] Atya A.M., *The validity of spinal mobility for prediction of functional disability in male patients with low back pain*, Journal of Advanced Research, 2013, 4, 43–49.

[2] Bagwell J.J., Fukuda T.Y., Powers C.M., *Sagittal plane pelvis motion influences transverse plane motion of the femur: Kinematic coupling at the hip joint*, Gait and Posture, 2016, 43, 120–124.

[3] Biernat E., *International physical activity questionnaire – Polish long version*, Polish Journal of Sports Medicine, 2013, 29, 1–15.

[4] Biernat E., Stupnicki R., Gajewski A.K., *International physical activity questionnaire (IPAQ) – Polish version*, Physical Education and Sport, 2007, 51, 47–54.

[5] Celis-Morales C.A., Perez-Bravo F., Ibañez L., Salas C., Bailey M.E.S., Gill J.M.R., *Objective vs. Self-Reported Physical Activity and Sedentary Time: Effects of Measurement Method on Relationships with Risk Biomarkers*, PLOS ONE, 2012, 7, e36345.

[6] Chaleat-Valayer E., Troncy A., Montané M., Bellaiche S., Berthonnaud E., *Biomechanical strategies of spine, pelvis and lower limbs to achieve the stand-to-sit task: A kinematic study with tridimensional motion analysis*, Ann. Phys. Rehabil. Med., 2016, 59S, e93.

[7] Cohen J., *Statistical Power Analysis for the Behavioral Sciences*, Academic Press, 2013.

[8] Côté P., Kreitz B.G., Cassidy J.D., Dzus A.K., Martel J., *A Study of the Diagnostic Accuracy and Reliability of the Scoliometer and Adam's Forward Bend Test*, Spine,1998, 23, 796–802.

[9] Dario A.B., Ferreira M.L., Refshauge K., Sánchez-Romera J.F., Luque-Suarez A., Hopper J.L. et al., *Are obesity and body fat distribution associated with low back pain in women? A population-based study of 1128 Spanish twins*, Eur. Spine J., 2016, 25, 1188–1195.

[10] Van Dijk M.J.H., Smorenburg N.T.A., Heerkens Y.F., Mollema J., Kiers H., Nijhuis-Van Der Sanden M.W.G., *Assessment instruments of movement quality in patients with non-specific low back pain: A systematic review and selection of instruments*, Gait & Posture, 2020, 76, 346–357.

[11] Gilleard W., Smith T., *Effect of obesity on posture and hip joint moments during a standing task, and trunk forward flexion motion*, Int. J. Obes., (Lond.), 2007, 31, 267–271.

[12] Hanna F., Daas R.N., El-Shareif T.J., Al-Marridi H.H., Al-Rojoub Z.M., Adegboye O.A., *The Relationship Between Sedentary Behavior, Back Pain, and Psychosocial Correlates Among University Employees*, Front Public Health, 2019, 7. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6465323/

[13] Heneweer H., Staes F., Aufdemkampe G., Van Rijn M., Vanhees L., *Physical activity and low back pain: a systematic review of recent literature*, Eur. Spine J., 2011, 20, 826–845.

[14] Hills A.P., Mokhtar N., Byrne N.M., *Assessment of Physical Activity and Energy Expenditure: An Overview of Objective Measure*, Front Nutr., 2014, 1, 5.

[15] Hoffman S.L., Johnson M.B., Zou D., Van Dillen L.R., *Differences in end-range lumbar flexion during slumped sitting and forward bending between low back pain subgroups and genders*, Manual Therapy, 2012, 17, 157–163.

[16] Laird R.A., Gilbert J., Kent P., Keating J.L., *Comparing lumbo-pelvic kinematics in people with and without back pain: a systematic review and meta-analysis*, BMC Musculoskelet. Disord., 2014, 15, 229.

[17] Laird R.A., Keating J.L., Kent P., *Subgroups of lumbo-pelvic flexion kinematics are present in people with and without persistent low back pain*, BMC Musculoskelet. Disord., 2018, 19. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6114878/

[18] Lear S.A., Hu W., Rangarajan S., Gasevic D., Leong D., Iqbal R. et al., *The effect of physical activity on mortality and cardiovascular disease in 130 000 people from 17 high-income, middle-income, and low-income countries: the PURE study*, The Lancet, 2017, 390, 2643–2654.

[19] Li X., Hu Q., Liu J., Nambisan S., Khattak A.J., Lidbe A. et al., *Pathway analysis of relationships among community development, active travel behavior, body mass index, and self-rated health*, International Journal of Sustainable Transportation, 2022, 16, 340–356.

[20] Littlewood C., May S., *Measurement of range of movement in the lumbar spine – what methods are valid? A systematic review*, Physiotherapy, 2007, 93, 201–211.

