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# Postural Stability of Sitting Women

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*The study examined the utility of stabilometric dimensions and explored whether the changes in sitting postures were manifested in functional measures of postural control. Eleven women participated in the study, which used 11 chair sitting postures: arms on laps or arms right angled; armrest at a height of 17, 20 and 23 cm; with or without backrest; slouch or straight back; legs right angled at knees or crossed legs. The backrest and armrest shifted 16.3% of body weight from a seat pan. The characteristics of stabilometric dimensions evaluated the influence of seat components and sitting behaviour on postural balance. The study attempted to evaluate stability and its application in human–seat interface design.*

woman     chair sitting     postural stabilometry

## 1. INTRODUCTION

Nowadays, many people work in call centres, business process outsourcing services, etc., where they adopt a sedentary lifestyle and eventually suffer from pain and discomfort. Office workers sit for many hours in different positions in various seat configurations. Wrong sitting postures damage muscles and discs leading to back pain [1]. Inappropriately designed seat components such as backrest, arm rest, seat cushions, foot rest facilities, etc., cause discomfort and impair postural stability. An ergonomically designed workstation assists to maintain efficient anatomical alignment while sitting and allows users to adopt a better posture [2]. Thus, sitting behaviour and seat components exert an influence on postural control.

Sitting dynamics depends on personal modes, sitting circumstances and seat configurations [3]. In relaxed sitting, human body constantly exhibits low amplitude passive oscillation and produces feedback for postural balance and control [4, 5, 6, 7]. Studies on postural stability emphasize the significance of optimization of combinations of sitting postures, comfort, ergo-design and aesthetic seat features [8, 9]. Research on sitting focuses on anthropometric, biomechanical and

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electromyographic measurements [10, 11], and on comfort rating [12]. However, data on the analysis of postural control in relation to sitting and seat dynamics is scant [13, 14]. There is a need to examine postural control while sitting with special emphasis on modes and seat systems.

Workers may adopt inappropriate postures for many hours during a day. A chair has to match the tasks performed by worker and help to maintain back health to avoid future problems [15]. Postural control and discomfort have been correlated and suggested as useful for studying biomechanics of sitting postures [16]. Lacoste, Therrien, Côté, et al. suggested that centre of pressure (COP) displacement parameter can help to evaluate seated stability and efficacy of seating components [17]. Postural control is a complex motor skill and is defined as an act to maintain, achieve or restore a state of balance in any posture or while carrying out activities [18]. Postural control requires the ability to balance the body in space through visual, vestibular and somatosensory systems and to provide an appropriate musculoskeletal response to perturbations [19]. Maintenance of an upright posture is a vital motor function [20] and postural control is essential for the maintenance of posture and task performance [21, 22]. In humans, when the centre of gravity falls outside the base of support, the body senses a threat to stability and in such situations relevant muscles get activated to prevent falling [18]. Postural control strategies depend on the assessment and control of many variables by the central nervous system [21]. Therefore, an analysis of sitting posture control and stability with respect to sitting behaviour will differ according to an individual's goal, environmental context and performed task.

Force platforms have been used to understand balance control while standing [11] and recently also while sitting [13, 14, 23]. Postural control in sitting subjects with brain injury, cerebral palsy, sit-to-stand ability was examined with COP displacement parameters. The time course of a ground reaction force vector of a whole body and its application (COP) along with $x$ and $y$ coordinates explain the nature of body sway [24] and have been viewed as reliable measure of postural balance and stability [25, 26, 27, 28]. COP displacement in $x$ and $y$ directions corresponds to medio-lateral COP and anterio-posterior COP sway time series, respectively. The relative displacements in medio-lateral and anterio-posterior directions are governed by an open loop control system to maintain postural stability [10]. Length and velocity of COP trajectory, range and deviations of COP displacement, diffusion stabilogram and its critical time interval have been used in SWAY analysis [23, 29]. When a sample group had significantly larger spatial components (sway area, maximum displacements or average velocity) in comparison to the other sample group, the former was considered less stable [30, 31, 32, 33]. Thus, force platform measurements can be used to study postural control in different sitting postures.

The study's hypothesis was that the subjects sitting in appropriate postures and on a seat configuration providing a relative stability would demonstrate postural stability, in terms of COP measures [27, 28].

