

Frequency Analyses of Postural Sway during Prolonged Sitting on a Large Gymnastics Ball and Stool

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Abstract Selected schools in Slovenia have launched an initiative to replace school chairs with large gymnastics balls (LGBs) in order to improve children's posture. The rationale given was that LGB affect posture in a way that is beneficial to the body because they mimic the frequencies of body movement during walking. To identify the influence of seating furniture on the frequency of postural sway, the postural dynamics of eight school children were studied. A comparison was made of their posture while they were sitting on a stool and on a LGB, each for 30 minutes. The lumbar lordosis (LL) and pelvic inclination (PI) angles were both studied. They were measured from the sagittal plane with a video measurement system (3 fps). From the time pattern of each angle, calculations were made to determine the frequency spectrum median and distribution of power in frequency spectra at four intervals: 1) 0.01–0.05 s⁻¹, 2) 0.05–0.1 s⁻¹, 3) 0.1–0.33 s⁻¹, and 4) 0.33–0.6 s⁻¹. It was determined that the median for LL is at a higher frequency on a LGB (LGB = 0.17 s⁻¹ ± 0.03 s⁻¹, stool = 0.14 s⁻¹ ± 0.03 s⁻¹, $p < 0.05$), but no differences were found in PI. Sitting on a LGB had more power in the third interval with a typical sway period of 5 s ($p < 0.05$), whereas sitting on a stool had more power in the first interval with a typical sway period of 33 s ($p < 0.05$). Sitting on a LGB influences the upper body dynamics and promotes a sitting posture with a period of sway that is closer to the sway pattern experienced during walking as compared to sitting on a stool.

Keywords: frequency spectrum, sitting dynamics, posture, measurement, seating furniture

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1. Introduction

Selected schools in Slovenia have considered partial substitution of standard classroom chairs with large gymnastics balls (LGB). It is known that poor posture during prolonged sitting is a predictive risk factor for lower back pain [1,2,3]. To reduce this possibility, a dynamic type of chair like a balance chair or LGB [4,5,6] was introduced as an alternative to a standard chair. Dynamic chairs force users into dynamic sitting, which is characterized by continuously changing posture. The rationale behind poor posture while using these chairs is that dynamically changing the posture is beneficial for users because it periodically loads and unloads different musculoskeletal segments, which reduces overload and injury, and improves nutrition of cartilage [7,8,9].

In order to evaluate the effect of dynamic seating, the sitting posture needs to be measured continuously during prolonged periods of sitting. Furthermore, the large amount of data measured needs to be processed in order to obtain parameters that are simple to understand and express characteristics of sitting dynamics in order to distinguish between the effects of different types of seats.

Various studies have evaluated the pattern of spinal posture during prolonged sitting [10]. The lumbar

flexion/extension angle was measured during sitting on a chair and analyzed to determine the preferred sitting postures that individuals changed among while sitting.

Frequency analysis is an alternative approach in analyzing human movement dynamics [11]. This kind of analysis is often used in studies of postural sway during a quiet stance [12]. Dynamic sitting requires balancing the upper body in a similar way to that used while standing. However, frequency analysis has not yet been applied in evaluating the dynamics of sitting.

This study investigated whether frequency analyses (the median of the power frequency spectrum) of pelvic inclination and lumbar spine curvature reveal a difference between sitting on a LGB and on a stool.

2. Methods

2.1. Experiment Participants

Eight schoolchildren (10–11 years old; four male, four female) with physically normal development participated in the study. Their average height was 147.2 ± 4.0 cm and their average weight was 38.0 ± 5.1 kg. A week before the measurements, a trained physiotherapist explained to them how to sit on a LGB. After initial instruction, each child sat on a LGB during classes for at least 1 day. The study

was approved by the ethics committee and parental approval was obtained for every child.

2.2. Experimental Protocol

Prior to the experiment, each child's overall height and popliteal height were measured to enable appropriate adjustment of the size of the LGB and the stool.

Children sat on a ball and on a stool during two separate sessions, each lasting 30 minutes.

