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Lumbopelvic sagittal standing posture associations with anthropometry, physical activity levels and trunk muscle endurance in healthy adults

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Background: Various factors, inherited and acquired, are associated with habitual spinal postures.
Objective: The purpose of this study was to identify the relationships between trunk muscle endurance, anthropometry and physical activity/inactivity and the sagittal standing lumbopelvic posture in pain-free young participants.
Methods: In this study, 112 healthy young adults (66 females), with median (IQR) age of 20 years (18.2–22 years), without low back pain, injury or trauma were included. Lumbar curve (LC) and sacral slope (SS) angles were measured in standing with a mobile phone application (iHandy level). Anthropometric, physical activity/inactivity levels (leisure-time sport involvement and sitting hours/day) and abdominal (plank prone bridge test) and paraspinal (Sorensen test) isometric muscle endurance measures were collected.
Results: LC and SS angles correlated significantly ($r = 0.80$, $p < 0.001$). Statistically significant differences for both LC ($p = 0.023$) and SS ($p = 0.013$) angles were identified between the male and female participants. A significant negative correlation was identified between the abdominal endurance time and LC ($r = -0.27$, $p = 0.004$); however, the power of this result (56%) was not sufficiently high. The correlation between

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abdominal endurance and SS was non-significant ($r = -0.17$, $p = 0.08$). In addition, no significant associations were identified between either of the sagittal lumbopelvic angles (LC–SS) in standing and the participants' body mass index (BMI), paraspinal endurance, leisure-time sport involvement or sitting hours/day. **Conclusion:** The potential role of preventive exercise in controlling lumbar lordosis via enhancement of the abdominal muscle endurance characteristics requires further confirmation. A subsequent study, performed in a larger population of more diverse occupational involvement and leisure-time physical activity levels, is proposed.

Keywords: Muscle fatigue; physical activity; abdominal; lumbar; spine.

Introduction

Neuromuscular control of spinal postures and movements is key, contributing in parallel to load minimization and injury or degeneration prevention of passive spinal structures.[1] Pelvic and spinal alignment in the sagittal plane is crucial for maintaining a balanced stance, forming the basis for many functional activities.[2] Postural deviations are considered to be among the factors progressively leading to or associated with the presence of painful spinal musculoskeletal disorders.[3–6] and degeneration.[7] However, this is still a matter of debate, as not all relevant studies have clearly demonstrated detrimental effects on spinal structures or symptoms development linked to postural deviations.[8]

Previous studies have substantiated that sagittal spinal posture is influenced by age progression,[9] sex[9,10] and increased body mass index (BMI).[2,11] Additionally, spinal posture has been significantly associated with the paraspinal muscle endurance levels,[12–14] although other researches have not substantiated such a relationship for the lumbar curve (LC), with a significant relationship only demonstrated between abdominal performance and pelvic inclination in women.[15] Furthermore, different types of occupational demands,[16] physical activity levels for asymptomatic men only[15] and specific long-term athletic training[17] may influence standing posture. However, no associations between lumbar lordosis and physical activity levels[18] and lifestyle or occupational demands have also been reported.[19] Postural assessment has also been studied in adolescent populations,[20,21] as adolescence may be an opportune time period to influence improvements in spinal posture via certain postural exercise interventions[17,22] and possibly prevent musculoskeletal pain episodes in the future. A predictive role of adolescent spinal non-neutral posture at 14 years for back pain development at 17 years of age in the same population has been established, however, among a multitude of other factors collectively contributing to the pain experience.[23] On the other hand, apart from environmental and lifestyle factors, familial predisposition seems to be also influential, at least for certain hyperlordotic postures.[24]