## 2. METHODS

Eleven healthy and young women were the subjects of the study; their mean (*SD*) age was 31.7 (6.9) years. Their mean (*SD*) height and body weight were 150.4 (5.1) cm and 48.3 (5.7) kg, respectively. The subjects' mean (*SD*) body mass index was 21.6 (3.2) and spine length was 44.7 (4.7) cm. The subjects with similar body stature and mass were selected because stabilometric dimensions depend on body height or weight [10]. The subjects had a normal range of muscle strength, flexibility and segmental alignment [29]. The subjects did not have history of motor problems, neurological diseases, vestibular impairment or back-related complaints.

### 2.1. Experimental Setup

A rig test of a simulated seat system was used in chair-sitting trials under a controlled situation (Figure 1). The experimental setup included two multicomponent piezoelectric force platforms sized 40 × 60 cm (Kistler, Switzerland); one placed on the ground served as a footrest (P1), the other placed 40.5 cm above the ground served as a seat pan (P2). The platforms were vertically adjusted and stabilized by a heavy duty mechanical jacking mechanism. The seat system allowed the subjects to place their feet comfortably. A backrest and an armrest were isolated components and were not attached to the platforms. The seat system made it possible to adjust the angle of the backrest and height of the armrest.

## 2.2. Sitting Postures

The study included 11 chair sitting postures (Figure 2) with reference to sitting behaviour and seat component combination, i.e., influence of the armrest and its height on the back in supported and unsupported conditions.

The subjects were divided into three groups:

- group 1
  - posture A: unsupported sitting with straight back, arms right angled at elbow, legs right angled at knee;
  - posture B: unsupported sitting with straight back, arms on a lap, legs right angled at knee;
  - posture C: slouched posture, arms on lap, legs right angled at knee;
  - posture D: unsupported sitting with straight back, one leg crossed over the other, arms on lap;
  - posture E: supported sitting at a recline of 95°, arms on lap;
- group 2: supported sitting with
  - posture F: armrest at 17 cm;
  - posture G: armrest at 20 cm;
  - posture H: armrest at 23 cm;
- group 3: unsupported sitting with
  - posture I: armrest at 17 cm;
  - posture J: armrest at 20 cm;
  - posture K: armrest at 23 cm.

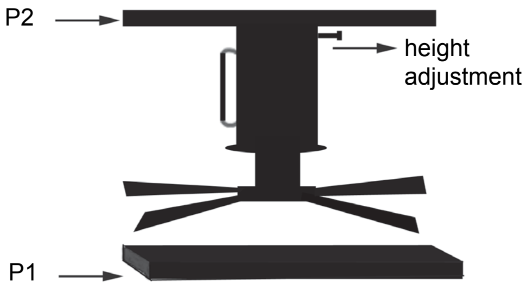

**Figure 1. Experimental setup.** *Notes.* P1 = footrest, P2 = seat pan.

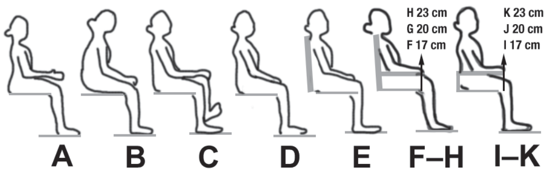

**Figure 2. Sitting postures.**

## 2.3. Force Platform Measurement and COP Displacement Parameters

The subjects were informed about the experimental setup and the procedure before they gave their written consent [34]. The force platforms were calibrated before experiments. The subjects attended a laboratory in the morning to ensure that the sitting trials were performed in non-fatigue condition. The force platforms connected to amplifier control units (Kistler, Switzerland) and a data logger (BTS Bioengineering, Italy) provided the ground reaction forces corresponding to the fractions of body weight transferred to P1 and P2. The force platform signals analysed with SMART software (BTS Bioengineering, Italy) measured three orthogonal components of force ($f_x$, $f_y$ and $f_z$ acting from $x$, $y$ and $z$ direction) and obtained three moments around the three axes ($m_x$, $m_y$ and $m_z$). Analysis of weight of reaction forces at P1 and P2 provided the extent of body load transferred to the seat pan, armrest, backrest and feet. The platform signals from P2 were further analysed with SWAY software (BTS Bioengineering, Italy) and provided mediolateral and anterio-posterior directions of COP displacement [4, 6]. The trace graph (based on $x$ and $y$ co-ordinates of COP displacement) and the polar star graph (based on distance and angle between COP points and its barycentre) were used to identify COP spread patterns (Figure 3). The star graph presents the envelope of the sway trace and each point of the envelope is defined by a radius (the segment between the point and the centre) and an angle [14]. The radius of each point is the mean radius, calculated from all COP points that fall in that sector. The inclination of the radius between the point and the centre is obtained by a mean angle, calculated among all COP angles of that sector [6, 35].