The children sitting on a stool (left) and LGB (right) wore optical markers during measurements. The video was recorded in a dim environment to facilitate automatic marker position extraction.

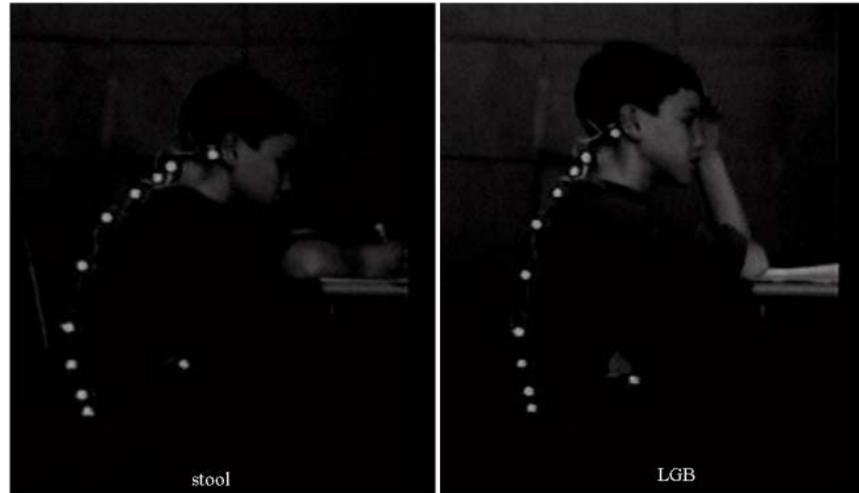


Figure 1. Optical markers in the sagittal plane

2.3. Assessment of Sitting Posture

The measurement technique has been described and evaluated in detail in previous studies [13]. In brief, the sitting posture of each child was recorded from a lateral view using a digital video camera (Figure 1). The camera was leveled on a tripod, and therefore the vertical side of the image was parallel to the direction of gravity. It was located 5 m from the child at a height of 1 m and positioned perpendicular to the plane of motion to decrease errors of perspective. Five markers constructed of a LED diode were fixed on the free end of a 2 cm long frame, as shown in Figure 2, and were positioned at the most superior parts of the spinal prominence of lumbar vertebrae L1, L3, and L5, of sacrum S2, and at the anterior superior iliac spine (ASIS).

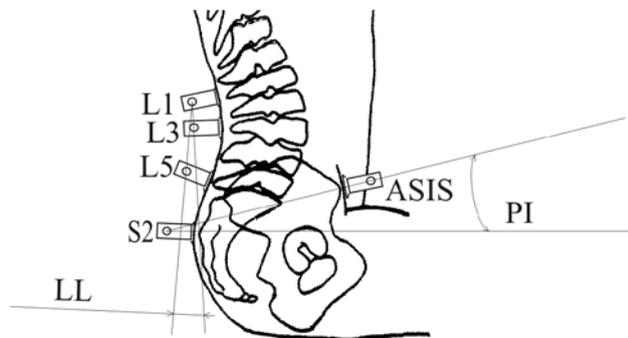


Figure 2. Definition of angles

The intensity of the light in the room was low; therefore, the optical markers were clearly visible on the recorded image. The images, which were digitized and fed into the computer with a spatial resolution of 320×280 pixels and with an acquisition rate of 3 frames per second, were analyzed to determine the position of each marker. For

this purpose, the researchers developed motion analysis software, which found the position of the marker in the first image and traced its position during the rest of the session.

Optical skin markers L1, L2, and L3 were used to define the lumbar lordosis (LL) angle; markers ASIS and S2 together with a horizontal line were used to define pelvic inclination (PI).

2.4. Definition of Angles

The marker's coordinates were used to determine two angles, which served to describe the sitting posture. The PI angle was defined as the sharp angle between the line connecting markers S2, ASIS, and the horizontal line (Figure 2). The LL angle was defined with markers L1, L3, and L5, as shown in Figure 2. The angle was considered negative in the case of kyphotic lumbar curvature.

