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The relationship between lumbopelvic flexibility and sitting posture in adult women

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ABSTRACT

Clinical observations have suggested that limited hamstring flexibility may be associated with sagittal spinal curvatures in spine flexed postures. Thus, limited hamstring flexibility may be related to large amounts of spine flexion in "slumped" sitting postures which could contribute to low back pain and injury. The aim of this study was to determine if hamstring and pelvic flexibility are associated with flexed sitting postures using a backless office chair. Forty-one healthy female adults aged 18–69 years were recruited. Subjects performed the Sit-and-Reach test to determine maximum flexibility values and lumbar and pelvic angles were measured with accelerometers. Participants then completed a standardized typing task for a 10-minute sitting trial at an ergonomically adjusted workstation. The results showed no association between hamstring flexibility and seated lumbar spine and pelvic angles ($p = 0.999$, $\eta^2 = 0.000$; $p = 0.901$, $\eta^2 = 0.006$). Greater pelvic flexibility was associated with a more upright lumbar sitting posture ($p = 0.023$; $\eta^2 = 0.132$) but with no specific pelvic sitting posture ($p = 0.660$; $\eta^2 = 0.005$). Different movement strategies during the Sit-and-Reach test were detected: all participants moved through their lumbar spine; but only those with 'excellent' flexibility also used their pelvis. Individuals in the 'excellent' flexibility group were significantly shorter than those with 'poor' and 'good' flexibility ($p = 0.020$; $\eta^2 = 0.190$). In conclusion, hamstring flexibility does not influence sitting posture but pelvic flexibility does. Other factors such as acetabulofemoral joint limitations, consciousness of posture, or the seat itself may also influence sitting posture. Different movement strategies as well as height appear to contribute to the Sit-and-Reach test which should be researched further.

1. Introduction

The introduction of computers and mobile technology has changed the way many occupational tasks are done, resulting in increased periods of prolonged sitting (Egger, Vogels, & Westerterp, 2001; Jans et al., 2007). This means that most people spend much of their workday in flexed spine postures. Research suggests that decreased activity in the general population is related to a higher prevalence of musculoskeletal pain, noting that sedentary behaviour is associated with higher instances of lower back pain (LBP) (Amorim et al., 2017). LBP is one of the major healthcare issues faced by society (Hoy et al., 2012): it is the leading cause of years lived with disability globally (Hartvigsen et al., 2018) and has a very high (70–85%) lifetime chance of development (Andersson 1999). LBP is also one of the leading causes of lost work time and productivity (Goetzel et al., 2003) and accounts for 25% of all workplace injuries and 40% of workplace-associated costs (Reeves et al., 2005).

Sitting involves a large amount of hip and low back flexion, with spine angles shown to approach 70% of the maximum flexion range in office chairs (De Carvalho et al., 2017). This may be a problem, since increased flexion has been linked to increased intradiscal loading (Nachemson, 1966) and weakened posterior lumbar structure, which are all contributing factors to increased risk of LBP development (Corlett, 2006). It has been suggested that the primary curvatures of the spine should be maintained in the sitting position, namely the concave curve of the low back (lordosis) and the convex curve of the upper back (kyphosis), to avoid overly flexing the spine (Drzał-Grabiec et al., 2016). More neutral sitting postures allow the lumbar spine to adopt a position of minimal tissue strain and allow for even distribution of loads throughout the spine (Scannell & McGill, 2003). Therefore, minimizing spine flexion in sitting is often the goal of chair designers and therapists

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alike. But what if there are internal constraints to adopting more neutral spine postures in sitting? Clinical observations have suggested that the extensibility of the hamstring muscles may be associated with specific sagittal spinal curvatures in trunk flexion, such as flattened or exaggerated low back curves (López-Miñarro et al., 2009). The hamstrings are considered to be knee flexors and hip extensors, contracting to tilt the pelvis posteriorly (Bencardino, & Mellado, 2005). Due to the hamstrings' attachment to the ischial tuberosity this muscle group is considered to influence lumbopelvic flexibility (Kendall, McCreary, Provance, Rodgers, & Romani, 2005). Studies have supported this observation, showing that shortened hamstring muscles lead to decreased pelvic tilt in trunk flexion (Gajdosik, Hatcher & Whitsell, 1992; Reis and Macedo, 2015) and handling tasks (Carregaro & Coury, 2009).