The sensory inputs such as visual, vestibular, and somato-sensory have been known to influence postural control [36, 37]. During the stabilometric measurements, the subjects had to sit quietly in the selected sitting posture with bare feet and eyes open. They also had to look at a point marked at a distance of 3 m [13]. The subjects used the seat system for ~10 min. During the tests, the seat pan was set 40.5 cm from the ground to allow the subjects to place their feet comfortably on the platform. Backrest slope angle was kept at 95° from the horizontal seat surface so the trunk–thigh angle was in comfort range in sitting. Positions of buttocks and feet were marked on the platforms and were similar for all subjects. The sitting positions were maintained during all the trials. Between the trials, the subjects could take a rest or walk around to avoid monotony and fatigue. Each subject attended a laboratory for three days to complete the protocol. Four sitting postures were tested during a 3-h experimental trial. Between the trials, the subjects had a 30-min break. The acquisition of platform signals was repeated thrice for 30 s at sampling frequency of 100 Hz and was further processed in nine blocks of 10 s.

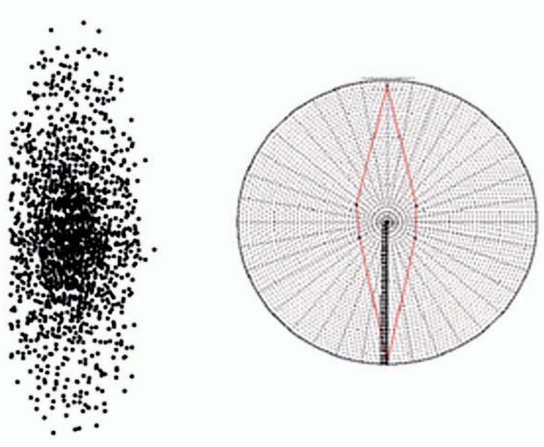

**Figure 3. Centre of pressure (COP) trace and polar star graph of anterio-posterior spread pattern of COP displacement.**

### 2.4. Statistical Analysis

SPSS version 16 was used to analyse 1088 platform signal acquisitions. To evaluate the influence of sitting postures and seat components on COP parameters, three groups were analysed separately: (a) group 1: sitting postures A, B, C, D and E; (b) group 2: unsupported sitting postures B, I, J, K; (c) group 3: supported sitting modes E, F, G, H. One-way repeated measures analysis of variance (ANOVA) was performed to test differences in COP displacement parameters between the sitting postures in the three groups with time block as a covariate. The least significant difference test was applied to obtain post hoc multiple comparison of the test measures, with respect to variation in the sitting postures. Linear regression analysis was performed to ascertain the relationship between medio-lateral and anterio-posterior COP displacements of the subjects.

## 3. RESULTS

### 3.1. Force Distribution

In the simulated sitting system, upper body and part of upper leg were supported by the force platform, which served as a seat pan, whereas lower leg and part of upper leg were supported by the floor surface. Table 1 presents the relative values of force distribution at the seat pan and the footrest. The force at the seat pan was the highest in postures C (381.2 N) and A (380.2 N). The combined force at P1 and P2 in posture C (468.4 N) and A (467.4 N) was ~99% of the total body weight measured in the standing posture. In posture D, combined force at P1 and P2 was very close to the standing body weight. With supported back, as in posture E, load at the seat pan was reduced by ~8%, comparing to the unsupported back in posture B. In unsupported sitting, the increase in armrest height in postures I, J and K reduced load on the seat pan to 351.8, 337.1 and 335.2 N, respectively. In supported sitting, the increase in armrest height in postures F, G and H reduced load on the seat pan to 322.4, 319.5 and 316.5 N, respectively. These results show shifts of body load from the seat pan to the armrest and back, and marginally to the feet.

### 3.2. Stabilometric Dimensions

The analysis included basic dimensions such as radius of the stabilogram, velocity, trajectory length, and medio-lateral and anterio-posterior directions of COP displacements (Table 2–3). The sitting postures did not influence the radius of stabilogram and COP trajectory length. Repeated measures of ANOVA indicated that medio-lateral direction of COP displacement varied significantly for the different sitting postures ($p < .01$).

