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ORIGINAL ARTICLE

Cohort study of postural sway and low back pain: the Copenhagen City Heart Study

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Abstract

Purpose Low back pain is a significant health problem with a high prevalence. Studies of smaller cohorts of low back pain patients have indicated increased body sway. The present paper tests the hypothesis of an association between low back pain and postural sway in a large randomly selected population.

Methods The current study used the fifth examination (2011–2015) of The Copenhagen City Heart Study where 4543 participated. The participants answered a self-administered questionnaire regarding pain, physical activity, smoking, alcohol consumption, education, and other lifestyle factors. Measurement of postural body sway was performed using the CATSYS system.

Results Totally 1134 participants (25%) reported to have low back pain. Subjects with low back pain had higher sway area and sway velocity than subjects without.

Conclusion When using multivariate statistical analysis, confounding factors such as male gender, higher age, larger body height, low education level, smoking, and low activity level explained the association between low back pain and postural sway.

Keywords Low back pain · Postural sway · CATSYS · Population study · Epidemiological study

Background

Low back pain is a significant health problem associated with high treatment costs, sick leave, and individual suffering. Its prevalence increases with age and is in average about 20% in those aged between 20 and 59 years old [1]. The underlying cause of low back pain is unclear but studies of postural sway, being an indicator of sensory-motor control, in smaller cohorts of low back pain patients have indicated increased sway in most but not in all studies [2–5]. Other pain conditions along the spine such as neck pain in whiplash and tension-type headache are associated with impaired sensory-motor control in the neck muscles as part of their pathophysiology [6]. Accordingly, postural sway may be of specific interest for understanding of the pathophysiology of low back pain as well as for its clinical presentation including a potential risk factor for fall-accidents due to bodily imbalance [7]. Few portable test systems allow an easy evaluation of postural sway, but the coordination ability test system (CATSYS), can be used when exploring neurological disturbances in not hospitalized subjects [8].

The present study was designed to test the hypothesis of a potential association between low back pain and postural sway in The Copenhagen City Heart Study, a large population-based cohort. In this random sample of the general population, it was possible to analyze postural sway as an independent variable in relation to self-reported low back pain and hence adjust for possible confounders. Such an analysis has not previously been carried out.

Methods

Population

The Copenhagen City Heart Study is a prospective cardiovascular population study comprising a random sample of

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19,329 white men and women between 20 and 93 years of age drawn from the Copenhagen Population Register as of January 1, 1976.

The original purpose of the study was to focus on prevention of coronary heart disease and stroke. During the years many other aspects have been added to the study: Pulmonary diseases, heart failure, pain (including low back pain), dementia, ageing, stress, vital exhaustion, social network, arthrosis, diet, alcohol, allergy and genetics.

The first examination was carried out in 1976–1978 with 14,223 participants (response rate 74%). The current study used data from the fifth examination (2011–2015). Details have been described elsewhere [9, 10]. All former participants still alive, 9215 men and women, and a random sample of 1000 new persons from 20 to 29 years of age were invited to this fifth examination, where 4543 participated (response rate 49%). All participants were also asked to have their balance tested during the fifth examination and of these 4305 took part in the CATSYS measurements. Some withdrew from the balance test due to inability to stand unaided and some participants had not their balance tested due to technical problem with the equipment.

Measurements

Established procedures and examinations for cardiovascular disease epidemiological surveys were used [11]. A self-administered questionnaire requesting information about pain in several body locations, physical activity, smoking, alcohol consumption, education, among other background and lifestyle factors. High weekly alcohol consumption was defined as above 14 units/week in women and above 21 units/week in men. It was possible to register persistent or recurrent body pain experienced during the last 6 months in several locations in the body inclusive the lower back. Physical activity in leisure was graded in four levels: (1) Inactive or light activity < 2h/week, (2) light activity 2–4 h/week, (3) heavy activity 2–4 h/week, (4) heavy activity > 4h/week. The questionnaire was checked by the staff [9].

