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Simultaneous measurement of center of pressure and center of mass in assessing postural sway in healthcare workers with non-specific back pain: protocol for a cross-sectional study

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Simultaneous measurement of center of pressure and center of mass in assessing postural sway in healthcare workers with non-specific back pain: protocol for a cross-sectional study

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ABSTRACT

Introduction Low back pain (LBP) is widely prevalent in healthcare workers. It is associated with impaired postural and core stability. So far, center of pressure (CoP) measures have been commonly recorded through the use of a force plate in order to assess postural stability. However, this approach provides limited information about the center of mass (CoM) movement in the lumbar region in individuals with LBP. Recent developments in sensor technology enable measurement of the trunk motion which could provide additional information on postural sway. However, the question remains as to whether CoM measures would be more sensitive in discriminating individuals with mild and moderate back pain than traditional CoP analyses. This study aims to investigate the sensitivity of CoP and CoM measures under varied stable, metastable and unstable testing conditions in healthcare workers, and their relationship with the level of subjective reported back pain.

Methods and analysis This is a cross-sectional controlled laboratory study. A group of 90 healthcare professionals will be recruited from rehabilitation centers within local areas. Participants will complete the Oswestry Disability Questionnaire. The primary outcome will be the rate their back pain on the 0-10 Low Back Pain Scale (1-3 mild pain and 4-6 moderate pain). Secondary outcomes will include variables of postural and core stability testing during bipedal and one-legged stance on a force plate, a foam mat placed on the force plate, and a spring-supported platform with either eyes open or eyes closed. Both CoP using the posturography system based on a force plate and CoM using the inertial sensor system placed on the trunk will be simultaneously measured.

Ethics and dissemination Projects were approved by the ethics committee of the Faculty of Physical Education and Sports, Comenius University Bratislava (Nos. 4/2017, 1/2020). Findings will be published in peer-reviewed journals and presented at conferences.

52 **Keywords:** core stability, inertial sensor system, low back pain scale, Oswestry Disability
53 Questionnaire, postural stability

Strengths and limitations of this study

- Balance problems were often reported in individuals with severe back pain. However, little attention has been paid to those with mild to moderate back pain. This study is designed to investigate whether postural and core stability impairments can be revealed in healthcare workers at the early stages of low back pain.
- Nowadays, inertial sensor systems represent a novel approach for assessment of postural sway which are easy-to-use in practice and could be more sensitive in discriminating within and between-group differences among the different balance tasks.
- Concurrent measurement of CoP and CoM displacements under ten different conditions (bipedal and one-legged stance on a stable, metastable and unstable platform with either eyes open or eyes closed) could provide useful information on postural and core stability in individuals with mild to moderate back pain.
- Though a limitation will be that the sample consists mainly of female participants due to the higher number of women working in the healthcare sector, it is worth noting that the prevalence rate of low back pain in this population is high with the majority of cases occuring after starting work.
- Adding measurement of trunk sway in the functional testing of healthcare workers using an inertial sensor system could identify back problems earlier and more efficiently, thus addressing them well before chronic back disorders occur. This novel approach may offer unique advantages by regular assessment of both postural and core stability without the restrictions of a lab environment.

INTRODUCTION

Healthcare workers are at the highest risk of back problems[1-10] with the lower back the most frequently affected, followed by the neck, upper back and shoulders. The prevalence of low back pain (LBP) is high in both nurses and physiotherapists when compared to other health care professions. The lifetime prevalence of LBP in nurses is as high as 90%[11] and recurrence rates exceed 70%[12]. In physical therapists the lifetime prevalence ranges between 26–79.6%.[13] This is related to mainly younger females working in rehabilitation settings[13] with the majority of cases (78.3%) occurring after starting work.[14] This imbalance between their lower aerobic capacity and muscle strength[15] and physical work demands, especially high postural demands, may lead to excessive loading of the musculoskeletal system[16], hence increasing the risk of back problems. Among the major risk factors of LBP are specific handling tasks while manually moving, transferring and lifting patients.[17-25] It is also associated with awkward and static postures for an extended period of time[19,22,23,25] and frequent bending the trunk[18,19]. Aberrations of posture create a strain on ligaments and muscles that indirectly affects the curvature of the lumbar spine and may play a role in the development of LBP.[26] This leads to the impairment of postural and core stability[27] and therefore their proper assessment is important for prevention of back problems, increased workforce efficiency and overall quality of life.

So far, postural stability has been assessed using posturography systems based on a force plate measurement of the vertical-ground reaction force and computing the CoP. The CoP is calculated from horizontal moment and vertical force data generated by triaxial force platforms and represents the center of distribution of the total force applied to the supporting surface. This method allows evaluation of various aspects of postural control such as steadiness, which is the ability to keep the body as motionless as possible, and symmetry, which is the ability to distribute weight evenly between the two feet in an upright stance. However, the force platform method evaluates secondary consequences of swaying movements, not the movements themselves.[28] Increasing CoP measures does not necessarily link to postural instability. It may be indicative of underlying neural or sensorimotor dysfunction, but CoP movements may successfully stabilize the CoM. Thus, it provides limited information about the trunk motion in the lumbar region, which is particularly important in LBP individuals. Recent meta-analysis by Sadler et al.[29] reported that a restriction in lateral flexion and hamstring range of motion as well as reduced lumbar lordosis are associated with an increased risk of developing LBP. Chronic low back pain affects the lower lumbar spine and limits the maximal range of lumbar extension. Specifically, the sacral inclination angle is larger in chronic LBP patients and this angle is related to the maximal range of lumbar extension.[30]

Therefore a novel approach is needed in functional testing of these individuals that would be more sensitive in revealing subtle impairments of both postural and core stability associated with back problems. Previously, the CoP-CoM measure was used to evaluate postural sway in populations of various ages and performance levels (e.g. ballet dancers).[31,32,33,34] The CoP-CoM that represents the scalar distance at a given time between CoP and CoM has been proposed for better understanding the postural control system.[35] However, the CoM acceleration can be a more convenient measure instead of the CoP-CoM measure in the evaluation of postural control.[36] Alternatively, a CoP/CoM ratio of basic stabilographic variables can be calculated from simultaneous measurement of both parameters. Most balancing skills against gravity can be framed in the CoP–CoM interplay and can be modelled as a combination/alternation of two basic intermittent stabilization strategies: the standard CoP stabilization strategy, where the CoM is the controlled variable and the CoP is the control variable, and the CoM stabilization strategy, where CoP and CoM must exchange their role because the range of motion of the CoP is strongly constrained by environmental conditions.[37] While the CoP is acquired from the force plate, the CoM movement is monitored by optical cameras using the markers placed on the body. This parameter can be extracted with a 3D motion analysis system utilized in a research setting. However, this system is costly, time-consuming, requires skilled staff and it is not suitable for routine balance testing in daily practice. Therefore user-friendly, portable and low-cost diagnostic systems well suited for testing in the field in a relatively short time period is required.