The "core" muscles are considered to consist of transversus abdominis (TrA) and multifidus (MULT) muscles, providing mainly stability to the low back and pelvis, in coordination with the more superficial trunk musculature. A significant decrease in thickness measurements of TrA has been identified in 20 healthy adults when assuming a swayback compared to a neutral lumbopelvic posture, denoting better activation of TrA in the latter standing posture.[25] Similar results of decreased activation in the internal oblique/TrA muscles have been recently reported in 37 adults, when a slouched sitting posture was assumed.[26] The muscle tone of the deep trunk muscles has been lately described as predictive of both positive (TrA) and negative (MULT) outcomes among the low back pain (LBP) sufferers.[27] A history of LBP in a mostly young mixed-sex cohort has also been shown to affect the thickness of TrA more than the MULT one.[28] Therefore, except LBP presence, also extreme flexion (flatback) or extension (lordotic) lumbar spine postures affect the activation of deep trunk muscles, rendering the relevant spinal segments "unprotected" in the case of prolonged or increased spinal loading.

The purpose of this study was to identify certain factors that correlate with standing lumbopelvic posture in healthy participants, with the aim to focus on those factors that are considered to be modifiable. For instance, advice on BMI reduction or adopting more active physical activity lifestyles (increasing exercise frequency in general or increasing trunk-specific exercise) could then be proposed as preventive measures against spinal pain. Such factors can be targeted by physical therapists, to promote the adoption of more optimal spine standing postures, documented to be less frequently related with non-specific LBP episodes.

Methods

Study design

Cross-sectional correlational design is used to explore the associations between sagittal lumbopelvic posture in standing and anthropometric, leisure-time activity/inactivity habits and trunk muscle endurance performance variables.

Participants

The study took place at Metropolitan College with volunteers being students of one of the campuses of this institution. The exclusion criteria for the participation of this study were any injury-trauma and/or active LBP and menstruation or pregnancy (females) to avoid any influence of those factors on habitual standing posture. Recruitment of participants took place from November 2016 to January 2017 and was achieved via e-mail notifications of the purposes of the study, sent to 450 students of the School of Health. E-mail notifications were sent out twice, in the beginning of November and a reminder at the beginning of December 2016. Totally 125 students responded to the research call. However, 10 students finally were not able to make their assessment appointments and three had a fairly recent incident of back pain, therefore were excluded. Finally, 112 healthy adults (46 males and 66 females) participated voluntarily in this research study. The descriptive statistics of participants are presented in Table 1. A written informed consent, presenting the purposes and aims of this study and the inclusion–exclusion criteria, was signed by all participants prior to their inclusion to the study. The study protocol was approved by the Ethics Committee of Metropolitan College. All rights of participants were protected at all times, according to the Declaration of Helsinki.

Lumbopelvic sagittal standing postural assessment

Lumbar posture can be clinically assessed with the Bubble inclinometer which is a device with a good reliability and validity or with a wide variety of other measurement instruments such as pantograph, kyphometer, flexible curve and lately, the smartphones.[29] Sagittal lumbopelvic posture in standing was assessed in two previous studies with the use of a smartphone (iHandy free application).[29,30] The first of those studies verified the inter-rater within-day ($ICC = 0.96$) and intra-rater between-day ($ICC = 0.81$, $SEM = 3^\circ$ and $MDC_{90\%} = 7^\circ$) reliabilities of the lumbar curve in 30 healthy participants, with the smartphone measurement displaying comparable accuracy to the one with a Bubble inclinometer ($ICC = 0.85$, $SEM = 3^\circ$ and $MDC_{90\%} = 6^\circ$).[29] The within-day intra-rater reliability of this postural assessment method was further confirmed, measuring two angles in quiet standing posture, the sacral slope (SS; $ICC_{2,1} = 0.97$, $SEM = 1.61^\circ$ and $MDC_{95\%} = 4.46^\circ$) and the lumbar curve ($ICC_{2,1} = 0.96$, $SEM = 2.13^\circ$ and $MDC_{95\%} = 5.9^\circ$), in a larger group of asymptomatic participants ($n = 183$).[30] The validity of the method to differentiate between male and female participants' SS and LC angles has also been established in the latter study.[30]

Table 1. Descriptive statistics of ratio-type variables (anthropometric, two posture measures and two trunk muscle endurance test measures) from all participants ($n = 112$).