Body height without shoes, and bodyweight were measured.

Measurement of postural body sway was performed using the CATSYS system, invented in 1986 with the aim of diagnosing neurological disturbances [8, 12]. It recorded signal data from a 35 × 45cm balance plate, containing three force sensors. The force center coordinates were recorded as the subject tried to keep balance during the recording period. During the test the subject stood erect on the balance plate facing a fixed point straight ahead, without shoes and legs 2 cm apart. There were two test periods, one where the subject had open eyes, followed by one with closed eyes, both test periods had a duration of 60 s. Impermeant of visual input generally increases postural sway and it has been suggested that it would be more pronounced in individuals with back pain [3]. The two different test conditions with open and closed eyes were designed to challenge the role of visual input on the body balance. The sway area was defined as the smallest area for the smallest polygon in the horizontal plane, measured in mm^2. The sway velocity was calculated by dividing the total length of the trajectory with the recording period, measured in mm/s.

Statistics

The distribution of continuous variables was assessed by Kolmogorov–Smirnov tests for normality and evaluation of histograms. Differences in continuous variables between groups were assessed by nonparametric Kruskal–Wallis test, and differences in categorical variables were assessed by Chi-Square test. All analyses were stratified by gender. The relation between sway and variables were first assessed by bivariate analysis one at a time. Subjects were divided into three groups (low, middle and high sway) based on gender specific tertiles of CATSYS test results, to test for difference in variables between the three groups of sway. Secondly, the association between sway, as the dependent variable, and low back pain, as the independent variable, was assessed by the GENMOD procedure, with stepwise increasing adjustments of gender, age, height, weight, education level, smoking status, alcohol intake and leisure time activity level in multivariate analysis. Parameter estimates were generated by the maximum likelihood method. All statistical analyses were performed using SAS Enterprise Guide version 7.15 (SAS Institute Inc, Cary, NC, USA). The level of significance was set at $p < 0.05$.

Results

Gender characteristics

Participants' mean age was 57.6 ± 17.7 years. More females (56%) than males (44%) participated in the study. BMI was higher in men than in women (26.5 kg/m^2 vs. 25.4kg/m^2, $p < 0.0001$). There was a higher frequency of smoking among men than among women (21% vs. 17%, $p = 0.0007$). Mean reported intake of alcohol was higher in men than in women (11.1 unit/week vs. 6.0 unit/week, $p < 0.0001$). The frequency of high weekly alcohol consumption was higher in men than in women (14% vs. 10%, $p < 0.0001$). There were differences between education level among gender ($p < 0.0001$), with more men than women having craft training (28% vs. 21%) and more women than men having a short education (13% vs. 6%). More men than women had vigorous activity in leisure time (12% vs. 5%, $p < 0.0001$).

Women reported pain in more body parts than men (1.8 vs. 1.1 places, $p < 0.0001$) and also reported a higher pain index (3.9 vs. 3.2 index, $p < 0.0001$). More women than men were taking painkilling pills (17% vs. 10%, $p < 0.0001$).

Low back pain

A total of 1134 participants (25%) reported to have low back pain. Women reported more low back pain than males (28% vs. 21%, $p < 0.0001$). Subjects with low back pain were older than subjects without. Subjects with low back pain had higher BMI than subjects without. There was a higher smoking prevalence in subjects with low back pain than in subjects without pain in this body part. There was a generally lower education level in subjects with low back pain, than in subjects without pain in this body part. Subjects with low back pain reported lower leisure time activity level, than subject without this pain. Subjects with low back pain, reported pain in more other body parts than subject without this pain. A higher proportion of subjects with low back pain were taking painkilling pills, than subjects without pain in this body part (Table 1).