Recent developments in measurement technology (wireless inertial sensors, BioStamp sensor, Kinect depth camera etc.) enable the measurement of CoM trajectories and can constitute an alternative to the posturography systems based on force platforms.[38,39,40,41] Though an estimate of the CoM is somewhat difficult to obtain, trunk sway can be measured through an inertial measurement unit fixed onto the trunk. It provides similar variables as postuprography systems based on force platforms.[42] Data obtained through inertial sensors are valid and reliable and can be useful for balance assessment in healthy adults[43-47], older people[43,48,49], patients with various diseases[50-55], as well as athletes[56]. Yet, there is a lack of information concerning their use in healthcare workers and their ability to reveal differences in core stability between individuals with mild to moderate back pain and healthy controls consistent with the force plate measurement.

This warrants further investigation on more sensitive testing methods of core stability within samples of healthcare workers prone to back pain that would provide additional information on control and regulation of CoM position than traditional CoP analyses. Therefore, the purpose of this study will be to investigate within and between-group differences in CoP and CoM sway in healthcare workers with and without mild to moderate back pain. A secondary aim will be to examine the relationships between CoP and CoM measures and the level of subjective reported back pain. We will test the hypothesis that CoM measures recorded by an inertial sensor system would be more sensitive in revealing impaiments of postural and core stability in individuals with back problems than typically used CoP analyses, and that it would be associated with mild to moderate level of back pain which is more difficult to identify using traditional methods assessing postural sway.

METHODS AND ANALYSIS

Study design

This study will adopt a fully controlled research design with measurements of CoP and CoM sways under a variety of testing conditions in healthcare workers with non-specific back pain. We are planning to assess 90 participants in 10 different balance tasks with simultaneous measurement of force plate and inertial sensor variables. The timetable will be specified when the coronavirus crisis is over. The study will be implemented and reported in line with the SPIRIT statement.

Participants

A group of 90 healthcare female and male professionals, namely physiotherapists, will be recruited from rehabilitation centers within local areas (Figure 1). Those who will report non-specific back pain[57,58] with duration of less than 6 weeks (acute), between 6 and 12 weeks (sub-acute) and for more than 12 weeks (chronic)[59-62] will be eligible to participate in the study. Inclusion criteria for LBP individuals and healthy controls will require no history of neurological or orthopedic conditions that might influence balance. Individuals who had previously undergone surgery or other medically invasive procedures for low back pain will be excluded from participation in the study. The participants' characteristics will be sumarized prior to the testing.

Upon arrival at the laboratory, participants will be verbally informed of the main purpose of the study, procedures, risks and benefits, confidentiality, the voluntary nature of their participation and provided an opportunity to ask questions. Written informed consent will be obtained from all participants prior to inclusion. All information and data obtained will be anonymized and stored in password-protected computers, which will only be accessed by the researchers.

Assessment of participant's level of back pain

Participants will be divided into two groups based on the low back pain scale, which is widely used in the medical settings to collect information about the level of patient's pain. The scale ranges from 0 to 10, with 0 being no pain at all and 10 being unbearable pain. Participants experienced mild pain (pain score 1-3), which does not interfere with most activities and is easy to manage both physically and psychologically, and moderate pain (pain score 4-6), which interferes with many activities of daily living and requires changes to daily lifestyle to manage pain symptoms for the last three months, will be considered. A control group (age-matched ±2 years) will include those reporting no pain.

They will also complete the Oswestry Low Back Pain Disability Questionnaire, which is considered the 'gold standard' of low back functional outcome tools and gives a subjective percentage score of level of function (disability) in activities of daily living[63]. Measurements obtained with the Oswestry Disability Questionnaire are reliable and have sufficient width scale to reliably detect improvement or worsening in most subjects[64]. Additional information associated with back pain will be also obtained (e.g., the amount of daily practice with clients, sporting activities, previous injuries and diseases etc.).

Procedures

Participants will be requested to avoid any strenuous exercises prior to the study. Before testing, participants will be given a visual demonstration of the proper exercise technique and will be informed of the instructions during testing. In order to eliminate the learning effect, they will be encouraged to practice (1–2 trials) of the measurement procedure beforehand.

Afterwards, participants will be asked to stand barefoot on a force plate with their arms relaxed comfortably at their sides. They will be instructed to stand in an upright position with their feet abducted at 10° and their heels separated mediolaterally by a distance of 6 cm. A series of 30-s trials[65] will be conducted in a randomized order under varied conditions: 1) bipedal stance on a force plate with eyes open, 2) bipedal stance on a force plate with eyes closed, 3) right leg stance on a force plate with eyes open, 4) left leg stance on a force plate with eyes open, 5) bipedal stance on a foam mat (Airex Balance Pad) placed on the force plate with eyes open, 6) bipedal stance on a foam mat (Airex Balance Pad) placed on the force plate with eyes closed, 7) bipedal stance on a spring-supported platform with eyes open, 8) bipedal stance on a spring-supported platform with eyes closed, 9) right leg stance on a spring-supported platform with eyes open, and 10) left leg stance on a spring-supported platform with eyes open. Twenty seconds of rest will be allowed between tasks.

Measurement of CoP variables under stable and unstable conditions

Basic parameters of postural sway under stable conditions (i.e., mean CoP position in the X- and Y-axis, mean CoP velocity, mean CoP acceleration, mean CoP trace length, mean distance from the middle of the CoP, mean squared distance from the middle of the CoP, and area of CoP trace) will be registered by using a FiTRO Sway Check (FiTRONiC, Bratislava, Slovakia). The system measures the actual force in the corners of the force plate and calculates an instant position of the CoP (sampling rate: 100 Hz, 12 bit AD signal conversion, resolution of the CoP position: less than 0.1 mm, measuring range: 0-1000 N/s, non linearity: +/- 0.02% FS, combined error: 0.03%, sensitivity: 2mV/V +/- 0.25%, overload capacity: 150% / sensor). Analyses of repeated measurements revealed that reliability of CoP variables is good to excellent with no significant day-to-day changes. The Romberg quotient (EC/EO sway ratio) will also be calculated.