	Min	Max	Mean	Standard deviation
Height (cm)	150	198	173	9.5
Body mass (kg)	45	115	69.7	14.3
BMI (kg/m^2)	17.6	39.8	23.1	3.5
Lumbar curve (°)	9.9	52.9	24.2	8.1
Sacral slope (°)	5.2	34.5	17.6	6.1
Plank prone bridge endurance test (s)	16	245	88.6	47.4
Modified Sorensen endurance test (s)	34	370	126.3	54.6

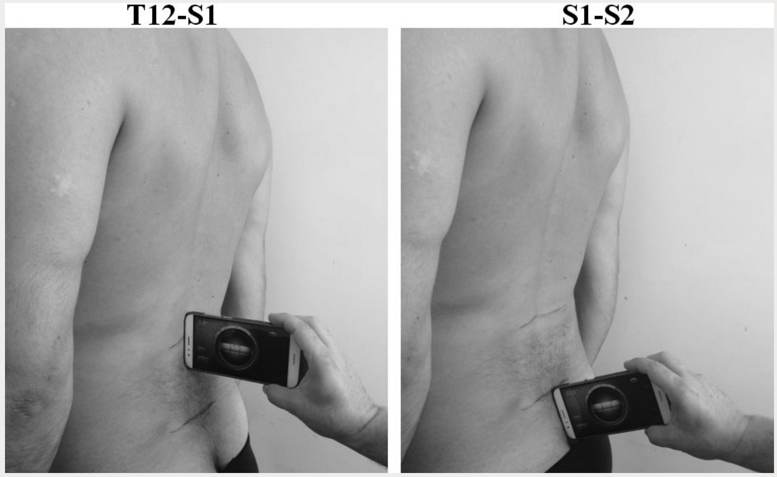

Fig. 1. Lumbar curve and sacral slope measurement technique with the smartphone placed at T12–L1 and S1–S2 interspaces.

Therefore, the use of smartphones as measurement tools of spinal angles has adequate evidence-base to be used further.

The iHandy level application was used to measure the SS and LC angles in standing (Table 1). The angle readings from the smartphone, when placed with its upper vertical side at T12–L1 and S1–S2 spinous processes, were recorded (Fig. 1). The sacral slope value corresponded to the reading from S1–S2 and the lumbar curve value corresponded to the sum of the absolute readings from T12–L1 and S1–S2. Additional measurement details of SS and LC parameters are presented analytically elsewhere.[29,30]

Trunk muscle endurance assessment

As core stability is linked to a continuous role of the trunk muscles in the maintenance of mid-range neutral-zone postures,[1] the endurance capacity of those is commonly assessed.[13,31]

For the purposes of this study, the timed endurance to complete exhaustion of the abdominal muscles was measured via the performance of the plank prone bridge test [Table 1 and Fig. 2(a)]. According to a recent study, the application of the prone bridge test (plank test) is a valid and highly reliable method ($ICC = 0.87 - 0.89$) for the measurement of abdominal muscle endurance,[32] although muscles of the entire anterior aspect of the body are activated in this test. The plank test can be considered a functional endurance test, as it requires simultaneous isometric muscle activation of all the anterior chain muscles.[32,33]

Also, the timed endurance to complete exhaustion of the paraspinal muscles was measured via the performance of a modification of the Sorensen test [Table 1 and Fig. 2(b)]. The Sorensen test is a valid and reliable method to evaluate the