Body sway

Of all participants N:4305 (95%) participated in the CAT-SYS examination, with result from N:4048 subjects when

Table 1 Characteristics versus reported low back pain stratified by gender N:4543

	Women N:2563 (*56*)			Men N:1980 (*44*)		
	Pain 726 (*28*)	No pain 1837 (*72*)	◆ *p*-value	Pain 408 (*21*)	No pain 1572 (*79*)	◆ *p*-value
Age (years)	61.9 ± 17.0	56.2 ± 18.4	< 0.0001	59.2 ± 15.5	56.9 ± 17.5	0.0453
Obese BMI ≥ 30 (n)	153 (*22*)	247 (*14*)	< 0.0001	75 (*19*)	239 (*16*)	0.1446
BMI (kg/m^2)	26.2 ± 5.0	25.1 ± 4.7	< 0.0001	26.8 ± 4.1	26.4 ± 4.1	0.0183
Height (cm)	164.1 ± 7.4	165.1 ± 7.0	0.0024	178.1 ± 8.1	178.5 ± 7.3	0.5029
Weight (kg)	70.3 ± 13.6	68.2 ± 12.7	0.0004	85.2 ± 14.4	84.0 ± 14.3	0.0255
Smoking			< 0.0001			0.0091
Current	156 (*22*)	281 (*16*)		101 (*25*)	308 (*20*)	
Former	324 (*45*)	716 (*40*)		182 (*45*)	650 (*42*)	
Never	238 (*33*)	790 (*44*)		122 (*30*)	581 (*38*)	
Alcohol (items/w)	5.7 ± 7.1	6.2 ± 6.9	0.0189	11.8 ± 12.1	10.9 ± 10.4	0.7985
High alcohol intake	65 (*9*)	183 (*10*)	0.4364	71 (*17*)	206 (*13*)	0.0258
Education			< 0.0001			< 0.0001
Non	100 (*14*)	227 (*12*)		72 (*18*)	191 (*12*)	
Short	106 (*15*)	234 (*13*)		28 (*7*)	90 (*6*)	
Profession	185 (*26*)	357 (*20*)		133 (*33*)	424 (*27*)	
Higher	204 (*28*)	477 (*26*)		70 (*17*)	296 (*19*)	
University	127 (*18*)	530 (*29*)		103 (*25*)	564 (*36*)	
Activity leisure time			< 0.0001			0.0097
Passive	94 (*13*)	114 (*6*)		49 (*12*)	128 (*8*)	
Low active	335 (*47*)	742 (*41*)		155 (*39*)	532 (*34*)	
Active	268 (*38*)	844 (*47*)		160 (*40*)	696 (*45*)	
Vigorous	17 (*2*)	104 (*6*)		37 (*9*)	189 (*12*)	
Pain places (0–13)	4.1 ± 3.7	0.9 ± 1.5	< 0.0001	3.2 ± 2.3	0.6 ± 1.1	< 0.0001
Pain index (0–10)	4.5 ± 2.1	3.3 ± 2.2	< 0.0001	4.1 ± 2.1	2.7 ± 2.2	< 0.0001
Painkilling pills	252 (*36*)	172 (*10*)	< 0.0001	107 (*27*)	83 (*5*)	< 0.0001
Sway area open eyes (mm^2)	317 ± 292	270 ± 321	< 0.0001	453 ± 530	384 ± 357	0.0042
Sway area closed eyes (mm^2)	478 ± 472	413 ± 536	< 0.0001	793 ± 858	758 ± 834	0.0312
Sway velocity open eyes (mm/s)	11.0 ± 5.9	9.7 ± 5.2	< 0.0001	13.5 ± 7.9	12.5 ± 6.7	0.0164
Sway velocity closed eyes (mm/s)	16.5 ± 10.6	14.6 ± 10.1	< 0.0001	22.2 ± 15.1	21.6 ± 14.7	0.0595