Under unstable conditions, variables of postural sway will be registered by using the FiTRO Sway Check system (FiTRONiC, Bratislava, Slovakia). The device consists of a square platform supported by 4 springs with an elasticity coefficient of 40 $N.mm^{-1}$. Shifting the CoM in the horizontal plane leads to changes of body weight distribution to the 4 corners of the platform. Force acting in each corner is calculated as a product of the coefficient of elasticity of the spring used and vertical distance measured by means of a fine sensor. The analog signals are AD-converted and sampled by computer at the rate of 100 Hz. Calculations of instant CoP position is based on force distribution to the 4 corners of the platform. Basic parameters of postural sway (i.e., mean CoP velocity and mean CoP displacements in medio-lateral and anterior-posterior directions) will be analysed. A previous study revealed that such unstable conditions improve the discriminatory accuracy of balance tests, thereby better differentiating between groups of various ages, i.e. young adults (aged 19-24 years), early middle-aged adults (aged 25-44 years) and late middle-aged adults (aged 45-64 years)[66]. Comparing with static balance tests with eyes open and eyes closed (AUC = 0.66, 95% CI = 0.62–0.69 and 0.70, 95% CI = 0.65–0.74, respectively), testing of postural stability while standing on a spring-supported platform increased significantly the discriminatory power (AUC = 0.82, 95% CI = 0.78–0.86; *P* = 0.006 and 0.87, 95% CI = 0.84–0.90; *P* = 0.009, respectively). It is therefore likely that assessing postural sway under such unstable conditions would be more sensitive in discriminating healthcare workers with and without mild to moderate back pain.

Measurement of CoM variables under stable and unstable conditions

Simultaneously, the CoM variables will be measured using the Gyko inertial sensor system (Microgate, Bolzano, Italy) fixed with an elastic belt on the participant's posterior trunk, near the body CoM. The height of the Gyko device positioned on the trunk will be set up before measurement in order to avoid its influence on data obtained.[67] The Gyko system consists of 3D accelerometer for measurement of linear accelerations to which the device is subjected, 3D gyroscope for measurement of angular velocities of the device, and 3D magnetometer for measurement of a magnetic field to which the device is subjected. It provides data measurements up to 1000 times per second (1 kHz) which guarantee their high temporal resolution. On the basis of these data, specific software algorithms describe the kinematics of the analysed body segment. It determines three main measures of body sway: sway length and area, sway travel speed, and sway frequency. Recent study by Jaworski et al.[68] showed moderate to good relative reliability scores for all the postural stability measures, with ICC values ranging from 0.62 to 0.70. For most of the analysed variables, SEM% ranged from ~10% to 14%.

Statistical Analyses

Statistical analysis of the collected data will be performed using the SPSS program for Windows, version 24.0 (SPSS, Inc., Chicago, IL, USA). The hypothesis of normality will be analysed via the Kolmogorov-Smirnov test. A parametric analysis will be performed when the data is normally distributed. The sample size calculation conducted with $\alpha = 0.05$ (5% chance of type I error) and $1 - \beta = 0.80$ (power 80%) and using the previous results that showed variations in sway variables among groups of various ages and levels of physical fitness indicated a sample size of 27 per group. Given that the goal of postural and core stability assessment is to track their subtle impairments in healthcare workers with mild to moderate back pain, stepwise multivariate binary logistic regression will be performed to determine whether CoM measures obtained by an inertial sensor system are able to differentiate among these groups and healthly controls even more sensitively when compared to the accuracy of CoP measures. The healthcare groups will be used as the dependent variable while sway metrics will be used as independent variables. Two-way analysis of ANOVA (group x condition) will be performed to determine between-group differences in CoP and CoM variables. A Bonferroni pairwise correction will be applied to mitigate the multiple-comparison bias. Between-group effect sizes (Cohen's d) will be calculated by using a pooled standard deviation. An effect size of 0.80 and higher is considered as large, 0.50–0.79 as medium, 0.20–0.49 as small and 0–0.19 as trivial.[69]

Associations between the Oswestry Disability Index and CoP and CoM measures under a variety of testing conditions will be assessed using Pearson's product moment correlation coefficient (r). Values of $r = 0.10$ indicate a small, $r = 0.30$ a medium and $r = 0.50$ a large correlation. A standard multiple regression analysis will be conducted to determine which independent variables of postural and core stability are significant predictors of back pain. The amount of variance explained will be reported by the coefficient of determination (r^2). The level of significance will be set at $\alpha = 5\%$. Data will be presented as mean ± standard deviation (SD).

Patient and public involvement

Patients and the public will be not directly involved in the present study. Local medical centers will provide support for recruitment of healtcare workers with non-specific back pain. Test results will be provided to participants on request and the overall outcomes will be available to them on completion of the study.

Ethics and dissemination

The procedures described are in accordance with the ethical standards on human experimentation stated in compliance with the 1964 Helsinki Declaration and its later amendments. Projects were approved by the ethics committee of the Faculty of Physical

Education and Sports, Comenius University in Bratislava (Nos. 4/2017 and 1/2020). Findings will be published in peer-reviewed journals and presented at scientific conferences.

DISCUSSION

The present study will address the issues of sensitivity of CoP and CoM measures in revealing subtle impairments of postural and core stability in healthcare workers with mild to moderate back pain. It will also provide insight into the relationships between these measures and their level of subjective reported back pain. We assume that roughly a measurement of CoM displacement by means of an inertial sensor system placed on the trunk will be capable distinguishing within and between-group differences much better as compared to the force plate-based measurement. We also propose stronger associations between CoM measures and the level of their back pain than current methods based on a force platform analysis of CoP sway.

Though posturography systems based on force plate postural sway assessments are considered the gold standard, they are relatively expensive, immobile and may not be practical for field testing. Inertial sensors represent an easy to administer and low cost method feasible for core stability testing outside research settings. The sensor can be attached to the upper[70,71] or lower back[72-74], which yields additional information about the trunk motions. However, data obtained in healthcare workers with back problems, especially those at the early stages of low back pain are sparse. Therefore there is a need to confirm the usefulness of inertial sensors in this population in order to reveal slight impairments of postural and core stability and so support strategies for preventing chronic back pain. Given that the goal of balance control is to maintain the CoM within the limits of stability, its measurement may provide better insights into the mechanisms of both postural and core stability[75], especially in individuals with low back pain. However, some studies have found that sway metrics derived from accelerometers[76] or the

BioStamp sensor[40] are unable to separate mildly impaired individuals with multiple sclerosis from healthy controls in challenging balance conditions. In this regards, a recent systematic review by Ghislieri et al.[77] highlighted that efforts in the validation of wearable inertial sensors for assessing balance against traditional posturographic approaches should focus on the evaluation of the sensitivity of the outcome measures.