Essentially because of the linkage between the pelvis and spine, tight hamstrings could theoretically constrain the position of the pelvis in seated postures. This constraint on pelvic motion could theoretically translate to the lower lumbar vertebral joints also affecting their posture. Delisle, Gagnon, & Sicard (1997) described this in a study where posterior pelvic tilt affects sagittal spinal curve resulting in more flexion in the lumbar spine. This results in an altered posture of the intervertebral joints which consequently changes the loading patterns experienced by these joints. Therefore, a lack of joint mobility has the potential to interact with biomechanical loading, causing changes in pressure distribution in the spine and potentially leading to spinal disorders (da Silva Dias and Gómez-Conesa, 2008). A study comparing hamstring muscle length and pelvic tilt reflects this theoretical pathway, suggesting that limited hamstring flexibility has been associated with lower back pain during dynamic forward bending in healthy individuals (Fasuyi et al., 2017). This finding was different from earlier work by Rafty and Marshall (2012) who did not find reduced hamstring flexibility to be a factor in low back pain development. These contradictory findings suggest the need for more research about the influence of lumbopelvic biomechanics on posture and pain. Specifically, it is not known whether or not hamstring flexibility influences the spine posture adopted during sitting. Therefore, the purpose of this study was to determine if hamstring flexibility and pelvic flexibility, as measured by the Sit-and-Reach (SR) test, influence lumbar and pelvic postures adopted during a short exposure to office chair sitting. A secondary outcome was to examine the contributions of the pelvis and lumbar spine in total forward bending during spine flexion.

2. Methods

2.1. Participants

Forty-one healthy females, with no musculoskeletal injuries, were recruited from the local population. Exclusion criteria included neurological or orthopedic disorders affecting posture or flexibility. The study only included females to minimize variation since hamstring flexibility has been shown not to be comparable between males and females (Muyor et al., 2014) and to increase the statistical power of our sample. Participant characteristics are included in Table 1. This study received ethical approval from the local Health and Research Ethics Approval Board and all participants completed the informed consent process prior to participating.

2.2. Instrumentation

Global physical activity questionnaire (GPAQ). The Global Physical Activity Questionnaire, appropriate for young and middle-aged adults (18–65 years), was collected to measure habitual practices of physical activity. This tool consists of sixteen activity questions grouped into three domains: activity at work, traveling to and from places, and recreational activities.

Health screening form. A customized questionnaire developed for this study was used to gather information regarding the current status of the participant's health in terms of LBP and neurological and orthopedic disorders in order to confirm inclusion/exclusion criteria. The questionnaire asked for past episodes of back injury, infection, arthritis, or spine surgery. Furthermore, the questionnaire also required participants to rate the current level of low back pain on a 100 mm visual analog scale (VAS) with anchors of 0 = "no pain" to 100 = "worst pain imaginable".

Accelerometers. To provide lumbar spine and pelvic flexion angles, two tri-axial accelerometers (ADXL335, Analog Devices, Norwood, MA, USA) were fixed to the skin overlying the spinous processes of the first lumbar vertebrae (L1) and second sacral vertebrae (S2) spinous processes in the +y down orientation using double sided tape. Accelerometer data were collected continuously during each trial, sampled by a 16-bit A/D board at a frequency of 32 Hz (Optotrack Data Acquisition Unit, NDI, Waterloo, ON, Canada).

Sit-and-reach (SR) test. The SR test was conducted to test hamstring flexibility as well as pelvic and spinal range of motion during forward bending (Fig. 1). The subject sat on the floor while keeping the legs straight and then bent forward as far as possible. The feet were placed barefoot against a box that had a ruler on top measuring in centimeters extending 15 cm over the end of the box. The subject reached as far as possible and the distance reached with the fingertips was measured to determine hamstring flexibility. The test was performed slowly to minimize stress on the low back and reduce risk of injury. The SR test has an acceptable reproducibility and a moderate criterion-related validity with an intraclass correlation coefficient of 0.92 (0.88–0.95) and a typical percentage error of 8.74 (7.55–10.43) (Ayala, de Baranda, Croix, & Santonja, 2012). In addition to the standard protocol, accelerometer data were collected during this trial to provide average lumbar and pelvic angles at the end range of motion (point of maximum hamstring flexibility).

2.3. Data collection

This study was collected between January and February 2018. All experiments were collected early in the day to eliminate variability due to diurnal effects. Participants were instructed not to engage in prolonged sitting throughout the day prior to data col-

Table 1
Average anthropometric data and the SR score, their standard deviations, p-values and effect sizes of all 39 participants based on flexibility groups.

	Flexibility Groups				
	Poor	Good	Excellent	p	η^2
SR Score (cm, SD)	15.59 (2.70)	25.69 (2.67)	37.58 (6.19)	0.000	0.806
Height (cm, SD)	172.93 (7.13)	170.97 (5.94)	163.93 (9.70)	0.016	0.206
Age (years, SD)	26.22 (13.96)	22.19 (1.47)	24.21 (9.13)	0.528	0.035
Weight (kg, SD)	75.08 (20.93)	65.80 (8.49)	65.17 (8.01)	0.135	0.105

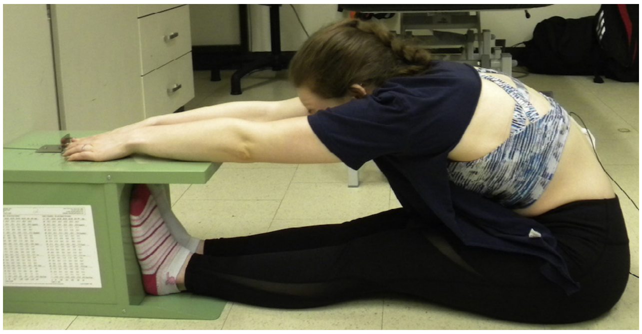

Fig. 1. Representative Sit-and-Reach test end point for one participant. Measures of lumbar spine and pelvic angles were collected during the test with two accelerometers placed on the participants back (top accelerometer visible at the right side of the picture).