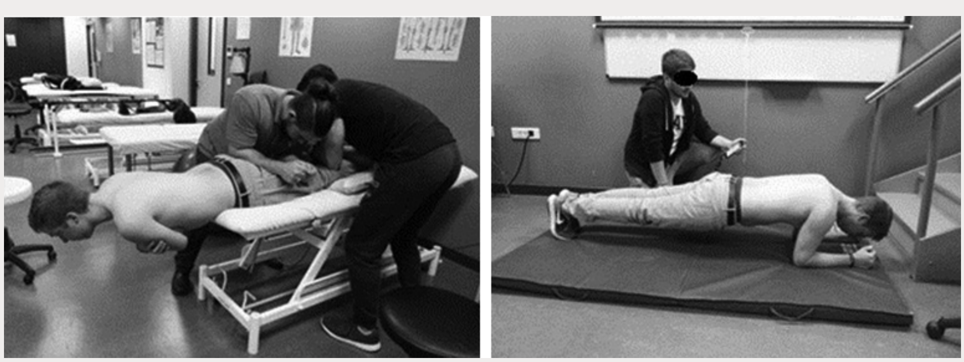

Fig. 2. Procedures for (a) plank prone bridge endurance test and (b) modified Sorensen endurance test to complete exhaustion.

endurance capacity of the trunk extensors, with the additional posterior chain muscles also active (gluteals, hamstrings), during a timed isometric activation of those muscles to complete exhaustion while maintaining the unsupported upper body in the horizontal position, with the buttocks and legs firmly held by three canvas straps and arms folded across the chest.[34,35] The Modified Trunk Extension Testing method (modification of the Sorensen test) follows the same principles as the original test, with the only difference from the standard procedure being the replacement of straps with the participation of a clinician who should firmly hold the subjects' lower extremities onto the examination table. This procedure is also a very reliable variation of Sorensen test method.[31,36]

Anthropometric and self-report physical activity/inactivity characteristics

A questionnaire compiled by the research team was given to participants to fill in, comprising factors that could potentially be associated with their lumbopelvic sagittal standing posture. The questionnaire included items on sex, anthropometric characteristics (age, body mass index), exercise frequency and intensity characteristics (the Baecke Sport Activity subscale),[37] as well as the time spent sitting daily expressed in three categories (less than 3 h/day, 3–5.9 h/day and more than 6 h/day).[38]

Experimental procedures

A pilot study was conducted between the members of the research team, to familiarize with and finalize all measurement procedures. All participants read and completed a form before the beginning of measurements concerning the purposes and the aims of the study, anthropometric and physical activity pattern details. All participants then assumed the standing position with their lower limbs parallel to each other and arms by their side. Three measurements were sequentially conducted by two members of the team for the measurement of SS and LC. One investigator placed the phone in the back of participants, according to anatomical landmark identification for the measurement of the two angles of interest (Fig. 1) viewing the phone from its posterior aspect, without looking at its screen, and another noted the angles in a blinded fashion to avoid biasing results between the three measurements. Additionally, between the three measurements of SS and LC, participants were requested to relax and walk a short distance (10 steps) in order to alter their body posture between measurements. Moreover, one investigator was involved with palpation of anatomical landmarks and skin-marking and another two investigators coordinated the plank test and the Modified Trunk Extension test (modified Sorensen test) procedures (Fig. 2). Prior to the beginning of fatigue testing, participants performed adequate warm-up, under the supervision of the investigators, which included stretches and mild spine mobilizing exercises in order to avoid any muscle strain injury during fatigue testing.

Data analysis

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS), version 20. The variables collected corresponded to different levels of measurement: sex was nominal-type measurement, number of hours spent in sitting/day was ordinal-type measurement and age, BMI, the Baecke Sport Index and the abdominal and paraspinal muscles endurance tests data corresponded to ratio-type measurements. The corresponding normality of distribution tests per variable were initially performed; sex was assessed with the Binomial test, hours spent sitting/day were assessed with the chi-square test and all variables related to ratio type were assessed with the Kolmogorov–Smirnov test.