The strength of this study will be that CoP and CoM measures will be registered simultaneously under ten different testing conditions (bipedal and one-legged stance on stable, metastable and unstable platform with either eyes open or eyes closed). This will allow the estimation of sensitivity of postural and core stability testing in discriminating within and between-group differences among various balance tasks. This will be supported by investigating the relationship between these measures and the level of back pain in healthcare workers. The sample will consist not only of older healthcare workers who often experience back problems, but also their younger conterparts because the majority of back pain occurs in female physical therapists working in rehabilitation settings[13] after starting work.[14] Revealing impairments of postural and core stability in these individuals can identify back problems more efficiently and well before chronic back disorders occur.

The weakness is that a sample will most likely consist mainly of female participants due to the higher number of women working in healthcare sector. Further research should therefore be focused on investigation of subtle variations of trunk sway and its underlying individual characteristics in male healthcare workers with non-specific back pain using the inertial sensors fixed on lower and/or upper part of their posterior trunk. The sensitivity of this method to reveal changes in postural and core stability in this population over a period of time should also be investigated.

In conclusion, this is a cross-sectional study designed to investigate 1) within and between-group differences in CoP and CoM measures in healthcare workers with and without mild to moderate back pain, and 2) the relationships between these measures and their subjective level of reported back pain. This includes simultaneous registration of CoP and CoM sways during tasks of increased difficulty from stable, through metastable to unstable conditions with and without vision while standing on either two legs or one. Binary stepwise logistic regression will be performed to determine which CoM measures are able to differentiate among healthcare workers with mild to moderate back pain and healthly controls. To evaluate potential associations between these measures and their level of back pain, the Pearson correlation coefficient will be calculated for each sway metric.

Simultaneous monitoring of CoP and CoM sway can give new insight into the postural and core stability in healthcare workers with mild to moderate back pain. The use of a wireless inertial sensor system placed on the trunk will enable the measurement of balance during a variety of tasks without being restricted to a laboratory environment. This simple and widely applicable assessment might predict balance and related back problems in healthcare workers and in this way reduce further health-related consequences.

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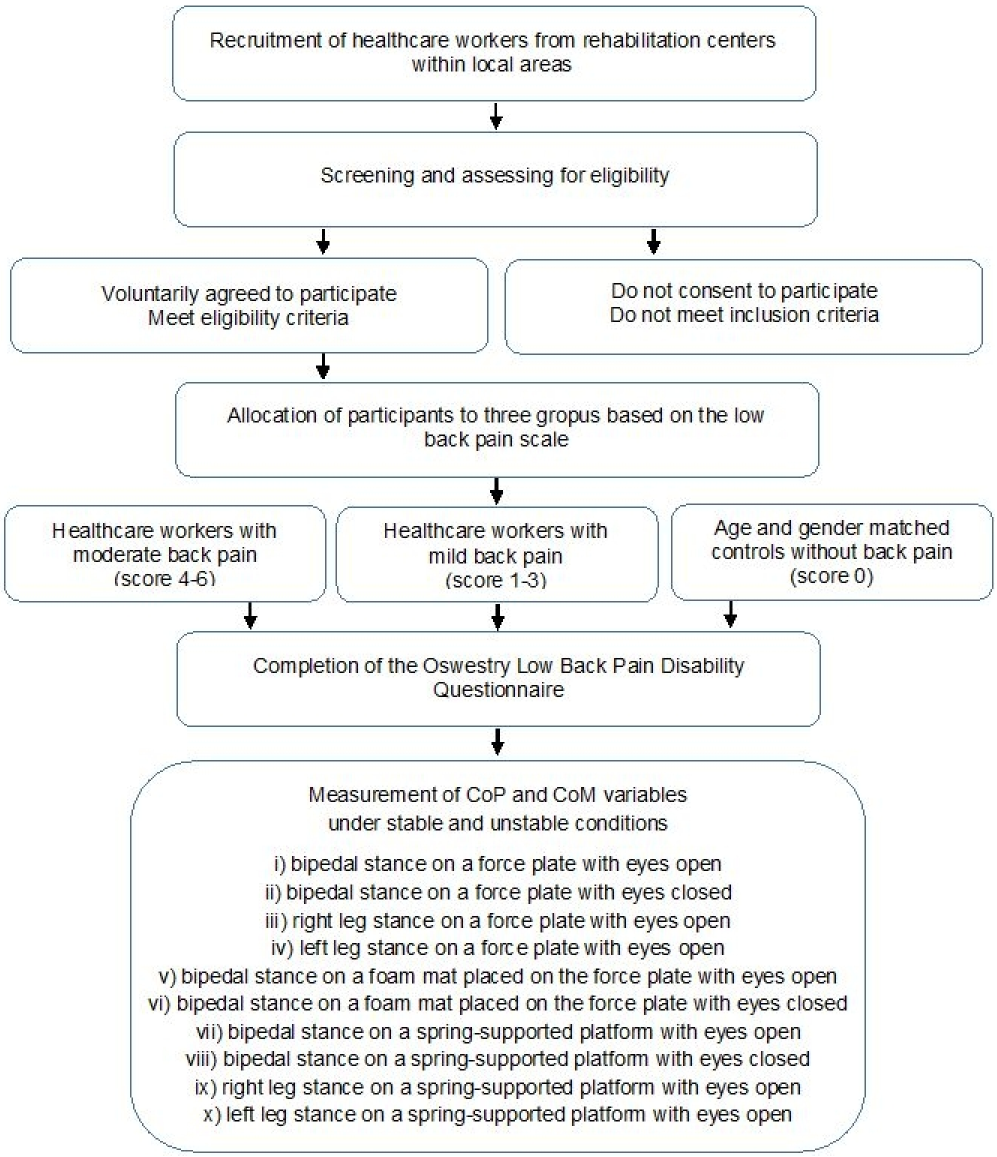
Figures

Figure 1 Flow chart of the study design.