Continuous variables are expressed as mean ± SD, and categorical variables are expressed as total number and *(%)* in cursive. Information about smoking *status* was missing in N:94 subjects. Information about education was missing in N:25 subjects. Information about leisure time activity was missing in N:79 subjects

◆Kruskal–Wallis test for horizontal difference in continuous variables between pain groups and χ^2 test when categorical variables, stratified by gender

Table 2 Comparison of participants with and without CATSYS examination with open eyes

	No CATSYS N:495 (*11*)	CATSYS with open eyes N:4048 (*89*)	*p*-value ◆
Females	267 (*54*)	2296 (*57*)	0.239
Age (years)	60.9 ± 19.1	57.2 ± 17.5	< 0.0001
BMI (kg/m^2)	26.1 ± 4.6	25.8 ± 4.5	0.4229
Smoking			0.0893
Current	106 (*22*)	740 (*19*)	
Former	205 (*43*)	1667 (*42*)	
Never	168 (*35*)	1563 (*39*)	
Education			0.0144
Non	87 (*18*)	503 (*12*)	
Short	50 (*10*)	408 (*10*)	
Manual	118 (*24*)	981 (*24*)	
Higher	110 (*22*)	937 (*23*)	
University	124 (*25*)	1200 (*30*)	
Low back pain	125 (*25*)	1009 (*25*)	0.8741

Continuous variables are expressed as mean ± SD. Categorical variables are expressed as total number and *(%)* in cursive. Information about smoking status was missing in N:94 subjects. Information about education was missing in N:25 subjects

◆Kruskal–Wallis test for horizontal difference in continuous variables between pain groups and χ^2 test when categorical variables, stratified by gender

the test was executed with open eyes, and results from N:3949 subjects when the test was performed with closed eyes. Subjects who did not complete the CATSYS examination were older and had a lower education level. The reported frequency of low back pain did not affect whether participants completed the CATSYS examination with open eyes (Table 2). Similar results were found when eyes were closed (Supplementary Table 2b).

Body sway and characteristics

At the CATSYS examination women had lower sway area and sway velocity than men, both with open and closed eyes ($p < 0.0001$). Subjects with low back pain had higher sway area and sway velocity than subjects without this pain (Table 1). With increasing age there were a dose respond increase in the sway area group ($p < 0.0001$) (Fig. 1). In independent bivariate analysis it was found that high sway area with open eyes was associated with increasing frequency of low back pain, increasing age, increasing BMI, current smoking, low education level, low activity level in leisure time and more body pain (Table 3). Same results were found when characteristics were associated to sway area with closed eyes, and sway velocity both with open and closed eyes (supplementary Table 3b–d).

Multi variates analysis

In the fully adjusted multivariate model, the association between sway area with open eyes and low back pain disappeared. In the final model were male gender (65.5044,