The main analysis of this study included unrelated *t*-tests, Kruskal–Wallis and bivariate correlations. To explore possible differences in LC and SS angles between the categories of nominal (sex) and ordinal variables (sitting hours/day), unrelated *t*-tests were run for sex and Kruskal–Wallis tests for sitting hours/day. To explore possible associations between LC and SS angles and ratio-type variables (age, BMI, Baecke Sport Index subscale, modified Sorensen endurance and abdominal plank endurance tests), Pearson's bivariate correlations were run. Pearson's correlation values that were significant were considered as weak if $r < 0.25$, fair if $0.25 < r < 0.50$, moderate-to-good if $0.50 < r < 0.75$ and good-to-excellent if $r > 0.75$.[39] The significance level for all comparisons was initially set at 0.05. However, due to several correlation tests performed, the significance level was adjusted according to the Holm–Bonferroni method.[40] *A priori* sample size estimation suggested that for the nine correlations of interest (four explanatory variables × two lumbopelvic upright standing variables — SS and LC, plus one correlation between SS and LC), the adjusted a-level would be 0.00625; therefore, to achieve 80% power with a fair correlation of $R = 0.33$ the required sample size would be $n = 112$ participants. Also, upon completion of recruitment, an achieved power calculation was performed. Should sufficient power been not achieved, the sample size in a new study required to achieve an 80% power was additionally calculated. An online program for computing power and sample size for correlational designs (https://sample-size.net/correlation-sample-size/).[41] was utilized to perform all relevant calculations.

Results

Nearly all variables conformed to a normal distribution, apart from sitting hours and age. For sitting hours, the distribution of participants into the set categories were: 38 participants for less than 3 h/day, 60 for 3–5.9 h/day and 14 for more than 6 h/day. For age, the median [inter-quartile range (IQR)] values were 20 years (18.25–22 years). Since participants were of a rather narrow age range, no correlations between age and lumbopelvic sagittal posture variables were performed. The descriptive statistics of the remaining ratio-type variables are analytically presented in Fig. 1.

Statistically significant male–female differences for both angles were identified with unrelated t-tests; specifically, for LC, the mean (SD) values were 25.6° (8.1°) for females and 22.1° (7.7°) for males, $p = 0.023$, and for SS, the mean (SD) values were 18.8° (6°) for females and 15.9° (5.8°) for males, $p = 0.013$. However, there were no statistically significant differences either for SS ($p = 0.056$) or for LC ($p = 0.345$) between the three levels of the "sitting hours/day" variable, analyzed with the Kruskal–Wallis non-parametric test. Similarly, no significant associations were identified between BMI or physical activity levels (Baecke Sport Index) or paraspinal endurance and the lumbopelvic (LC or SS) standing posture (Table 2). On the contrary, significant correlations between lumbar curve and sacral slope angles ($r = 0.80$, $p < 0.001$) and between lumbar curve and abdominal isometric endurance ($r = -0.27$, $p = 0.004$) were identified (Table 2). To account for the multiple correlations performed (nine Pearson's correlations in total), adjustment of the level of significance was performed according to the Holm–Bonferroni method, with the a-level being lowered for the correlation between LC and SS to $a = 0.0056$ and that between LC and abdominal endurance to $a = 0.00625$. Therefore, these two latter correlations remained significant after this adjustment.

For the correlation between LC and abdominal endurance ($r = -0.27$), with a sample size of $n = 112$ participants and a significance level of $a = 0.00625$, the statistical power achieved was 56%. Based on the observed correlation value and the adjusted significance level, a sample size of 170 participants would have been required to achieve an adequate power level of 80%.

Table 2. Correlations of lumbopelvic angles with ratio-type variables.

		Sacral slope	Lumbar curve
Lumbar curve	R	**0.80****	1
	Sig. (two-tailed)	0.0001	
BMI	R	−0.05	0.10
	Sig. (two-tailed)	ns	ns
Leisure-time sport activity (Baecke Sport Index)	R	0.03	0.02
	Sig. (two-tailed)	ns	ns
Plank prone bridge endurance test	R	−0.17	**−0.27****
	Sig. (two-tailed)	ns	0.004
Modified Sorensen endurance test	R	0.04	−0.07
	Sig. (two-tailed)	ns	ns