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Simultaneous measurement of center of pressure and center of mass in assessing postural sway in healthcare workers with non-specific back pain: protocol for a cross-sectional study

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Simultaneous measurement of center of pressure and center of mass in assessing postural sway in healthcare workers with non-specific back pain: protocol for a cross-sectional study

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ABSTRACT

Introduction Low back pain (LBP) is widely prevalent in healthcare workers. It is associated with impaired postural and core stability. So far, center of pressure (CoP) measures have been commonly recorded through the use of a force plate in order to assess postural stability. However, this approach provides limited information about the center of mass (CoM) movement in the lumbar region in individuals with LBP. Recent developments in sensor technology enable measurement of the trunk motion which could provide additional information on postural sway. However, the question remains as to whether CoM measures would be more sensitive in discriminating individuals with mild and moderate back pain than traditional CoP analyses. This study aims to investigate the sensitivity of CoP and CoM measures under varied stable, metastable and unstable testing conditions in healthcare workers, and their relationship with the level of subjective reported back pain.

Methods and analysis This is a cross-sectional controlled laboratory study. A group of 90 healthcare professionals will be recruited from rehabilitation centers within local areas. Participants will complete the Oswestry Disability Questionnaire. The primary outcome will be the rate their back pain on the 0-10 Low Back Pain Scale (1-3 mild pain and 4-6 moderate pain). Secondary outcomes will include variables of postural and core stability testing during bipedal and one-legged stance on a force plate, a foam mat placed on the force plate, and a spring-supported platform with either eyes open or eyes closed. Both CoP using the posturography system based on a force plate and CoM using the inertial sensor system placed on the trunk will be simultaneously measured.

Ethics and dissemination Projects were approved by the ethics committee of the Faculty of Physical Education and Sports, Comenius University in Bratislava (Nos. 4/2017, 1/2020). Findings will be published in peer-reviewed journals and presented at conferences.

52 **Keywords:** core stability, inertial sensor system, Low Back Pain Rating Scale, Oswestry
53 Disability Questionnaire, postural stability

Strengths and limitations of this study

- This is a cross-sectional study designed to investigate whether postural and core stability impairments can be revealed in healthcare workers at the early stages of low back pain.
- To get insight into postural and core stability in individuals with mild to moderate back pain, both CoP and CoM displacements will be measured simultaneously under ten different conditions (bipedal and one-legged stance on a stable, metastable and unstable platform with either eyes open or eyes closed).
- A wireless inertial sensor system placed on the trunk will be used for assessment of postural sway to examine its sensitivity in discriminating within and between-group differences under a variety of balance tasks.
- Binary stepwise logistic regression will be performed to determine which CoM measures are able to differentiate among healthcare workers with non-specific back pain and healthy controls, while the Pearson correlation coefficient will be calculated for each sway metric to evaluate their associations with self-reported ratings of back pain.
- A limitation is that the sample will consist mainly of female participants due to the higher number of women working in the healthcare sector, however in whom the prevalence rate of low back pain is high with the majority of cases occuring after starting work.

INTRODUCTION

Healthcare workers are at the highest risk of back problems[1-10] with the lower back the most frequently affected, followed by the neck, upper back and shoulders. The prevalence of low back pain (LBP) is high in both nurses and physiotherapists when compared to other health care professions. The lifetime prevalence of LBP in nurses is as high as 90%[11] and recurrence rates exceed 70%[12]. In physical therapists the lifetime prevalence ranges between 26–79.6%.[13] This is related to mainly younger females working in rehabilitation settings[13] with the majority of cases (78.3%) occurring after starting work.[14] This imbalance between their lower aerobic capacity and muscle strength[15] and physical work demands, especially high postural demands, may lead to excessive loading of the musculoskeletal system[16], hence increasing the risk of back problems. Among the major risk factors of LBP are specific handling tasks while manually moving, transferring and lifting patients.[17-25] It is also associated with awkward and static postures for an extended period of time[19,22,23,25] and frequent bending the trunk[18,19]. Aberrations of posture create a strain on ligaments and muscles that indirectly affects the curvature of the lumbar spine and may play a role in the development of LBP.[26] This leads to the impairment of postural and core stability[27] and therefore their proper assessment is important for prevention of back problems, increased workforce efficiency and overall quality of life.

So far, postural stability has been assessed using posturography systems based on a force plate measurement of the vertical-ground reaction force and computing the CoP. The CoP is calculated from horizontal moment and vertical force data generated by triaxial force platforms and represents the center of distribution of the total force applied to the supporting surface. This method allows evaluation of various aspects of postural control such as steadiness, which is the ability to keep the body as motionless as possible, and symmetry, which is the ability to distribute weight evenly between the two feet in an upright stance. However, the force platform method evaluates secondary consequences of swaying movements, not the movements themselves.[28] Increasing CoP measures do not necessarily link to postural instability.[29,30] Variables such as length, area, displacement, and velocity may be indicative of underlying neural or sensorimotor dysfunction, but CoP movements may successfully stabilize the CoM or center of gravity (CoG) over the base of support.[31] Thus, it provides limited information about the trunk motion and stability in the lumbar region, which is particularly important in LBP individuals. Lumbar extension strength, lumbar lordosis angle and lumbosacral angle decrease more in chronic LBP patients whose CoG is located posterior to the center when compared to those whose CoG is located at the center.[32] In addition, their moving speed and movement distance of the static CoG increase.[32] This takes much more effort for them to maintain a neutral position and control posture.[32] Recent meta-analysis by Sadler et al.[33] reported that a restriction in lateral flexion and hamstring range of motion as well as reduced lumbar lordosis are associated with an increased risk of developing LBP. Chronic low back pain affects the lower lumbar spine and limits the maximal range of lumbar extension. Specifically, the sacral inclination angle is larger in chronic LBP patients and this angle is related to the maximal range of lumbar extension.[34]

Therefore a novel approach is needed in functional testing of these individuals that would be more sensitive in revealing subtle impairments of both postural and core stability associated with back problems. Previously, the CoP-CoM measure was used to evaluate postural sway in populations of various ages and performance levels (e.g., ballet dancers).[31,35-37] The CoP-CoM that represents the scalar distance at a given time between CoP and CoM has been proposed for better understanding the postural control system.[38] However, the CoM acceleration can be a more convenient measure instead of the CoP-CoM measure in the evaluation of postural control.[39] Alternatively, a CoP/CoM ratio of basic stabilographic variables can be calculated from simultaneous measurement of both parameters. Most balancing skills against gravity can be framed in the CoP–CoM interplay and can be modelled as a combination/alternation of two basic intermittent stabilization strategies: the standard CoP stabilization strategy, where the CoM is the controlled variable and the CoP is the control variable, and the CoM stabilization strategy, where CoP and CoM must exchange their role because the range of motion of the CoP is strongly constrained by environmental conditions.[40] While the CoP is acquired from the force plate, the CoM movement is monitored by optical cameras using the markers placed on the body. This parameter can be extracted with a 3D motion analysis system utilized in a research setting. However, this system is costly, time-consuming, requires skilled staff and it is not suitable for routine balance testing in daily practice. Therefore user-friendly, portable and low-cost diagnostic systems well suited for testing in the field in a relatively short time period is required.