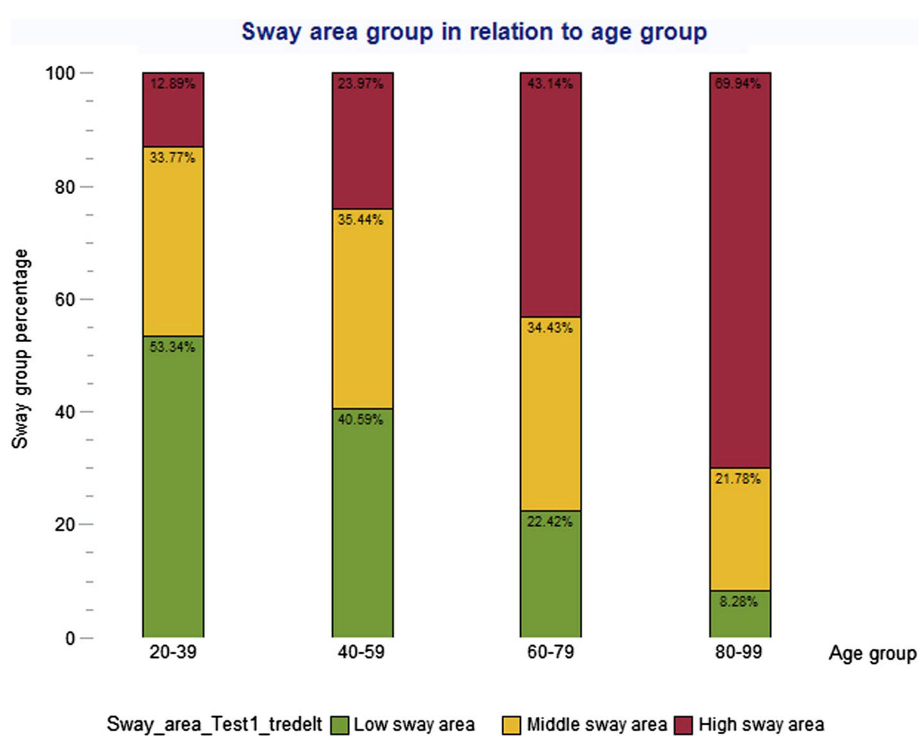

Fig. 1 Sway area group in relation to age group

Table 3 Characteristics divided into tertile depended on the sway area with open eyes

	Women N:2563 (*56*)				Men N:1980 (*44*)			
Sway area divided into 3 gender specific groups	Low sway N:757	Middle sway N:771	High sway N:768	♦ *p*-value	Low sway N:579	Middle sway N:588	High sway N:585	♦ *p*-value
Sway area (mm²)	108 ± 35	215 ± 34	526 ± 445	< 0.0001	151 ± 52	303 ± 50	736 ± 536	< 0.0001
Age (years)	49.1 ± 16.8	56.6 ± 16.9	66.3 ± 15.8	< 0.0001	49.4 ± 15.8	56.2 ± 16.4	65.3 ± 14.5	< 0.0001
Obese BMI ≥ 30	84 (*11*)	119 (*15*)	158 (*21*)	< 0.0001	62 (*11*)	90 (*15*)	127 (*22*)	< 0.0001
BMI (kg/m²)	24.4 ± 4.4	25.4 ± 4.8	26.2 ± 5.0	< 0.0001	25.7 ± 3.8	26.5 ± 4.0	27.2 ± 4.4	< 0.0001
Height (cm)	164.9 ± 6.8	165.0 ± 7.3	164.6 ± 7.3	0.3563	178.3 ± 7.0	179.5 ± 7.2	177.7 ± 8.0	< 0.0001
Weight (kg)	66.3 ± 11.6	69.1 ± 12.9	70.9 ± 13.9	< 0.0001	81.6 ± 13.0	85.3 ± 14.0	85.9 ± 15.3	< 0.0001
Smoking				0.0304				< 0.0001
Current	112 (*15*)	133 (*18*)	133 (*18*)		111 (*20*)	110 (*19*)	141 (*25*)	
Former	288 (*39*)	323 (*43*)	330 (*44*)		203 (*36*)	248 (*43*)	275 (*48*)	
Never	341 (*46*)	301 (*40*)	286 (*38*)		255 (*45*)	221 (*38*)	159 (*28*)	
Alcohol (items/w)	6.1 ± 6.2	5.9 ± 6.8	6.1 ± 7.8	0.0691	11.2 ± 10.5	12.0 ± 10.9	10.6 ± 10.7	0.0133
High alcohol intake	73 (*10*)	73 (*9*)	78 (*10*)	0.8944	74 (*13*)	96 (*16*)	84 (*14*)	0.2262
Education				< 0.0001				< 0.0001
Non	74 (*10*)	99 (*13*)	107 (*14*)		65 (*11*)	71 (*12*)	87 (*15*)	
Short	84 (*11*)	98 (*13*)	118 (*15*)		36 (*6*)	33 (*6*)	39 (*7*)	
Profession	121 (*16*)	167 (*22*)	203 (*27*)		129 (*22*)	145 (*25*)	216 (*37*)	
Higher	221 (*29*)	193 (*25*)	202 (*26*)		99 (*17*)	122 (*21*)	100 (*17*)	
University	252 (*34*)	212 (*28*)	133 (*17*)		248 (*43*)	215 (*37*)	140 (*24*)	
Activity leisure time				< 0.0001				< 0.0001
Passive	35 (*5*)	50 (*7*)	81 (*11*)		41 (*7*)	47 (*8*)	65 (*11*)	
Low active	271 (*36*)	332 (*43*)	372 (*50*)		171 (*30*)	181 (*31*)	248 (*43*)	
Active	397 (*53*)	350 (*46*)	270 (*36*)		258 (*45*)	281 (*49*)	229 (*40*)	
Vigorous	46 (*6*)	32 (*4*)	27 (*4*)		105 (*18*)	69 (*12*)	35 (*6*)	
Pain places (0–13)	1.5 ± 2.0	1.8 ± 2.4	2.1 ± 2.5	< 0.0001	1.0 ± 1.6	1.1 ± 1.8	1.3 ± 1.9	0.0068
Pain index (0–10)	3.5 ± 2.0	3.7 ± 2.2	4.3 ± 2.3	< 0.0001	2.8 ± 2.0	3.1 ± 2.3	3.7 ± 2.4	< 0.0001
Painkilling pills	66 (*9*)	144 (*19*)	176 (*23*)	< 0.0001	39 (*7*)	40 (*7*)	78 (*14*)	< 0.0001
Low back pain	179 (*24*)	205 (*27*)	272 (*35*)	< 0.0001	99 (*17*)	117 (*20*)	137 (*23*)	0.0265