**TABLE 1. Force Distribution at Seat Pan and Footrest**

| | P1 | | P2 | |
|---|---|---|---|---|
| **Posture** | ***M*** | ***SD*** | ***M*** | ***SD*** |
| A | 8.9 | 1.2 | 38.8 | 5.4 |
| B | 9.0 | 1.3 | 38.6 | 5.6 |
| C | 8.9 | 1.3 | 38.9 | 5.7 |
| D | 9.0 | 1.0 | 38.5 | 4.5 |
| E | 9.6 | 1.2 | 36.0 | 5.3 |
| F | 10.3 | 1.1 | 32.9 | 5.0 |
| G | 10.3 | 1.3 | 32.6 | 5.8 |
| H | 10.4 | 1.2 | 32.3 | 5.3 |
| I | 9.6 | 1.4 | 35.9 | 6.0 |
| J | 9.9 | 1.3 | 34.4 | 5.6 |
| K | 10.0 | 1.3 | 34.2 | 5.7 |

*Notes.* P1 = seat pan, P2 = footrest. For a description of postures, see section 2.2.

**TABLE 2. Stabilometric Dimensions in Different Sitting Postures**

| | Posture (*M* ± *SD*) | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | **A** | **B** | **C** | **D** | **E** | $f^a$ |
| Medio-lateral COP displacement (mm) | 6.0 ± 3.9 | 6.6 ± 4.1 | 6.6 ± 3.9 | 9.1 ± 8.6 | 13.7 ± 2.1 | 22.7** |
| Anterio-posterior COP displacement (mm) | 194.6 ± 24.0 | 194.6 ± 27.2 | 169.2 ± 28.8 | 167.5 ± 28.8 | 159.1 ± 26.0 | 0.97 |
| COP trajectory length (mm) | 1291 ± 590 | 1381 ± 774 | 1330 ± 594 | 1304 ± 613 | 1382 ± 738 | 1.5 |
| Radius of stabilogram (mm) | 1.2 ± 0.4 | 1.2 ± 0.53 | 1.1 ± 0.5 | 1.3 ± 1.0 | 1.2 ± 0.6 | 0.04 |
| Velocity of COP displacement (mm/s) | 129 ± 59 | 135 ± 66 | 133 ± 60 | 131 ± 61 | 138 ± 74 | 14.1* |

*Notes.* * $p < .05$, ** $p < .001$; a = ANOVA, COP = centre of pressure.

**TABLE 3. Influence of Armrests on COP Parameters**

| | Unsupported Back (*M* ± *SD*) | | | | |
|---|---|---|---|---|---|
| **Parameter** | **B** | **I** | **J** | **K** | $f^a$ |
| Medio-lateral COP displacement (mm) | 6.6 ± 4.1 | 10.6 ± 7.2 | 7.6 ± 6.7 | 8.9 ± 4.5 | 30.8** |
| Anterio-posterior COP displacement (mm) | 194.6 ± 27.2 | 178.3 ± 15.9 | 183.2 ± 20.4 | 195.4 ± 19.3 | 299.5** |
| Radius of stabilogram (mm) | 1.2 ± 0.5 | 1.5 ± 0.5 | 1.6 ± 0.5 | 1.5 ± 0.4 | 2.7 |
| COP trajectory length (mm) | 1381 ± 774 | 1577 ± 526 | 1745 ± 593 | 1695 ± 555 | 0.6 |
| Velocity of COP displacement (mm/s) | 134.4 ± 65.6 | 157.6 ± 52.4 | 174.7 ± 59.3 | 169.7 ± 55.5 | 2.01 |

| | Supported Back (*M* ± *SD*) | | | | |
|---|---|---|---|---|---|
| **Parameter** | **E** | **F** | **G** | **H** | $f^a$ |
| Medio-lateral COP displacement (mm) | 13.7 ± 9.2 | 11.4 ± 8.3 | 12.1 ± 11.5 | 7.6 ± 6.7 | 10.3* |
| Anterio-posterior COP displacement (mm) | 159.1 ± 26 | 170.4 ± 16.3 | 166.6 ± 21.5 | 171.8 ± 23.6 | 2.6 |
| Radius of stabilogram (mm) | 1.2 ± 0.6 | 1.3 ± 0.4 | 1.6 ± 1.4 | 1.6 ± 0.8 | 0.9 |
| COP trajectory length (mm) | 1382 ± 738 | 1752 ± 613 | 1712 ± 625 | 1729 ± 616 | 1.9 |
| Velocity of COP displacement (mm/s) | 138.3 ± 73.9 | 175.4 ± 61.4 | 171.4 ± 62.5 | 173 ± 61.7 | 1.85 |

*Notes.* * $p < .01$, ** $p < .001$; a = ANOVA, COP = centre of pressure.