Recent developments in measurement technology (wireless inertial sensors, BioStamp sensor, Kinect depth camera etc.) enable the measurement of CoM trajectories and can constitute an alternative to the posturography systems based on force platforms.[41-44] Though an estimate of the CoM is somewhat difficult to obtain, trunk sway can be measured through an inertial measurement unit fixed onto the trunk. It provides similar variables as postuprography systems based on force platforms.[45] Data obtained through inertial sensors are valid and reliable and can be useful for balance assessment in healthy adults[46-50], older people[46,51,52], patients with various diseases[53-58], as well as athletes[59]. Yet, there is a lack of information concerning their use in healthcare workers and their ability to reveal differences in core stability between individuals with mild to moderate back pain and healthy controls consistent with the force plate measurement.

Therefore, further research is needed to determine the sensitivity of novel testing methods of core stability within samples of healthcare workers prone to back pain which would provide more information on control and regulation of CoM position than traditional CoP analyses. The purpose of this study will be to investigate within and between-group differences in CoP and CoM sway in healthcare workers with and without mild to moderate back pain. A secondary aim will be to examine the relationships between CoP and CoM measures and the level of subjective reported back pain. We will test the hypothesis that CoM measures recorded by an inertial sensor system would be more sensitive in revealing impaiments of postural and core stability in individuals with back problems than typically used CoP analyses, and that it would be associated with mild to moderate level of back pain which is more difficult to identify using traditional methods assessing postural sway.

METHODS AND ANALYSIS

Study design

This study will adopt a cross-sectional research design comparing CoP and CoM measures under a variety of testing conditions in healthcare workers with and without non-specific back pain, and investigating their relationship with subject's pain rating score. We are planning to assess 90 participants in 10 different balance tasks with simultaneous measurement of force plate and inertial sensor variables. The timetable will be specified when the coronavirus crisis is over. The study will be implemented and reported in line with the SPIRIT statement.

Participants

A group of 90 healthcare female and male professionals, namely physiotherapists, will be recruited from rehabilitation centers within local areas (Figure 1). Those who will report non-specific back pain[60,61] with duration of less than 6 weeks (acute), between 6 and 12 weeks (sub-acute) and for more than 12 weeks (chronic)[62-65] will be eligible to participate in the study. Inclusion criteria for LBP and healthy individuals will require no history of neurological or orthopedic conditions that might influence balance. Individuals who had previously undergone surgery or other medically invasive procedures for LBP will be excluded from participation in the study. The participants' characteristics will be sumarized prior to the testing.

Upon arrival at the laboratory, participants will be verbally informed of the main purpose of the study, procedures, risks and benefits, confidentiality, the voluntary nature of their participation and provided an opportunity to ask questions. Written informed consent will be obtained from all participants prior to inclusion. All information and data obtained will be anonymized and stored in password-protected computers, which will only be accessed by the researchers.

Assessment of participant's level of back pain

The Numerical Pain Rating Scale (NPRS) for pain intensity and the Oswestry Disability Index (ODI) for functional status will be used in the proposed study.[66]

Participants will be divided into two groups based on the Low Back Pain Rating Scale, which is widely used in the medical settings to collect information about the level of patient's pain.[67] The NPRS is valid and reliable[68], has good sensitivity and generates data that can be statistically analysed[69]. A 2-point change on the NPRS represents clinically meaningful change that exceeds the bounds of measurement error.[70] The scale ranges from 0 to 10, with 0 being no pain at all and 10 being unbearable pain. Participants experienced mild pain (pain score 1-3), which does not interfere with most activities and is easy to manage both physically and psychologically, and moderate pain (pain score 4-6), which interferes with many activities of daily living and requires changes to daily lifestyle to manage pain symptoms for the last three months, will be considered. The third group (age-matched ±2 years) will include healthy participants reporting no pain. To better differentiate between no pain and pain of different intensities, the scale will be more precisely described, as follows: no pain (0), faint pain (1), mild pain (2), moderate pain (3), uncomfortable pain (4), distracting pain (5), and distressing pain (6).

Participants will also complete the Oswestry Low Back Pain Disability Questionnaire, which is considered the 'gold standard' of low back functional outcome tools and gives a subjective percentage score of level of function (disability) in activities of daily living[71]. Measurements obtained with the Oswestry Disability Questionnaire are reliable and have sufficient width scale to reliably detect improvement or worsening in most subjects[72]. A recent critical assessment of various scales for low back pain by Garg et al.[73] revealed that Oswestry Disability Index (ODI) have good construct validity, reliability and responsiveness over short intervals. Additional information associated with back pain will be also obtained (e.g., the amount of daily practice with clients, sporting activities, previous injuries and diseases etc.).

Procedures

Participants will be requested to avoid any strenuous exercises prior to the study. Before testing, participants will be given a visual demonstration of the proper exercise technique and will be informed of the instructions during testing. In order to eliminate the learning effect, they will be encouraged to practice (1–2 trials) of the measurement procedure beforehand.

Afterwards, participants will be asked to stand barefoot on a force plate with their arms relaxed comfortably at their sides. They will be instructed to stand in an upright position with their feet abducted at 10° and their heels separated mediolaterally by a distance of 6 cm. A series of trials will be conducted in a randomized order under varied conditions: 1) bipedal stance on a force plate with eyes open, 2) bipedal stance on a force plate with eyes closed, 3) right leg stance on a force plate with eyes open, 4) left leg stance on a force plate with eyes open, 5) bipedal stance on a foam mat (Airex Balance Pad) placed on the force plate with eyes open, 6) bipedal stance on a foam mat (Airex Balance Pad) placed on the force plate with eyes closed, 7) bipedal stance on a spring-supported platform with eyes open, 8) bipedal stance on a spring-supported platform with eyes closed, 9) right leg stance on a spring-supported platform with eyes open, and 10) left leg stance on a spring-supported platform with eyes open. Participants will perform three 120 s trials under each condition.[74,75] A 5-min break will be allowed after every three trials. However, during more demanding tasks (i.e., one-legged stance on a spring-supported platform) a 120 s trial will be interrupted by short rest periods (2 sets of 60 s trials or 4 sets of 30 s trials depending on the task difficulty). Ten balance tasks will be randonly conducted over two 90-min sessions.