Continuous variables are expressed as mean ± SD, and categorical variables are expressed as total number and *(%)* in cursive. Information about smoking status was missing in N:94 subjects. Information about education was missing in N:25 subjects. Information about leisure time activity was missing in N:79 subjects. Women were grouped based on tertiles of their sway area: low sway (area < 162), middle sway (162 ≤ area < 280), high sway (280 ≤ area). Men were grouped based on tertiles of their sway area: low sway (area < 227), middle sway (227 ≤ area < 410), high sway (410 ≤ area)

♦Kruskal–Wallis test for horizontal difference in continuous variables between sway groups and χ^2 test when categorical variables, stratified by gender

$p < 0.0001$), higher age (6.2872, $p < 0.0001$), larger body height (4.5330, $p < 0.0001$), no education (39.4188, $p = 0.0420$), current smoking (32.8925, $p = 0.0351$), reduced alcohol intake (−1.9622, $p = 0.0015$) and low activity level (136,5229, $p < 0.0001$) positively associated with sway area with open eyes (Table 4).

In the fully adjusted multivariate model, the association between sway area with closed eyes and low back pain disappeared. In the final model were male gender (140.8595, $p < 0.0001$), higher age (14.3720, $p < 0.0001$), larger body height (12.5300, $p < 0.0001$), no education (103.8899, $p = 0.0045$) and low activity level (162.3480, $p = 0.0024$)

Table 4 Sway versus low back pain with various adjustments (Model: sway = low back pain + adjustments)

Test	Sway area (mm^2) with open eyes		Sway area (mm^2) with closed eyes		Sway velocity (mm/s) with open eyes		Sway velocity (mm/s) with closed eyes	
Model	Estimate	*p*-value	Estimate	*p*-value	Estimate	*p*-value	Estimate	*p*-value
1	42.3783	0.0011	16.6530	0.5179	0.8815	0.0001	0.7177	0.1313
2	27.4183	0.0266	− 7.0161	0.7684	0.4387	0.0297	− 0.0067	0.9873
3	26.7280	0.0307	− 9.4108	0.6909	0.4158	0.0393	− 0.0459	0.9119
4	23.5200	0.0615	− 14.7494	0.5350	0.3654	0.0732	− 0.1288	0.7579
5	21.4704	0.0878	− 18.3118	0.4415	0.3259	0.1103	− 0.2033	0.6259
6	15.5754	0.2185	− 24.5259	0.3060	0.2558	0.2100	− 0.2284	0.5839