Fig. 2. Representative self-selected posture of a participant during the 10-minute standardized typing trial at an ergonomically adjusted workstation.

lection and to restrain from strenuous activity 24 hours prior to testing. After arriving at the laboratory, the informed consent process was completed with the research team and then the questionnaires (GPAQ and health screening form) were completed by the participant. Participants were then instrumented with the accelerometers as described above. Sensors were further secured in place using two 2.5 inch pieces of flexible medical tape (Hypafix). The participant was instructed to flex slightly forward without achieving end range of motion to ensure that the sensors were fixed firmly and did not move with respect to the skin throughout the range of motion.

The SR test was then conducted 3 times. During each SR trial, the participant moved forward at their own pace to begin the test and verbalized once the maximum reach was obtained (Fig. 1). The maximum reach was held for 3 s during which synchronized accelerometer data were collected. The research team verbalized when the participant could relax again. A 1 minute rest period was given in between the SR trials. After the SR test, the participant was seated at an adjustable computer workstation on an office chair seat pan (backrest removed). At this time, both the workstation and chair were adjusted to each individual by the research team according to ergonomic recommendations (Occupational Safety Health Association, 2017). Specifically, the chair was adjusted so that the individual's thighs were approximately horizontal, the lower legs were vertical with both feet flat on the floor, and the torso and neck were in-line and approximately vertical. Further, the monitor was set up at a distance of 50–100 cm with a viewing angle of 15–20°. The keyboard was set up at approximately elbow height at a distance that allows the participant to keep their elbows close to their body and their forearms to be horizontal. Participants were informed that this represented the starting posture for all people in the study; however, they would be free to move as they normally would at the workstation without getting up from the seat during the trial. During the 10 minute sitting trial, participants completed a standardized typing task that consisted of copying text using a custom typing program (Matlab r2017, The Mathworks, Nattick, MA, USA) into a text box (Fig. 2). Time-varying accelerometer data were collected throughout the trial.

2.4. Data processing and analysis

The GPAQ data were reduced according to the GPAQ analysis guide. Overall energy expenditure was calculated using the metabolic equivalent with moderate intensity activities being equal to 4.0 METs and vigorous intensity activities being equal to 8.0 METs (World Health Organization, 2005).

Accelerometer data were filtered using a 2nd order Butterworth low pass filter at an effective cut off frequency of 1 Hz, calibrated with respect to gravity and then used to calculate relative lumbar (the relative angle between the L1 and S2 sensor) and pelvic tilt angles (the S2 sensor with respect to gravity) using trigonometric equations with custom written software in Matlab (Matlab r2017, The Mathworks, Nattick, MA, USA). Processed time-varying spine and pelvic angles were averaged for the 3 s SR trial (pelvic and lumbar SR angles) and the 10 minute sitting trial (lumbar and pelvic sitting angles). The average pelvic angle during the SR was then used to divide participants into two even pelvic groups: 'more anterior pelvic tilt' and 'less anterior pelvic tilt'.

SR score was measured as the fingertip distance of the outstretched arms to the nearest cm when the participant vocalized "endpoint". The value was observed and recorded by the same research team member throughout the study for consistency. The average value of the 3 trials was used for each participant. Using this averaged SR score, participants were then divided into three flexibility groups by applying thresholds following Heyward (1998): 'poor', 'good', and 'excellent'.

2.5. Statistics

All data were analyzed using SPSS version 23 (IBM corporation, Armonk, NY, USA). Descriptive statistics were presented as means and standard deviations and were calculated for all variables. A one-way general linear analysis of variance (ANOVA) was used to compare between flexibility groups (three levels: 'poor', 'good' and 'excellent') and pelvic groups ('more anterior pelvic tilt' and 'less anterior pelvic tilt') respectively for the following dependent variables: age, anthropometrics (height and weight), GPAQ score, SR score, lumbar and pelvic angles during the SR test at the end point, and lumbar and pelvic angles during the sitting trial. The level of significance was set at $p \leq 0.05$. To determine effect sizes, partial eta squared (η^2) was calculated where 0.01 is considered small, 0.06 medium and 0.14 considered large effects (Cohen, 1988). Tukey post hoc tests were conducted where necessary.

3. Results

No participants were excluded based on their responses to the Health Screening Questionnaire. Data for two participants were excluded due to a technical issue during collection. Therefore, the analyzed dataset included 39 participants.