Measurement of CoP variables under stable and unstable conditions

Basic parameters of postural sway under stable conditions (i.e., mean CoP position in the X- and Y-axis, mean CoP velocity, mean CoP acceleration, mean CoP trace length, mean distance from the middle of the CoP, mean squared distance from the middle of the CoP, and area of CoP trace) will be registered by using a FiTRO Sway Check (FiTRONiC, Bratislava, Slovakia). The system measures the actual force in the corners of the force plate and calculates an instant position of the CoP (sampling rate: 100 Hz, 12 bit AD signal conversion, resolution of the CoP position: less than 0.1 mm, measuring range: 0-1000 N/s, non linearity: +/- 0.02% FS, combined error: 0.03%, sensitivity: 2mV/V +/- 0.25%, overload capacity: 150%/sensor). Analyses of repeated measurements revealed that reliability of CoP variables is good to excellent with no significant day-to-day changes. The Romberg quotient (EC/EO sway ratio) will also be calculated.

Under unstable conditions, variables of postural sway will be registered by using the FiTRO Sway Check system (FiTRONiC, Bratislava, Slovakia). The device consists of a square platform supported by 4 springs with an elasticity coefficient of 40 $N.mm^{-1}$. Shifting the CoM in the horizontal plane leads to changes of body weight distribution to the 4 corners of the platform. Force acting in each corner is calculated as a product of the coefficient of elasticity of the spring used and vertical distance measured by means of a fine sensor. The analog signals are AD-converted and sampled by computer at the rate of 100 Hz. Calculations of instant CoP position is based on force distribution to the 4 corners of the platform. Basic parameters of postural sway (i.e., mean CoP velocity and mean CoP displacements in medio-lateral and anterior-posterior directions) will be analysed. A previous study revealed that such unstable conditions improve the discriminatory accuracy of balance tests, thereby better differentiating between groups of various ages, i.e. young adults (aged 19-24 years), early middle-aged adults (aged 25-44 years) and late middle-aged adults (aged 45-64 years).[76] Comparing with static balance tests with eyes open and eyes closed (AUC = 0.66, 95% CI = 0.62–0.69 and 0.70, 95% CI = 0.65–0.74, respectively), testing of postural stability while standing on a spring-supported platform increased significantly the discriminatory power (AUC = 0.82, 95% CI = 0.78–0.86; P = 0.006 and 0.87, 95% CI = 0.84–0.90; P = 0.009, respectively). It is therefore likely that assessing postural sway under such unstable conditions would be more sensitive in discriminating healthcare workers with and without mild to moderate back pain.

Measurement of CoM variables under stable and unstable conditions

Simultaneously, the CoM variables will be measured using the Gyko inertial sensor system (Microgate, Bolzano, Italy) fixed with an elastic belt on the participant's posterior trunk, near the body CoM. The height of the Gyko device positioned on the trunk will be set up before measurement in order to avoid its influence on data obtained.[77] The Gyko system consists of 3D accelerometer for measurement of linear accelerations to which the device is subjected, 3D gyroscope for measurement of angular velocities of the device, and 3D magnetometer for measurement of a magnetic field to which the device is subjected. It provides data measurements up to 1000 times per second (1 kHz) which guarantee their high temporal resolution. On the basis of these data, specific software algorithms describe the kinematics of the analysed body segment. It determines three main measures of body sway: sway length and area, sway travel speed, and sway frequency. Recent study by Jaworski et al.[78] showed moderate to good relative reliability scores for all the postural stability measures, with ICC values ranging from 0.62 to 0.70. For most of the analysed variables, SEM% ranged from ~10% to 14%.

Statistical Analyses

Statistical analysis of the collected data will be performed using the SPSS program for Windows, version 24.0 (SPSS, Inc., Chicago, IL, USA). The hypothesis of normality will be analysed via the Kolmogorov-Smirnov test. A parametric analysis will be performed when the data is normally distributed. The sample size calculation conducted with $\alpha = 0.05$ (5% chance of type I error) and $1 - \beta = 0.80$ (power 80%) and using the previous results that showed variations in sway variables among groups of various ages and levels of physical fitness indicated a sample size of 27 per group. Given that the goal of postural and core stability assessment is to track their subtle impairments in healthcare workers with mild to moderate back pain, stepwise multivariate binary logistic regression will be performed to determine whether CoM measures obtained by an inertial sensor system are able to differentiate among these groups and healthly controls even more sensitively when compared to the accuracy of CoP measures. The healthcare groups will be used as the dependent variable while sway metrics will be used as independent variables. Two-way analysis of ANOVA (group x condition) will be performed to determine between-group differences in CoP and CoM variables. A Bonferroni pairwise correction will be applied to mitigate the multiple-comparison bias. Between-group effect sizes (Cohen's d) will be calculated by using a pooled standard deviation. An effect size of 0.80 and higher is considered as large, 0.50–0.79 as medium, 0.20–0.49 as small and 0–0.19 as trivial.[79]

Associations between the Oswestry Disability Index and CoP and CoM measures under a variety of testing conditions will be assessed using Pearson's product moment correlation coefficient (r). Values of r = 0.10 indicate a small, r = 0.30 a medium and r = 0.50 a large correlation. A standard multiple regression analysis will be conducted to determine which independent variables of postural and core stability are significant predictors of back pain. The amount of variance explained will be reported by the coefficient of determination (r^2). The level of significance will be set at α = 5%. Data will be presented as mean ± standard deviation (SD).

Patient and public involvement

Patients and the public will be not directly involved in the present study. Local medical centers will provide support for recruitment of healthcare workers with non-specific back pain. Test results will be provided to participants on request and the overall outcomes will be available to them on completion of the study.

Ethics and dissemination

The procedures described are in accordance with the ethical standards on human experimentation stated in compliance with the 1964 Helsinki Declaration and its later amendments. Projects were approved by the ethics committee of the Faculty of Physical Education and Sports, Comenius University in Bratislava (Nos. 4/2017 and 1/2020). Findings will be published in peer-reviewed journals and presented at scientific conferences.