Adjustments in model 1: none. Adjustments in model 2: Gender and age. Adjustments in model 3: Gender, age, height and weight. Adjustments in model 4: Gender, age, height, weight and education. Adjustments in model 5: Gender, age, height, weight, education, smoking and alcohol. Adjustments in model 6: Gender, age, height, weight, education, smoking, alcohol and activity

positively associated with sway area with closed eyes (Table 4).

In the fully adjusted multivariate model, the association between sway velocity with open eyes and low back pain disappeared. In the final model were male gender (1.6232, $p < 0.0001$), higher age (0.1604, $p < 0.0001$), larger body height (0.0703, $p < 0.0001$), no education (0.6995, $p = 0.0252$), current smoking (0.6412, $p = 0.0109$) and low activity level (1.7132, $p = 0.0002$) positive associated with sway velocity with open eyes (Table 4).

In the fully adjusted multivariate model, the association between sway velocity with closed eyes and low back pain disappeared. In the final model were male gender (3.0995, $p < 0.0001$), higher age (0.3341, $p < 0.0001$), larger body height (0.2063, $p < 0.0001$), no education (1.8267, $p = 0.0041$), current smoking (1.1800, $p = 0.0211$) and alcohol intake (0.0909, $p < 0.0001$) positively associated with sway velocity with closed eyes (Table 4).

Discussion

The hypothesis that individuals with low back pain had an increased postural sway was supported in this study when using univariate statistical analysis. This in accordance with previous clinical studies as concluded in recent reviews [2–5]. However, when using multivariate statistical analysis, which the large number of participants allowed in this study, confounding factors explained the association found using univariate statistical analysis. This observation contrasts with the existing scientific literature. The most likely explanation is that this study is an epidemiological study comprising a large randomly selected population, while all studies on the issue in the literature are clinical studies including smaller numbers of participants, which does not provide the possibility to conduct a multivariate statistical analysis. To our knowledge this is the first and only epidemiological study addressing the association between low back pain and postural sway.

The strength of this design is the inclusion of individuals from both younger and older age groups and with many different characteristics. A study design providing the option to carry out multivariate statistical analysis taking potential confounding factors into consideration. Something which is not an option in smaller clinical studies. The validity of the observations in this study is supported by the similar results found when analyzing different measures of postural sway, such as sway area and sway velocity, all tests both with open and closed eyes.

The weakness in this study is the lack of a clinical examination of individuals with and without low back pain. So, we cannot exclude that an independent association between low back pain and increased sway in some patients with specific low back disease may exist.

The most important new observations in this study are the associations found between individual characteristics and sway. Those individuals, swaying the most, were the older, the men, the taller people and those with lowest education and the smokers. Future clinical studies may be more conclusive if the above-mentioned characteristics are taking into consideration when designing a clinical study in this field.

Postural sway can be measured by different equipment and under varying study condition. By the CATSYS system measurements of postural sway was attained in an easy and noninvasive manner in a large population. However, the wide variations in sway area and sway velocity between participants, and lacking cutoff values for morbid condition, makes the diagnostic value of postural sway low at the present. The epidemiological design used in this study will allow follow-up studies on the possible predictive significance of postural sway for future health and survival.

Conclusion

The hypothesis suggesting an independent association between self-reported low back pain and increased postural sway was not supported in this epidemiological study providing multivariate statistical analysis. Several covariates with postural sway were observed (age, gender, body heights, educational level and smoking status).

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00586-023-07925-9.

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Declarations

Conflict of interest None of the authors has any potential conflict of interest.

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