3.1. SR Groups

The flexibility classification using the SR scores resulted in 9, 16 and 14 individuals in the 'poor', 'good' and 'excellent' groups respectively. Characteristics for these groups are presented in Table 1. SR scores were significantly different, with a large effect size, between all three flexibility groups (Table 1). Specifically, there was significantly greater flexibility in the 'excellent' group compared to the 'good' ($p < 0.001$) and 'poor' ($p < 0.001$) groups, and significantly greater flexibility in the 'good' compared to the 'poor' group ($p < 0.001$).

Height was found to be significantly different, with a large effect size, between groups (Table 1). Individuals in the 'excellent' flexibility group were more likely to be shorter than in the 'poor' ($p = 0.026$) and 'good' ($p = 0.046$) flexibility groups. A nonsignificant trend was found between flexibility groups and lumbar ($p = 0.625$; $\eta^2 = 0.026$) and pelvic ($p = 0.157$; $\eta^2 = 0.098$) angles achieved during the SR test. The 'excellent' flexibility groups moved at both the lumbar spine and the pelvic in order to reach forward while those with 'poor' and 'good' flexibility primarily reached through their back (Fig. 3). There were no significant differences between flexibility groups for lumbar ($p = 1.000$; $\eta^2 = 0.000$) and pelvic ($p = 0.918$; $\eta^2 = 0.005$) angles adopted during the 10-minute sitting trial (Fig. 4). Age ($p = 0.528$; $\eta^2 = 0.035$), weight ($p = 0.135$; $\eta^2 = 0.105$), and the GPAQ energy expenditure ($p = 0.813$; $\eta^2 = 0.011$) were also not significantly different between flexibility groups.

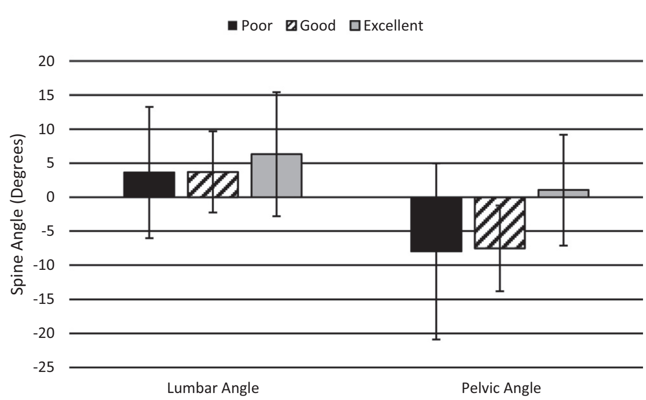

Fig. 3. Pelvic and lumbar angles during the SR test and their standard deviations (error bars) by the 3 flexibility groups. Positive values represent lumbar flexion and anterior pelvic tilt while negative values represent lumbar extension and posterior pelvic tilt. No significant differences were found between groups (lumbar $p = 0.625$ and pelvic $p = 0.157$); however, a trend was found where more anterior pelvic tilt was adopted in addition to lumbar flexion in the 'excellent' flexibility group.

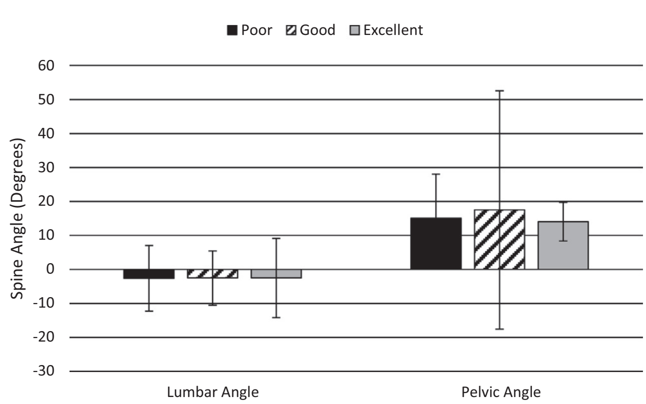

Fig. 4. Spine and pelvic angles adopted during the 10 minute sitting trial and their standard deviations (error bars) by flexibility groups. Positive values represent lumbar flexion and anterior pelvic tilt while negative values represent lumbar extension and posterior pelvic tilt. There were no statistically significant differences between flexibility groups for either lumbar ($p = 1.000$) or pelvic ($p = 0.918$) angles.