Table 4 presents the pair wise comparison of the sitting postures. The subjects exhibited the highest medio-lateral COP displacement in posture E. Posture A had significantly lower medio-lateral COP displacement ($p < .001$) than posture B. Postures A and B had significantly higher anterio-posterior direction of COP displacement (~194 mm) than postures C, D and E. Posture D caused relatively higher medio-lateral COP displacement ($p < .001$) with reference to posture B. Posture B had significantly higher anterio-posterior COP direction of displacement ($p < .001$) than posture C. The back support in posture E reduced anterio-posterior COP displacement ($p < .001$) with a compensatory increase in medio-lateral direction of COP displacement ($p < .001$), as compared to posture B.

The sitting postures significantly influenced specific deviation in the directions of anterio-posterior and medio-lateral COP displacement (Figure 4), velocity of COP displacement ($p < 0.01$). For the pooled data, the magnitude of medio-lateral COP displacement was 6–14 mm and anterio-posterior COP displacement 160–195 mm. Linear regression analysis demonstrated that the increase in medio-lateral COP displacement caused a corresponding decrease in anterio-posterior COP displacement (anterio-posterior COP displaced = 187.7 – medio-lateral COP displaced; $r = -.283$, $p < .001$).

### 3.3. Relation Between Armrest and Backrest

The heights of the armrests depended on the body stature (152.7 ± 6.5 cm) and the arm length (68.5 ± 4.20 cm) of the subjects, the seat height was constant. Postures B and E (arms on the lap, with and without the backrest) had lower medio-lateral COP displacement, COP trajectory length, radius of the stabilogram and velocity of COP displacement, than the postures where the armrest was part of the seat (Table 3–4).

However, in the unsupported sitting, the inclusion of the armrest and the relative height of the

**TABLE 4. Pair Wise Comparison of Sitting Postures With Least Significant Difference Test**

| Posture | | Medio-Lateral COP Displacement (mm) | Anterio-Posterior COP Displacement (mm) | Velocity of COP Displacement (mm/s) |
|---|---|---|---|---|
| A | B | *** | *ns* | * |
| | C | *** | *** | * |
| | D | *** | *** | *ns* |
| | E | *** | *** | ** |
| B | C | *ns* | *** | * |
| | D | *** | *** | * |
| | I | *** | *** | *ns* |
| | J | ** | *** | *ns* |
| | K | *** | *** | *ns* |
| | E | *** | *** | *ns* |
| C | D | *** | *ns* | *ns* |
| | E | *** | *** | *ns* |
| D | E | *** | *** | ** |
| I | J | *** | *** | *ns* |
| | K | *** | *** | *ns* |
| J | K | *** | *** | *ns* |
| E | G | *** | *ns* | *ns* |
| | H | *** | *ns* | *ns* |
| F | G | *** | *ns* | *ns* |
| | H | *** | *ns* | *ns* |
| G | H | *** | *ns* | *ns* |

*Notes.* * $p < .05$, ** $p < .01$, *** $p < .001$. COP = centre of pressure.

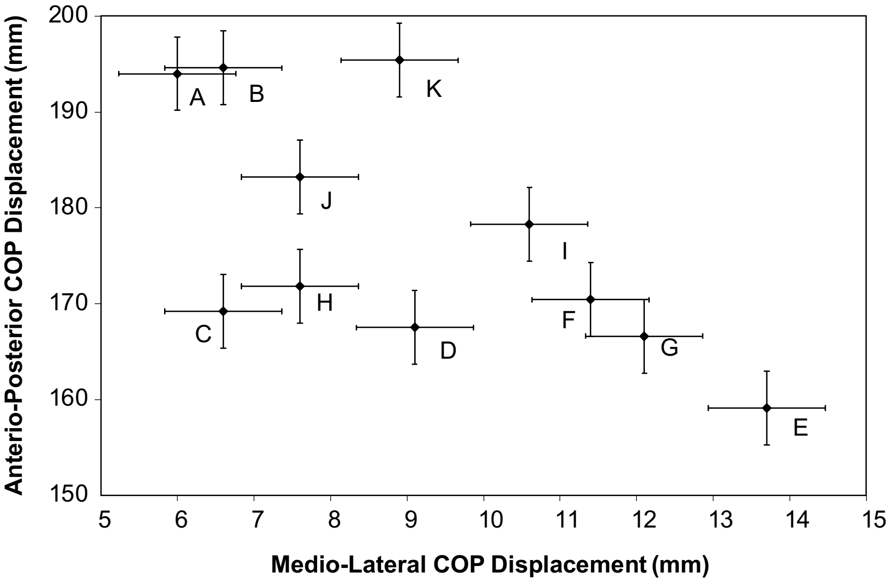

**Figure 4. Relationship between medio-lateral and anterio-posterior direction of centre of pressure (COP) displacement for different sitting postures.**