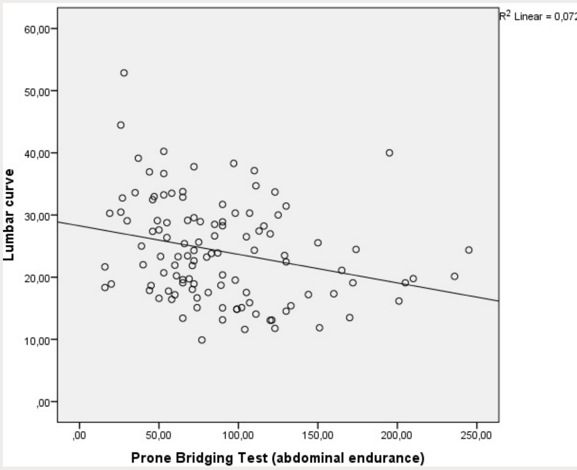

Fig. 3. Scatterplot of lumbar curve angle in upright standing against the plank prone bridge endurance test performed to complete exhaustion ($n = 112$).

Discussion

Previous studies have reported that extremes of posture in either direction may potentially increase the prevalence of spinal pain.[2,21] and lead to relatively earlier spinal degeneration in the long term.[7] The purpose of this study was to examine whether a list of modifiable anthropometric, lifestyle and muscle physical performance factors were associated with sagittal standing lumbopelvic posture (LC–SS) and one non-modifiable factor (sex). To this end, the effect of sex and an inactivity level index (sitting hours/day) on LC–SS, as well as the associations between BMI, a leisure-time sport activity index, abdominal and paraspinal muscles isometric endurance levels and LC–SS were examined in a mixed sample of 112 male–female college students.

Lumbopelvic posture variables (LC and SS) have been determined via placement of a smartphone operating the iHandy goniometer application, onto T12–L1 and S1–S2 spinous processes, under previously validated methodology.[29,30] The surface palpation methods utilized to identify the anatomical bony landmarks of interest present a limitation of our study, as palpatory methods usually have poor reliability and validity due to the difficulty in landmark identification,[42] as well as the reported between-subject anatomical landmark differences.[43]

Participants of this study were mostly between 18 years and 25 years old ($n = 103$, 92%); therefore, due to their limited age range the effect of age on lumbopelvic sagittal alignment was not examined. However, BMI did not demonstrate a significant correlation with lumbopelvic posture variables in our study and this is a matching finding only to one previous study.[9] This finding is most likely justified by the inclusion of only 18 (16%) overweight and five obese (4.5%) individuals in the sample of this study. In contrast, several other studies have confirmed significant associations between BMI and sagittal standing postures in children[11] and adults.[2,44] In particular, a cohort study with adult participants ($n = 489$) reported a strong relationship between overweight and obese participants and the types of non-neutral postural lumbopelvic variations in the sagittal plane, according to the Roussouly four-type classification.[2]

Conversely, significant relationships between sex and LC/SS were present. Several previous studies in adult[2,9,30] and adolescent[10] populations confirm this finding; therefore, the natural variation in standing posture between male and female participants should be taken into account when interpreting postural data in the standing position.

Concerning physical activity/inactivity levels, neither inactivity (sitting hours/day) nor leisure-time sport activity (Baecke Sport Index) was related to lumbopelvic posture in participants of this study. These physical activity/inactivity variables were based on self-report and therefore inadvertently relying on participants' recall.[45] Results of this study concur with two previous studies conducted in adults that had reported no association between lifestyle[2,19] or occupational demands on lumbar lordosis.[19] In contradistinction, a study of older-age industrial workers with flexion-related LBP reported that physical inactivity was associated with more posterior pelvic tilt.[6] However, participants of this study were younger and pain-free individuals, therefore these studies cannot be directly compared. Therefore, the effect of activity/inactivity levels in sagittal lumbopelvic posture may require further examination, as these variables may be linked to BMI or muscle performance state[13] or prolonged static postures under a variety of work-based environments.[45,46]