3.2. Pelvic groups

The pelvic group classification resulted in 19 individual with 'more anterior pelvic tilt' and 20 with 'less anterior pelvic tilt'. Characteristics for these groups can be found in Table 2. Participants with 'more anterior pelvic tilt' during the SR test were found to achieve a significantly greater pelvic angle during the SR than those with 'less anterior pelvic tilt' during the SR test ($p = 0.000$; $\eta^2 = 0.533$; Fig. 5). Participants with 'more anterior pelvic tilt' also achieved a significantly smaller lumbar angle ($p = 0.024$; $\eta^2 = 0.130$; Fig. 5) and a significantly greater SR score ($p = 0.008$; $\eta^2 = 0.176$; Table 2) than those with 'less anterior pelvic tilt'. During the 10-minute sitting trial, participants classified to have 'more anterior pelvic tilt' during the SR test were found to sit more upright than those with 'less anterior pelvic tilt' during the SR test ($p = 0.023$; $\eta^2 = 0.132$; Fig. 6). The pelvic angle during the sitting trial was found to vary greatly and no significance was found between the groups ($p = 0.660$; $\eta^2 = 0.005$; Fig. 6). The GPAQ energy expenditure ($p = 0.979$; $\eta^2 = 0.000$) as well as anthropometrics (Table 2) were found to be nonsignificant between the two pelvic groups.

4. Discussion

This study investigated if hamstring and pelvic flexibility, as measured by the SR test, are associated with lumbar and pelvic postures adopted during a brief sitting exposure. Our findings show that individuals classified to have 'more anterior pelvic tilt' during the SR test also sit more upright in their lumbar spine during the ten minutes of office chair sitting than those with 'less anterior pelvic tilt' during the SR test; however, the seated pelvic postures adopted were not different. A secondary purpose of the study was to examine the contributions of the lumbar and pelvic angles to the SR score. We found a trend suggesting that participants in the 'excellent' flexibility group completed the SR test moving at both the pelvis and the lumbar spine, whereas those in the other groups primarily moved through their lumbar spine; however, these differences were not statistically significant. We also found that height was significantly different between flexibility groups with shorter individuals achieving a higher SR score, suggesting they are more flexible.

The SR test is frequently used as a field test to assess lower back and hamstring flexibility due to its efficient and quick administration (Muyor et al., 2014). However, it is important to note that lumbar and pelvic angles during the SR or the similar toe-touch test can differ with different methodology such as whether a warm up is included and the method of measurement which is presented in Table 3. Our findings showed that hamstring flexibility, as measured by the SR test, does not appear to influence lumbar or pelvic angles when sitting in an office chair. Our result matches those of other research groups. Specifically, Muyor et al. (2013) did not find a relationship between hamstring flexibility as determined by a passive knee extension test and sitting posture in male cyclists. These findings suggest that pelvis and spine angles during sitting may instead be influenced by other factors such as hip mechanics, acetabulofemoral joint restrictions, seat type, or awareness of posture. However, these findings should be considered with caution as recent studies suggest that the SR score is not a good predictor of hamstring flexibility. Rather, it has been suggested that the pelvic angle during the SR test should be used to predict hamstring flexibility (Mier & Shapiro, 2013). Our study found no significant

Table 2
Average anthropometric data and the SR score, their standard deviations, p-values and effect sizes of all 39 participants based on pelvic groups.

	Pelvic Groups			
	More anterior pelvic tilt	Less anterior pelvic tilt	p	η^2
SR Score (cm, SD)	31.66 (9.85)	23.80 (7.49)	0.008	0.176
Height (cm, SD)	167.54 (7.82)	170.19 (9.03)	0.336	0.025
Age (years, SD)	25.47 (12.01)	22.30 (1.75)	0.251	0.035
Weight (kg, SD)	66.96 (16.87)	68.43 (6.92)	0.721	0.003

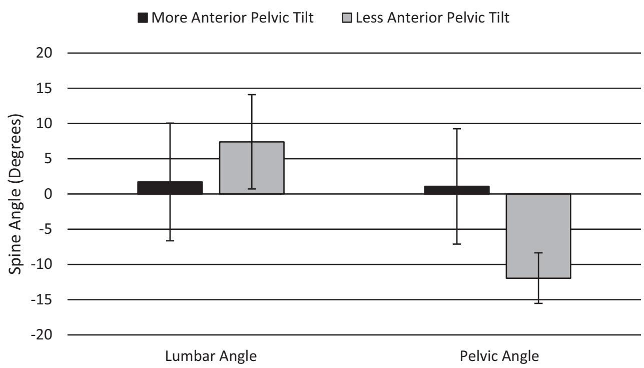

Fig. 5. Spine and pelvic angles adopted during the SR and their standard deviations (error bars) by pelvic groups. Positive values represent lumbar flexion and anterior pelvic tilt while negative values represent lumbar extension and posterior pelvic tilt. There were statistically significant differences between pelvic groups for both lumbar (p = 0.024) and pelvic (p = 0.000) angles.