2.5. Data Analysis

For each session measured, the researchers determined a power frequency spectrum (PFS) for the PI and LL time courses. The frequency range between $1/90 \text{ s}^{-1}$ and $3/5 \text{ s}^{-1}$ was then normalized. The median split PFS into two intervals so that the power in both was equal.

The researchers then determined the fraction of the power in four intervals: 1) $1/90-1/20 \text{ s}^{-1}$, 2) $1/20-1/10 \text{ s}^{-1}$, 3) $1/10-1/3 \text{ s}^{-1}$, and 4) $1/3-3/5 \text{ s}^{-1}$. Paired *t*-test statistics were used to compare groups between sitting on a LGB and sitting on a stool and between PI and LL.

3. Results

Altogether, 5,400 consequent values of the PI and LL angles were recorded for each session (Figure 3). The LL median of the PFS on the LGB occurs at higher

frequencies (Figure 4), which means that sitting on a LGB is characterized by higher frequency postural dynamics (LL median: LGB = $0.17 \text{ s}^{-1} \pm 0.03 \text{ s}^{-1}$, stool = $0.14 \text{ s}^{-1} \pm 0.03 \text{ s}^{-1}$, $p < 0.05$). The difference of the PI median of the power frequency spectrum is not significant (PI median: LGB = $0.13 \text{ s}^{-1} \pm 0.01 \text{ s}^{-1}$, stool = $0.13 \text{ s}^{-1} \pm 0.01 \text{ s}^{-1}$, $p > 0.05$).

Considering LL, the fraction of the power (Figure 5) in the intervals of PFS is larger in the third interval when sitting on a LGB (LGB: 4.09 ± 0.61 , stool: 3.39 ± 0.44 , $p < 0.05$) and in the first interval when sitting on a stool (LGB: 1.83 ± 0.61 , stool: 2.67 ± 0.81 , $p < 0.05$). There is no significant difference in the second and fourth intervals and there is no significant difference in PI for any interval.

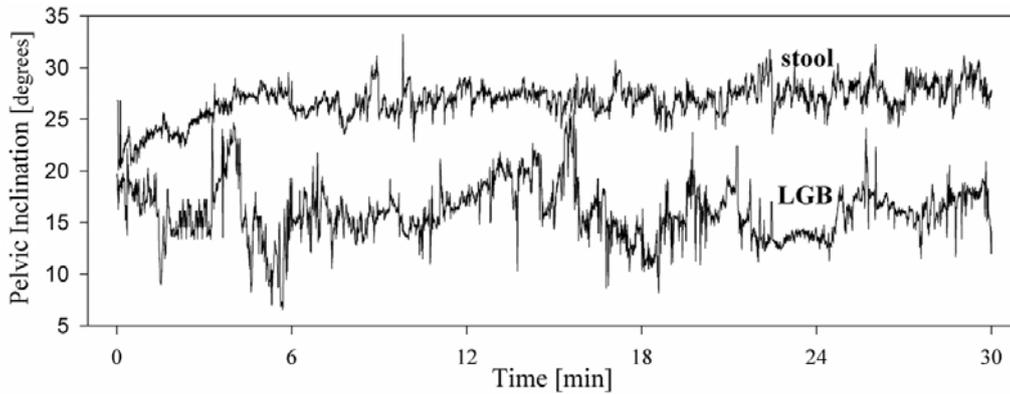


Figure 3. PI time course

The PI angle during 30 minutes of sitting on a stool (Figure 3, top line) and on a LGB (Figure 3, bottom line) was measured with an acquisition rate of 3 s^{-1} . Note that there is less fluctuation on the stool.

sway was found with a period of 33 s. These two periods represent a pattern of loading and unloading of tissues.

The nature of sitting on a LGB is that it requires maintenance of balance [14]. Posture balance maintenance resembles a standing or walking posture, in which balance must also be continuously maintained [12,15,16]. It is a matter of speculation whether the same mechanisms for balance maintenance are used in both cases.