Finally, only the plank prone bridge test (abdominal endurance) demonstrated a significant fair negative association with LC ($r = -0.27$, $p = 0.004$). However, the power achieved for this finding was 56%, lower to a standard acceptable level of power (80%). Furthermore, the cause-and-effect relationship between abdominal endurance and LC is not clear. Immediate variations in the recruitment of the deep abdominal muscles related to postural alterations have been demonstrated in studies with healthy participants,[25,26] with more mid-range postures favoring better activation of the abdominal muscles. Three previous cross-sectional research studies examining abdominal muscle performance utilizing other performance tests (leg-lowering test or four abdominal endurance tests of progressive difficulty from crook lying) to the one used in this study (plank test), have reported no[14,47] to very weak relationships[15] with lumbopelvic posture in standing. Differences in testing methods between this and previous studies as well as population differences may have accounted for this variation in results. Furthermore, in order to monitor whether increased or decreased abdominal muscle endurance through training/de-training may progressively contain or increase LC, studies of prospective rather than cross-sectional design may be required.

The lack of association between lumbopelvic posture and trunk extensor endurance (Sorensen test) in the sample of this study, consisting mostly of young participants, may be due to the fact that the majority of subjects did not present with flatback and/or posterior pelvic tilt, as verified by the lumbar curve mean (SD) data (Fig. 1). Trunk kyphotic[13] or lumbar lordotic[12] angles have been related to lower trunk extensor muscle endurance in past studies. Also, trunk extensor muscle endurance of adolescents and young adults has been predicted to a rather high percent (14.4%) by their mothers' trunk muscle endurance capacity.[48] In addition, a recent study examining the cross-sectional area of multifidus and erector spinae in relation to lumbopelvic posture also reported no correlation between the cross-sectional area of those muscles and the angles of SS or LC in a group of healthy asymptomatic participants.[49] Finally, according to the phasic and tonic muscles' categorization, the lumbar extensor muscles tend to develop muscle spasm with fatigue, therefore maintaining the position of the lumbopelvic passive structures, whereas fatigue-prone abdominal muscles tend to elongate, therefore not able to adequately control the lumbopelvic sagittal position.

There is moderate-quality evidence supporting the effectiveness of exercise alone or in combination with appropriate education in LBP prevention in previously asymptomatic populations.[50] Whether the positive effect of exercise for LBP prevention is more general or if it is mediated by maintaining more mid-range postures still remains unresolved, with some studies demonstrating associations between specific postures and LBP development, while most prospective studies demonstrating no effect.[8] As far as secondary prevention of back pain is concerned, a relevant pilot randomized–controlled trial has demonstrated that using motion sensors technology as biofeedback to improve movement and postural patterns in the treatment of subacute and chronic LBP was significantly more effective than clinical guidelines-based management.[51] Also, specific exercise may be required in contradistinction to more general, to instigate the targeted postural improvements.[17]

Among the limitations to this study, our results are restricted to only healthy young college students (undergraduate mostly and postgraduate) that were measured in a comfortable standing position. Additionally, cross-sectional studies, like the present one, could be vulnerable to reverse causality, with the cause-and-effect direction of effect between posture and all other variables difficult to establish with certainty.[52] Also, significant differences have been identified between the average 24-h lumbar lordosis measurement and static measurement in standing,[53] perhaps denoting the non-functional nature of static measurements followed in this study.

Future research work in this field can be performed in a larger sample of participants with and without LBP of working age range (18–65 years old), occupational and leisure-time physical activity involvement, to examine further the association between trunk muscle performance characteristics (endurance, strength and flexibility) and spinal posture.

This study identified a significant correlation between the lumbar curve in standing and abdominal endurance, as well as the influence of sex in standing lumbopelvic posture. The association of abdominal endurance with lumbar curve was fair and the power achieved was not sufficient, therefore, no clear recommendations can be provided for the factors that could act preventively against end-range lumbosacral postures. However, better isometric abdominal endurance was associated with less lumbar lordosis curve in young pain-free adults. The effect of sex in interpreting lumbopelvic posture should also be taken into account.

Conflict of Interest

The authors have no conflict of interest relevant to this paper.

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Author Contributions

George A. Koumantakis had an executive role in supervising this project, performed the statistical analysis and helped to design the manuscript. All authors designed and drafted the manuscript, have read and approved the final version of the manuscript and agreed with the order of presentation of the authors.

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