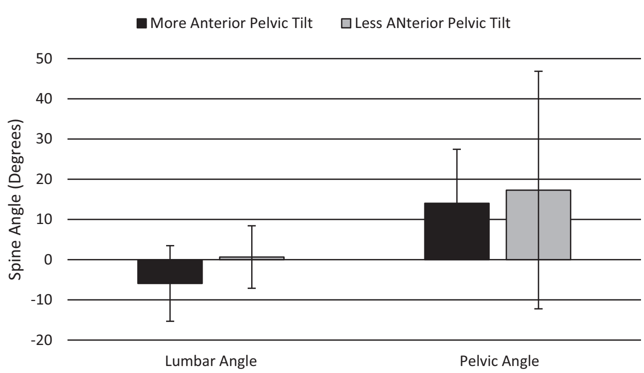

Fig. 6. Spine and pelvic angles adopted during the 10 min sitting trial and their standard deviations (error bars) by pelvic groups. Positive values represent lumbar flexion and anterior pelvic tilt while negative values represent lumbar extension and posterior pelvic tilt. There were statistically significant differences between pelvic groups for lumbar (p = 0.023) but not pelvic (p = 0.660) angles.

differences between the flexibility groups for pelvic and lumbar spine angles measured at the endpoint of the SR test suggesting that there is no relationship between the SR score and pelvic and lumbar spine angles. Thus, our test might not have been the best method to estimate hamstring flexibility. The SR score may have instead been influenced by other factors such as shoulder protraction, thoracic spine curvature, or height.

An interesting finding in this study was the identification of different movement strategies adopted to reach during the SR test. All participants reached forward by flexing their low back during the SR test, however, only those with 'excellent' flexibility completed the SR test moving through both their pelvis and lumbar spine. This difference suggests that less flexible individuals may not be able to utilize their pelvis and rely more on lumbar spine flexion during forward bending. Specifically, while the pelvic angle differed between the flexibility groups, all three groups achieved similar lumbar angles during the SR test supporting Gajdosik et al. (1992) findings that the pelvic angle during forward bending does not influence the lumbar angle. This is contrary to Mier & Shapiro (2013) who showed that during the SR test individuals utilize their lumbar spine more to compensate for decreased pelvic flexibility. Considering our pelvic groups, Mier & Shapiro's (2013) finding may be more applicable. The pelvic group with 'less anterior pelvic tilt' during the SR test achieved a greater lumbar angle during the SR than the group with 'more anterior pelvic tilt' during the SR test but did not manage to achieve a similar SR score. This suggests that individuals with limited pelvic flexibility bend more through their lumbar spine but cannot make up for their pelvic limitations. However, considering the findings of both flexibility and pelvic groups together, this may just mean that lumbopelvic flexibility is first achieved in the lumbar spine and only when the overall lumbopelvic flexibility is improved, this improvement is created in the pelvis. Future studies should analyze the different movement patterns during the SR test and how they influence sitting posture.

The significant difference found between flexibility groups for height suggests that shorter individuals are more flexible. This result, with a large effect size, contradicts previous findings in the literature conducted with a similar population, where anthropometrics were not found to have an effect on SR values (Simoneau, 1998). Slightly different methods including a warm up period could account for Simoneau's (1998) contradictory findings; however, our findings do support the notion that other factors than hamstring flexibility influence the SR score. Shorter individuals may after all have an advantage in the SR test as anthropometrics allow them to achieve a higher reached score. As neither of these suggestions can be said with certainty, this area should be explored further. Specifically, it should be investigated what factors, other than flexibility, influence the SR score and whether differences in flexibility can be attributed to a specific body region such as hamstring flexibility, lumbar or thoracic spine mobility, or shoulder mobility.

Based on our observations that the SR may not be the best method to estimate hamstring flexibility and Mier & Shapiro's

Table 3
Comparison of lumbar and pelvic angles in the toe-touch test and SR in similar female populations. Pelvic angles were adjusted for comparability while that was not necessary for the lumbar angle.

Study	Type of Flexion	Lumbar Angle	Pelvic Angle	Adjusted Pelvic Angle	Sensor Placement/Warmup
Current Study	SR	4.20 (8.34)	−5.56 (8.93)		L1, S2/ No
Mier & Shapiro, 2013	SR	19.8 (7.6)	109.3 (13.7)	19.3 (13.7)	T12, L5/ Yes
López-Miñarro et al. (2009)	SR	30 (8)	92 (13)	−2 (13)	T12, L5/ Yes
Pries et al. (2015)	Toe-touch test	17.6 (8.3)	99.4 (13.2)	Approx. −9.4 (13.2)	L1, S1/ No

(2013) suggestion that that the pelvic angle during the SR may be a better predictor of hamstring flexibility than the SR score, participants were split into two pelvic groups. Our findings suggest that pelvic and lumbar angles achieved during the SR as well as the SR score are in some way associated with the movement pattern trend as discussed above. Further, the pelvic angle achieved during maximum forward flexion seems to be associated with the lumbar angle during the 10-minute sitting trial. However, the pelvic sitting angle varied greatly in both groups. The association between pelvic groups and the lumbar sitting angle could mean that individuals with a greater anterior pelvic tilt rely less on their lumbar spine for flexion and carry this over into sitting. At the same time, the varying lumbar angles could be explained by different levels of leaning forward or backward of the torso. However, this cannot be said with certainty and future studies should separately analyze the influence of lumbar and pelvic range of motion on sitting posture.