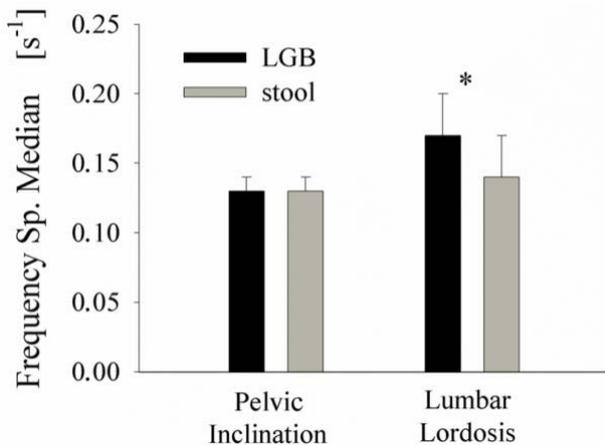


Figure 4. Frequency spectra median

Figure 4 shows that the median value of LL was found to be at significantly (*) higher frequencies when sitting on a LGB. There is no difference in PI.

Figure 5 shows the power of each interval with respect to a LGB and a stool. Intervals in units of s^{-1} are 1) $1/90-1/20$, 2) $1/20-1/10$, 3) $1/10-1/3$, and 4) $1/3-3/5$. Note the statistically significant (*) difference in the first and third intervals.

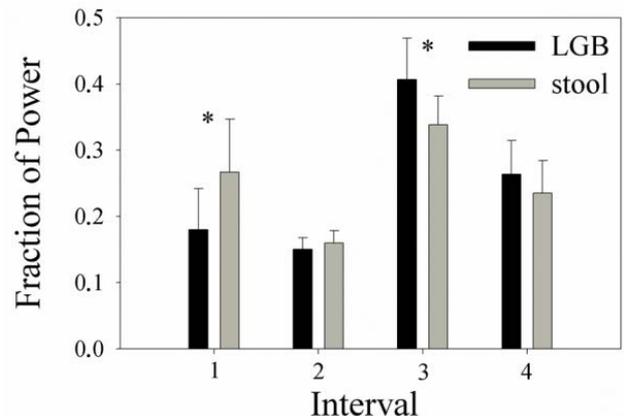


Figure 5. Four intervals of LL angle power frequency spectra4. Discussion

The human body requires movement to nourish structures such as the nucleus pulposus of the intervertebral disc and to provide periodic rest to muscles. Rotatory dynamic sitting [9,17] periodically changes the spinal load and the result is, as reported, increased spinal length.

The posture dynamics were measured from a sagittal plane, which was a limitation of this study's measurement technique. It is possible that the subjects also had sway dynamics in both the frontal and transversal plane. However, the researchers believe that dynamics in the sagittal plane demonstrate the majority of postural dynamics.

Higher frequency of sway on a LGB is associated with more frequent muscular activity. This dynamic was not

4. Discussion

This study showed that while sitting on a LGB only the upper part of the body adopts a more dynamic posture (as indicated by the LL median), whereas the PI dynamics remained fairly similar whether sitting on a LGB or a stool.

Regarding the sway of the upper body, this study found that while sitting on a LGB there is more sway with a typical period of 5 s as compared to a stool, where more

pursued in this study and warrants further investigation in the future [4,5].

Recently, in rehabilitation of children with cerebral palsy, hippotherapy was introduced based on the movement of riding a horse. It seems that riding a horse decreases the spastic tension of muscles and develops proper motor reflexes. Perhaps the same mechanism is created during dynamic sitting on a LGB.

It is expected that the effect of dynamic sitting is most pronounced when the periodicity of movements while sitting is similar to the periodicity of movements during walking because the body is well adapted to it.

5. Conclusion

With regard to the selection of the type of classroom seating, this study has demonstrated that the dynamics of sitting on a LGB have some characteristics of standing or walking, which the researchers believe is beneficial as an occasional seating substitute in the classroom [4,5,18].

This study shows the importance of frequency spectra analyses in understanding postural dynamics. It enables comprehensive integration of a large quantity of measured data.

Acknowledgments

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Statement of Competing Interests

The authors have no competing interests.

List of Abbreviations

LGB = large gymnastics ball.
 PI = pelvic inclination angle.
 LL = lumbar lordosis angle.
 PFS = power frequency spectrum.

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