armrest influenced medio-lateral and anterio-posterior COP displacements (*p* < .001). In posture I (armrest at 17 cm), the subjects exhibited significantly higher anterio-posterior COP displacement (*p* < .001), as compared to posture K (armrest at 23 cm). Also, the increase in the armrest height from 20 (posture J) to 23 cm (posture K), caused a significant increase in anterio-posterior COP displacement (*p* < .001). Posture J (armrest at 20 cm) had significantly lower (*p* < .01) medio-lateral COP displacement than postures I (armrest at 17 cm) and K (armrest 23 cm), but higher than posture B (arms on the lap) (*p* < .001). The support back mediated change was noted in the medio-lateral direction of COP displacement (*p* < .05). Posture G had considerably higher medio-lateral COP displacement (*p* < .05) than posture H.

### 3.4. COP Spread Pattern

The sitting postures influenced the characteristic spread pattern of COP displacement. The examination of nearly 1100 COP spread patterns identified seven polar star graph patterns, which were differently distributed in sitting postures (Figure 5). Because there was no relationship between sitting mode and COP spread pattern, the anterio-posterior (Pattern 3) spread of COP displacement was predominant in postures A, C, D and E (Figure 6). Medio-lateral COP displacement spread (Pattern 1) was predominant in posture B. Pattern 3 of COP spread became predominant with the inclusion of the armrest in the unsupported and supported sitting postures.

## 4. DISCUSSION

Prolonged sitting at work has been reported as a risk factor for pain [17]. Seat arrangements at a workstation have an influence on subjects' musculoskeletal system [38]. Postural stress caused by poor workstation ergonomics is associated with musculoskeletal problems of subjects working with video display terminals [39, 40]. Sitting postures are factors causing pain among working subjects [41]. Postural balance and stability influence maintenance of interrupted sitting postures and sitting comfort with the stabilometric approach described by the body sway pattern [10] and are used to evaluate sitting behaviour [13, 14]. Inadequate postures provoke an increase in intradiscal pressure and successively increase the risk of musculoskeletal discomfort. Ergonomics investigations on sitting postures provide information on the construction of chairs and work seats providing stability [42]. Sitting discomfort,

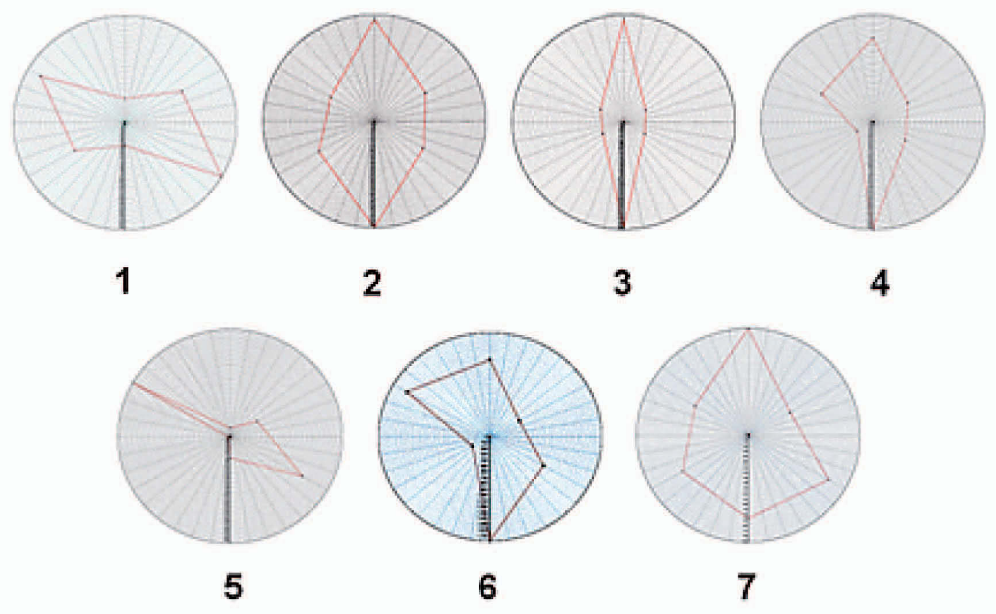

Figure 5. Centre of pressure (COP) displacement spread patterns: 1 medio-lateral, butterfly; 2 centralized; 3 anterio-posterior; 4 anterior; 5 lateral; 6 central with medio-lateral deviation; 7 multi-centric.