There are several limitations to this study. First of all, only female participants were included in the dataset which means that the findings are not generalizable to males. Secondly, the range of flexibility studied was shifted to the "greater flexibility" end of the spectrum so that we do not know what the relationship between low or significantly inferior flexibility groups would be with seated postures. Thirdly, the SR test did not capture all factors that likely play a role in flexion (namely upper body and hip kinematics) and there is evidence that the SR test may not be the best representation of hip flexibility. Future work should consider using measures that can distinguish more specifically between hamstring, hip, and spine flexibility instead and repeat the protocol for a male population to compare results. Similarly, it would be helpful to specifically examine a population of individuals with low hip flexibility, perhaps this is the end of the spectrum where seated posture constraint comes into play. This would involve the recruitment of a clinical population whom were diagnosed short hamstrings. If higher lumbar flexion angles during sitting occur in a specific spectrum, interventions could be implemented that aim to increase hamstring flexibility.

In conclusion, in adult women, pelvic flexibility is associated with lumbar spine posture but not pelvic posture during sitting in an office chair. Hamstring flexibility, as measured by the SR alone, does not appear to influence sitting posture. It has to be considered that rather than hamstring flexibility influencing pelvic angles during sitting, there may be other factors involved such as acetabulofemoral joint limitations, consciousness of posture, the degree of leaning forward/back, or the seat type itself. The lumbar sitting angle does appear to be associated with pelvic flexibility, possibly because individuals with greater "anterior pelvic tilt" can spare their lumbar spine more. Forward reaching, as in the SR test, can be achieved in different ways altering the SR score. While all participants moved with their lumbar spine, only those with 'excellent' flexibility used both their pelvis and lumbar spine to achieve their SR score. Individuals with less pelvic flexibility also utilized their lumbar spine more. Therefore, it is important to consider lumbar and pelvic flexibility separately. A different measure of hamstring flexibility should be considered to examine the relationship between hip flexibility and sitting posture. Further, future work should include a male population and/or a population with lower lumbopelvic flexibility which may provide more information on the relationship between flexibility and seated posture.

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Conflict of interest statement

None of the authors have any conflicts of interest to disclose.

References

Amorim, A.B., Levy, G.M., Pérez-Riquelme, F., Simic, M., Pappas, E., Dario, A.B., Ferreira, P.H., 2017. Does sedentary behavior increase the risk of low back pain? A population-based co-twin study of Spanish twins. Spine J. https://doi.org/10.1016/j.spinee.2017.02.004.

Andersson, G.B.J., 1999. Epidemiological features of chronic low-back pain. Lancet 354 (9178), 581–585. https://doi.org/10.1016/S0140-6736(99)01312-4.

Ayala, F., de Baranda, P.S., Croix, M.D.S., Santonja, F., 2012. Reproducibility and criterion-related validity of the sit and reach test and toe touch test for estimating hamstring flexibility in recreationally active young adults. Phys. Ther. Sport 13 (4), 219–226. https://doi.org/10.1016/j.ptsp.2011.11.001.

Bencardino, J.T., Mellado, J.M., 2005. Hamstring injuries of the hip. Magn. Reson. Imag. Clin. 13 (4), 677–690. https://doi.org/10.1016/j.mric.2005.08.002.

Carregaro, R.L., Coury, H.J.C.G., 2009. Does reduced hamstring flexibility affect trunk and pelvic movement strategies during manual handling? Int. J. Ind. Ergon. 39 (1), 115–120. https://doi.org/10.1016/j.ergon.2008.05.004.

Cohen, J., 1988. Statistical Power Analysis for the Behavioral Sciences. Erlbaum, Hillsdale, NJ.

Corlett, E.N., 2006. Background to sitting at work: research-based requirements for the design of work seats. Ergonomics 49 (14), 1538–1546. https://doi.org/10.1080/00140130600766261.

da Silva Dias, R., Gómez-Conesa, A., 2008. Shortened hamstring syndrome. Fisiot.-Barcel. 30 (4), 186–193.

De Carvalho, Grondin, Callaghan, 2017. The impact of office chair features on lumbar lordosis, intervertebral joint and sacral tilt angles: a radiographic assessment. Ergonomics 60 (10), 1393–1404. https://doi.org/10.1080/00140139.2016.1265670.

Delisle, A., Gagnon, M., Sicard, C., 1997. Effect of pelvic tilt on lumbar spine geometry. IEEE Trans. Rehabil. Eng. 1997 (5), 360–366.

Drzał-Grabiec, J., Truszczyńska, A., Fabjańska, M., Trzaskoma, Z., 2016. Changes of the body posture parameters in the standing versus relaxed sitting and corrected sitting position. J. Back Musculos. Rehabil. 29 (2), 211–217. https://doi.org/10.3233/bmr-150616.

Egger, G.J., Vogels, N., Westerterp, K.R., 2001. Estimating historical changes in physical activity levels. Med. J. Australia 175 (11–12), 635–636.