DISCUSSION

The present study will address the issues of sensitivity of CoP and CoM measures in revealing subtle impairments of postural and core stability in healthcare workers with mild to moderate back pain. It will also provide insight into the relationships between these measures and their level of subjective reported back pain. We assume that roughly measurement of CoM displacement by means of an inertial sensor system placed on the trunk will be capable distinguishing within and between-group differences much better as compared to the force plate-based measurement. We also propose stronger associations between CoM measures and the level of their back pain than current methods based on a force platform analysis of CoP sway.

Though posturography systems based on force plate postural sway assessments are considered the gold standard, they are relatively expensive, immobile and may not be practical for field testing. Inertial sensors represent an easy to administer and low cost method feasible for core stability testing outside research settings. The sensor can be attached to the upper[80,81] and/or lower back[82-84], which yields additional information about the trunk motions. However, data obtained in healthcare workers with back problems, especially those at the early stages of low back pain are sparse. Therefore there is a need to confirm the usefulness of inertial sensors in this population in order to reveal slight impairments of postural and core stability and so support strategies for preventing chronic back pain. Given that the goal of balance control is to maintain the CoM within the limits of stability, its measurement may provide better insights into the mechanisms of both postural and core stability[85], especially in individuals with low back pain. However, some studies have found that sway metrics derived from accelerometers[86] or the BioStamp sensor[43] are unable to separate mildly impaired individuals with multiple sclerosis from healthy controls in challenging balance conditions. In this regards, a recent systematic review by Ghislieri et al.[87] highlighted that efforts in the validation of wearable inertial sensors for assessing balance against traditional posturographic approaches should focus on the evaluation of the sensitivity of the outcome measures.

The strength of this study will be that CoP and CoM measures will be registered simultaneously under ten different testing conditions (bipedal and one-legged stance on stable, metastable and unstable platform with either eyes open or eyes closed). This will allow the estimation of sensitivity of postural and core stability testing in discriminating within and between-group differences among various balance tasks. This will be supported by investigating the relationship between these measures and the level of back pain in healthcare workers. The sample will consist not only of older healthcare workers who often experience back problems, but also their younger conterparts because the majority of back pain occurs in female physical therapists working in rehabilitation settings[13] after starting work.[14] Adding measurement of trunk sway in the functional testing of healthcare workers using wireless inertial sensors could identify back problems earlier and more efficiently, thus addressing them well before chronic back disorders occur. This novel approach may offer unique advantages by regular assessment of both postural and core stability without the restrictions of a laboratory environment.

The weakness is that a sample will most likely consist mainly of female participants due to the higher number of women working in healthcare sector. Further research should therefore be focused on investigation of subtle variations of trunk sway and its underlying individual characteristics in male healthcare workers with non-specific back pain using the inertial sensors fixed on lower and/or upper part of their posterior trunk. The sensitivity of this method to reveal changes in postural and core stability in this population over a period of time should also be investigated.

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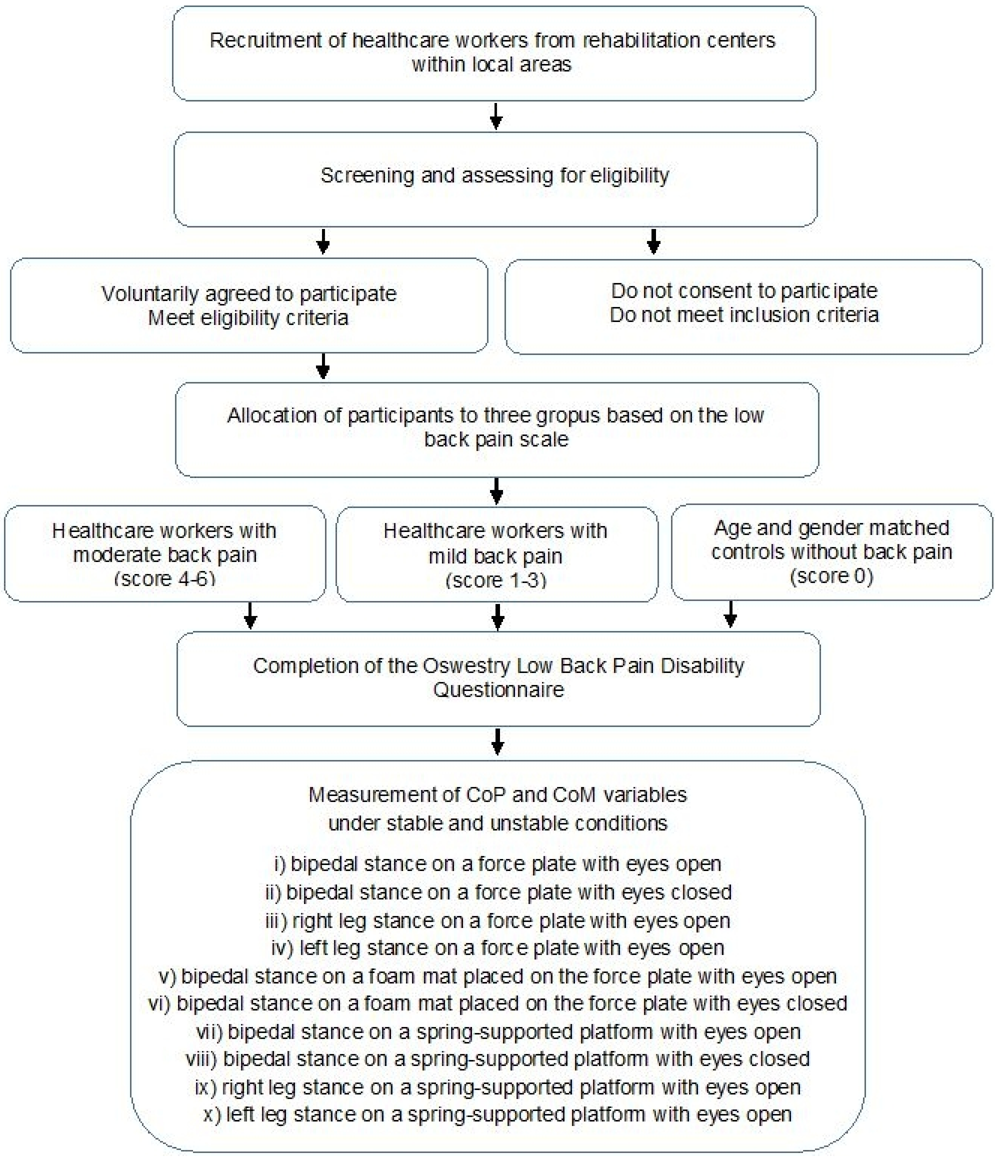
Figures

Figure 1 Flow chart of the study design.



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