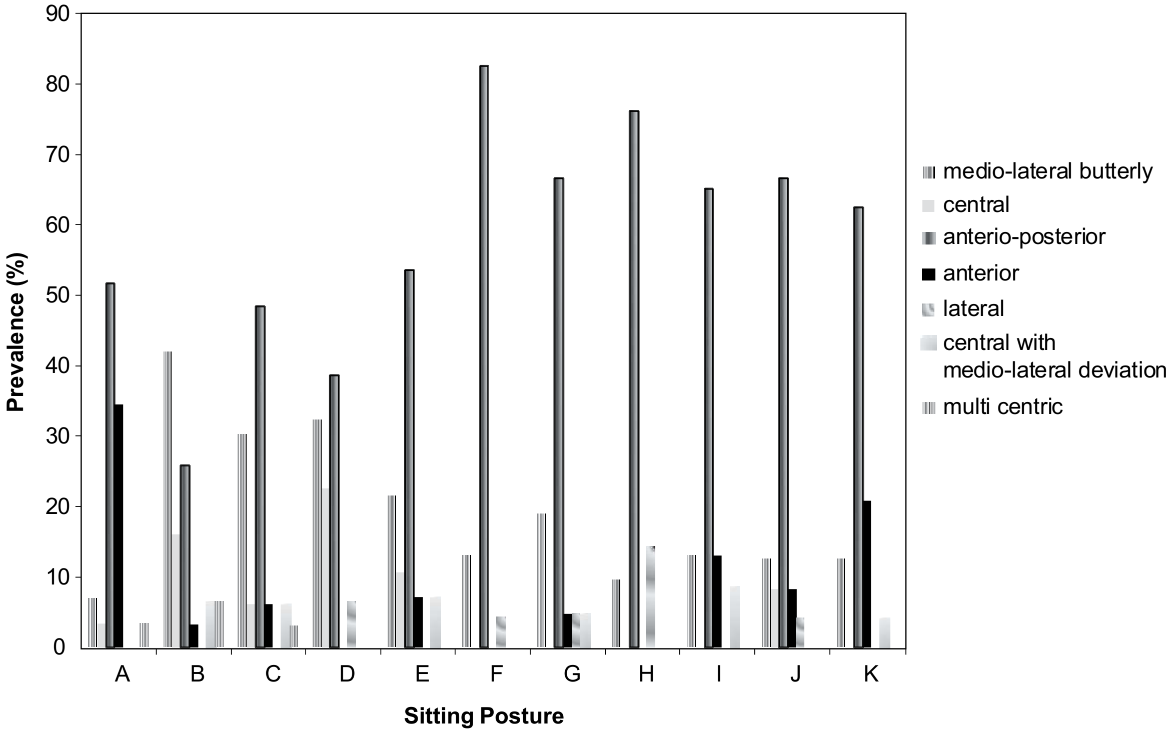

Figure 6. Centre of pressure spread patterns for different sitting postures.

traditionally evaluated with subjective rating scales, has been studied with regard to COP displacement parameters [7, 43]. Researchers explored the influence of postures and seat components during work [17]. Force platform measurements help to understand the overall differences in COP displacement parameters in sitting and enable to examine postural control mechanisms among the different sitting postures and sitting systems [44]. Human body exhibits passive oscillation, which produces feedback for postural control through afferent and efferent impulses [5, 6, 44]. The present study showed that sitting orientations combined with components of a seat may influence passive body acceleration, force distribution [4, 7, 17] and stabilometric characteristics [33]. The study aimed to examine stabilometric parameters in relation to the sitting postures and seat configurations.

Sitting on a chair in a slouched posture for a prolonged time constitutes a potential risk of back pain [45, 46]. The armrest as a seat component has been reported to give comfort to subjects [47]. Sitting with supported back alters contact area, reduces the peak pressure under ischium, reduces activity of muscles, maintains lumbar lordosis, rotates sacrum forward and increases the height of the lumbar intervertebral disc, which might help in reducing back strain [48, 49, 50]. Therefore, various sitting behaviour and seat components can lead to various effects on musculoskeletal health.

The time course of the whole body ground reaction force vector and its point of application (COP) [27] are the reliable measures of sitting postural stability [25, 26, 28]. However, research on the influence of a backrest and an armrest on the distribution of body load and stabilometric dimensions is scant [13]. Force distributed at the seat pan was the highest in the unsupported straight back posture or slouched posture, which was equivalent to ~81% of the body weight. The analysis indicated that in both the supported and unsupported sitting postures, body load shifted from the seat pan to the armrest, with an increase in the height of the armrest. Simultaneous inclusion of the armrest and backrest resulted in shifting 16.3% of the load from the seat pan, with approximately equal distribution on the armrest and back support [45]. Inclusion of the armrest caused a shift of load by 3%–5% from the seat pan to the foot rest; however, the load shifted to the foot rest was marginally higher in the supported sitting posture. The armrest as a seat component contributes to a reduction in the load at the seat. The extent of the load dissipated by the seat components suggests mitigation of compression and shear stress on the spinal and other paraspinal structures by the extent of the body load transferred in relative proportion from the seat pan to the armrest, back support and foot rest.