Fasuyi, F.O., Fabunmi, A.A., Adegoke, B.O., 2017. Hamstring muscle length and pelvic tilt range among individuals with and without low back pain. J. Bodywork Move. Ther. 21 (2), 246–250. https://doi.org/10.1016/j.jbmt.2016.06.002.

Gajdosik, R.L., Hatcher, C.K., Whitsell, S., 1992. Influence of short hamstring muscles on the pelvis and lumbar spine in standing and during the toe-touch test. Clin. Biomech. 7 (1), 38–42. https://doi.org/10.1016/0268-0033(92)90006-P.

Goetzel, R.Z., Hawkins, K., Ozminkowski, R.J., Wang, S., 2003. The health and productivity cost burden of the "top 10" physical and mental health conditions affecting six large U.S. employers in 1999. J. Occup. Environ. Med. 45(1), 5–14. doi:10.1097/00043764-200301000-00007.

Hartvigsen, J., Hancock, M.J., Kongsted, A., Louw, Q., Ferreira, M.L., Genevay, S., Smeets, R.J., 2018. What low back pain is and why we need to pay attention. Lancet. https://doi.org/10.1016/S0140-6736(18)30480-X.

Heyward, V.H., 1998. The Physical Fitness Specialist Certification Manual. The Cooper Institute for Aerobics Research, Dallas, TX, p. 48.

Hoy, D., Bain, C., Williams, G., March, L., Brooks, P., Blyth, F., Buchbinder, R., 2012. A systematic review of the global prevalence of low back pain. Arthrit. Rheum. https://doi.org/10.1002/art.34347.

Jans, M.P., Proper, K.I., Hildebrandt, V.H., 2007. Sedentary behavior in Dutch workers: differences between occupations and business sectors. Am. J. Prevent. Med. 33, 450–454. https://doi.org/10.1016/j.amepre.2007.07.033.

Kendall, F.P., McCreary, E.K., Provance, P.G., Rodgers, M.M., Romani, W.A., 2005. Muscles: Testing and Function, with Posture and Pain (Kendall, Muscles). Lippincott Williams & Wilkins, Philadelphia.

López-Miñarro, P.A., de Baranda Andújar, P.S., Rodríguez-García, P.L., 2009. A comparison of the sit-and-reach test and the back-saver sit-and-reach test in university students. J. Sports Sci. Med. 8 (1), 116.

Mier, C.M., Shapiro, B.S., 2013. Sex differences in pelvic and hip flexibility in men and women matched for sit-and-reach score. J. Strength Cond. Res. 27 (4), 1031–1035. https://doi.org/10.1519/JSC.0b013e3182651d79.

Muyor, J.M., López-Miñarro, P.A., Alacid, F., 2013. The relationship between hamstring muscle extensibility and spinal postures varies with the degree of knee extension. J. Appl. Biomech. 29 (6), 678–686.

Muyor, J.M., Zemková, E., Štefániková, G., Kotyra, M., 2014. Concurrent validity of clinical tests for measuring hamstring flexibility in school age children. Int. J. Sports Med. 35 (08), 664–669. https://doi.org/10.1055/s-0033-1353217.

Nachemson, A., 1966. The load on lumbar disks in different positions of the body. Clin. Orthopaed. Rel. Res. 45, 107–122.

Occupational Safety Health Association, 2017. Computer Workstation eTool. <https://www.osha.gov/SLTC/etools/computerworkstations/positions.html>.

Pries, E., Dreischarf, M., Bashkuev, M., Putzier, M., Schmidt, H., 2015. The effects of age and gender on the lumbopelvic rhythm in the sagittal plane in 309 subjects. Journal of Biomechanics 48 (12), 3080–3087.

Rafty, S.M., Marshall, P.W., 2012. Does a 'tight' hamstring predict low back pain reporting during prolonged standing? Journal of Electromyography and Kinesiology 22 (3), 407–411.
Reeves, Cholewicki, Milner, 200. Muscle reflex classification of low-back pain. J. Electromyogr. Kinesiol. 15 (1), 53–60. https://doi.org/10.1016/j.jelekin.2004.07.001.
Reis, F.J. Jandre, Macedo, A.R., 2015. Influence of hamstring tightness in pelvic, lumbar and trunk range of motion in low back pain and asymptomatic volunteers during forward bending. Asian Spine J. 9 (4), 535–540. https://doi.org/10.4184/asj.2015.9.4.535.
Scannell, J.P., McGill, S.M., 2003. Lumbar posture - Should it, and can it, be modified? A study of passive tissue stiffness and lumbar position during activities of daily living. Phys. Ther. 83 (10), 907–917. https://doi.org/10.1093/ptj/83.10.907.
Simoneau, G.G., 1998. The impact of various anthropometric and flexibility measurements on the sit-and-reach test. J. Strength Cond. Res. 12 (4), 232–237.
World Health Organization, 2005. WHO STEPS Surveillance Manual: The WHO STEPwise Approach to Chronic Disease Risk Factor Surveillance.