[21] Lusa S., Punakallio A., Mänttäri S., Korkiakangas E., Oksa J., Oksanen T. et al., *Interventions to promote work ability by increasing sedentary workers' physical activity at workplaces – A scoping review*, Applied Ergonomics, 2020, 82, 102962.

[22] Marras W.S., Davis K.G., Jorgensen M., *Gender influences on spine loads during complex lifting*, The Spine Journal, 2003, 3, 93–99.

[23] Mocanu G.-D., Iordan D.-A., *The influence of body index mass on the leisure types for the students of the faculty of physical education and sports*, Balneo and PRM Research Journal, 2021, 12, 233–247.

[24] Nowakowski P., *Kitchen Chores Ergonomics: Research and Its Application*, [in:] *Advances in Human Factors, Sustainable Urban Planning and Infrastructure*, J. Charytonowicz (Ed.), Springer International Publishing, Cham 2018, 43–52.

[25] PETERMAN J.E., BASSETT D.R. JR, HOLMES FINCH W., HARBER M.P., WHALEY M.H., FLEENOR B.S. et al., *Associations Between Active Commuting and Cardiovascular Disease in the United States*, Journal of Physical Activity and Health, 2021, 18, 1525–1531.

[26] PLAMONDON A., LARIVIÈRE C., DENIS D., MECHERI H., NASTASIA I., *Difference between male and female workers lifting the same relative load when palletizing boxes*, Applied Ergonomics, 2017, 60, 93–102.

[27] PLAMONDON A., LARIVIÈRE C., DENIS D., ST-VINCENT M., DELISLE A., *Sex differences in lifting strategies during a repetitive palletizing task*, Applied Ergonomics, 2014, 45, 1558–1569.

[28] REIS F.J.J., MACEDO A.R., *Influence of Hamstring Tightness in Pelvic, Lumbar and Trunk Range of Motion in Low Back Pain and Asymptomatic Volunteers during Forward Bending*, Asian Spine Journal, 2015, 9, 535–540.

[29] SALMON P.M., *Ergonomics issues in sport and outdoor recreation*, Theoretical Issues in Ergonomics Science, 2017, 18, 299–305.

[30] SJOLIE A.N., *Low-back pain in adolescents is associated with poor hip mobility and high body mass index*, Scandinavian Journal of Medicine and Science in Sports, 2004, 14, 168–175.

[31] SMUCK M., KAO M.-C.J., BRAR N., MARTINEZ-ITH A., CHOI J., TOMKINS-LANE C.C., *Does physical activity influence the relationship between low back pain and obesity?*, The Spine Journal, 2014, 14, 209–216.

[32] VILLUMSEN M., MADELEINE P., JØRGENSEN M.B., HOLTERMANN A., SAMANI A., *The variability of the trunk forward bending in standing activities during work vs. leisure time*, Applied Ergonomics, 2017, 58, 273–280.

[33] VISMARA L., MENEGONI F., ZAINA F., GALLI M., NEGRINI S., CAPODAGLIO P., *Effect of obesity and low back pain on spinal mobility: a cross-sectional study in women*, Journal of NeuroEngineering and Rehabilitation, 2010, 7, 3.

[34] WANNER M., GÖTSCHI T., MARTIN-DIENER E., KAHLMEIER S., MARTIN B.W., *Active Transport, Physical Activity, and Body Weight in Adults: A Systematic Review*, American Journal of Preventive Medicine, 2012, 42, 493–502.

[35] WESTERTERP K.R., *Physical activity and physical activity induced energy expenditure in humans: measurement, determinants, and effects*, Front. Physiol., 2013, 4, 90.

[36] WILMS B., ERNST B., THURNHEER M., WEISSER B., SCHULTES B., *Correction factors for the calculation of metabolic equivalents (MET) in overweight to extremely obese subjects*, Int. J. Obes. (Lond.), 2014, 38, 1383–1387.

[37] ZAWADKA M., ŁUKASIK E., SKUBLEWSKA-PASZKOWSKA M., SMOŁKA J., GAWDA P., JABŁOŃSKI M., *Analysis of the kinematic parameters of squatting in subjects with different levels of physical activity – A preliminary study*, Baltic Journal of Health and Physical Activity The Journal of Gdansk University of Physical Education and Sport, 2018, 10. Available from: http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.agro-f1fe91d7-932f-4d6c-9c00-2762b88dc065

[38] ZAWADKA M., SKUBLEWSKA-PASZKOWSKA M., GAWDA P., ŁUKASIK E., SMOŁKA J., JABŁOŃSKI M., *What factors can affect lumbopelvic flexion-extension motion in the sagittal plane? A literature review*, Hum. Mov. Sci., 2018, 58, 205–218.

[39] ZAWADKA M., SMOŁKA J., SKUBLEWSKA-PASZKOWSKA M., ŁUKASIK E., GAWDA P., *How Are Squat Timing and Kinematics in The Sagittal Plane Related to Squat Depth?*, Journal of Sports Science and Medicine, 2020, 19, 500–507.