This study, on the basis of the measures of counteracting forces at the seat pan and feet, and stabilometric parameters derived from COP coordinates, provided discrete information on the biodynamics of low amplitude motions in different sitting postures. Higher sway in medio-lateral and anterio-posterior directions is associated with impaired postural control [51] and, therefore, the increase in COP displacement indicates a relative increase in postural instability [52]. The research showed that subjects swayed more in fatigue than in nonfatigue condition as indexed by increased range, mean speed and the other COP displacement parameters [5]. In the present study, an inverse relationship between medio-lateral and anterio-posterior direction of COP displacements was observed in the sitting postures [53, 54]. With an intercept of ~188 mm, every unit increase in medio-lateral COP displacement caused a corresponding decrease in anterio-posterior COP displacement. In the unsupported sitting, the subjects tended to sway significantly more in anterio-posterior direction, in comparison to the slouched unsupported sitting. In the supported posture, the subjects swayed more in medio-lateral direction ($p < .001$). When the legs were crossed one over the other, medio-lateral COP displacement increased significantly, in comparison to the sitting postures where the legs were right angled at knees. When the arms moved from the lap to the armrest, anterio-posterior COP displacement increased highly in both the unsupported and supported posture. When the arms were on the lap, COP displacements, i.e., length of COP trajectory and velocity of COP displacement, were significantly lower than in the postures where the arms were placed on the armrest.

Anterio-posterior and medio-lateral COP spread patterns exhibited predominantly in different sitting postures. Also, the change of the arms positions influenced COP spread patterns. When the arms were positioned right angled at the elbow, as in postures A, E, G, H, I, J and K, anterio-posterior COP spread pattern was prevalent. When the arms rested on the lap (posture B, D and E), the subjects tended to sway medio-laterally. The study observed that the inclusion of the armrest and backrest allowed the body load to shift from the seat pan. However, the subject exhibited higher anterio-posterior sway pattern, in comparison to the situation when the arms rested on the lap. Postural stability increased when the arms rested on the lap than when the armrests were used, irrespective of the support of the back. The height of the armrest in the unsupported posture (17 cm) and the height of the armrest in the supported posture (20 cm) may provide relatively greater stability. Analysis of the selected sitting postures and seat adjustments indicates further scope of investigation with adjustment to seat features such as seat height, reclines of backrest, slope of the seat pan and seat contours. However, the present data suggest that variations in the sitting postures and seat components influence the body load distribution and response characteristics of COP displacement parameters and functional measures of postural stability.

### 4.1. Limitations

The findings of this study cannot be generalized because of the limited number of subjects and narrowed anthropometric differences. Only one force plate at the seat pan was used during this study. The use of two force plates, at the seat pan and at the feet, could help to record changes in postural control measurements in relation to the feet. The force platform measurements were quick and performed during breaks between tasks. However, further study might demonstrate variations for different tasks and longer recordings. The subjects of this study had similar age and body mass index, but the gender, age and body mass index based variations had to be considered. This study examined 11 sitting postured; however, in different workplaces there are innumerable sitting postures and seat configurations. The basis for the findings of this study are the force platforms; however, other biomechanical parameters with respect to electromyography and 3D motion data related to spinal profile can serve for further exploration of biomechanics of sitting. Subjective perception of workers concerning sitting postures and seat configuration should be also taken into consideration. However, this study finds application in many workplace situations which involve sitting postures, e.g., in factories, offices and schools.

## 5. CONCLUSION

Subjects make subtle postural orientation and adjustments depending on the circumstances of sitting and seat type. This study, which includes force platform measurements evaluating postural stability and discomfort, presents a novel way of studying sitting. The stabilometric analysis performed on the simulated seat system showed that the inclusion of the backrest and armrest allowed to shift ~17% of the body load from the seat pan, with equal distribution to either of the seat components. Also, the low amplitude body oscillation characteristics had distinct trend in the unsupported or supported sitting or slouched posture. The study attempted to examine typical stabilometric characteristics which could be useful in further research on the postural balance and control, and its importance in human–seat interface design.

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