The Effect of Modified Sitting Postures on Postural Sway and Reach Distance in Sitting

BY

ADEOLU ADEMILUYI

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Thesis Committee

Alexander S. Aruin, Chair and Advisor (Ph. D)

Tanvi Baht (Ph. D)

Gay Girolami (Ph. D)

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AP	Anterior-Posterior
ATL	Anterior Leg Support
BIS	Backward Inclined Seat
BR	Baseline Reach
COG	Center of Gravity
CKC	Closed Kinetic Chain
CloseH	Closed Kinetic Chain Sitting for The Upper Limb
CloseL	Closed Kinetic Chain Sitting for The Lower Limb
CNS	Central Nervous System
COM	Center of Mass
COP	Center of Pressure
FIS	Forward Inclined Seat
FR	Footrest
ML	Mediolateral
NoFR	No Footrest
OKC	Open Kinetic Chain
OpenH	Open Kinetic Chain Sitting for The Upper Limb
OpenL	Open Kinetic Chain Sitting for The Lower Limb
PTL	Posterior Leg Support

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SUMMARY

Sitting is an important aspect of daily life. While it is seen as a resting position for mostly healthy individuals, it serves as the principal position of function for individuals who spend most part of their time in the sitting position such as people who are too weak to stand or people who need wheelchair for mobility or people living with disabilities. Most of the latter group of individuals perform their activities of daily living (answering the phone, pick up objects, reaching for objects among others) in sitting position. In the process of performing these various tasks, there is a displacement of the center of mass of each individual within their base of support, which marks the perimeter for their limit of stability.

Individuals often exceed the limits of their stability while performing their everyday tasks, which could result in falls. With the increase in the number of wheelchair falls recorded yearly, it is important to develop ways to improve stability and function in the sitting position.

This thesis involved two studies conducted to better understand how well individuals behave and can function better in the sitting position. One (Chapter 2) focused on stability during quiet sitting and the second (Chapter 3) focused on the ability to utilize the advances of a chair design while performing reaching tasks.

In the first study, we collected data from 10 healthy subjects who sat on a chair placed on a force platform. The chair was able to accommodate 0°, 10° forward or 10° backward inclination of the seat and also allowed the person to sit with no lower limbs support (open kinetic chain) or with lower limbs crossed (closed kinetic chain).

Subjects were found to sway more in the backward inclined seat condition compared to the legs crossed condition in terms of mean sway velocity. Also, subjects had a higher mean distance of sway in the forward inclined seat condition compared to the legs crossed condition.

In the second study, 10 healthy subjects were required to reach forward while sitting in an adjustable chair with 0°, 10° forward or 10° backward inclination of the seat, with and without footrest and leg support and when holding the edge of the seat with the contralateral arm and legs crossed.

Subjects initial reach distance taken as a baseline (similar to normal everyday sitting) was compared with all the selected reaching conditions. Subjects reached farthest both when they held the edge of the seat with footrest in place and when they were in the posterior leg support with footrest conditions. The reaching distance was lesser when they sat with an anterior leg support with footrest and also when they were in the backward or forward inclined seat conditions.

The outcome of the study (Chapter 2) showed the variability in the postural stability of the participants. Subjects experienced more stability when they sat with their legs hanging freely (open kinetic chain) and had a similar level of stability in the legs crossed condition (closed kinetic chain). Further decrease in stability was experienced in the backward and forward inclined seat conditions. The results of the second study (Chapter 3) showed that subjects were able to reach farther when they held the edge of their seat whilst they had their feet on the footrest, and also when they had a posterior leg support behind their legs with the legs placed on a footrest. There was a decline in the extent to which subjects reached when they had their legs crossed, in the anterior leg support condition, and in the backward and forward inclined seat conditions.

The outcome of this studies would provide a background for future studies and add to the body of literature on sitting postural control.

CHAPTER I

1. BACKGROUND

Sitting can be considered relatively more stable compared to the standing posture. This can be attributed to certain factors such as the close proximity of the center of mass (COM) to the base of support (BOS) and wider base of support. With respect to human posture, stability has been defined as the ability to control the COM (a reference point at which the mean mass of the body acts) within the BOS (the point of contact of a body with the support surface) (Shumway-Cook and Woollacott 2007). The ability to maintain a stable posture depends on the interaction of an individual with the task and the environment (Shumway-Cook and Woollacott 2007).

Factors that contribute to an individual's performance during the control of posture can be divided into intrinsic and extrinsic factors. Intrinsic factors include the control of joint positions and the activation of specific muscles depending on postural demands. These set of organised functions are controlled primarily by the central nervous system (CNS). During postural control, the COM is the main variable controlled by the CNS (Scholz et al. 2007). On the other hand, the extrinsic factors that contribute to sitting postural control include the seat configuration, the task and gravity.

The human body uses three sensory systems to relate with the environment. The somatosensory system oversees the interconnection among different body segments and how the body relates to the support surface. The visual system oversees the relationship of the body to objects in the environment. The vestibular system takes note of the gravitational force with respect to the body (Shumway-Cook and Woollacott 2007).

In understanding the influence of environment on task, one can consider seat configuration and the effect of gravitational pull on the body (vertical projection of the center of mass). Changes in body position in sitting based on specific chair design have an effect on (1) dimension of the base of support; (2) position of the body's center of mass in relation to the base of support; and (3) the distribution of mass in the body with regards to lower limb support (Aruin and Zatsiorsky 1984; Aruin and Zatsiorsky 1989).

Sitting have been studied based on the influence of leg supports – anterior and posterior (Aruin and Shiratori 2003), seat inclination – forward and backward inclination (Kim et al. 2014), sitting with or without back rest (Nawayseh and Griffin 2010), foot rest (Nawayseh and Griffin 2010), and kinetic chain - open or closed kinetic chain (Khademi Kalantari and Berenji Ardestani 2014; Mesfar and Shirazi-Adl 2008).

Force platforms have been used to assess balance control in the standing position (Goldie et al. 1989; Geurts et al. 2005; Marigold and Eng 2006) and also in unsupported sitting (Genthon et al. 2007) by the computation of the trajectory and oscillation of the location of the center of pressure (COP).

Falls in the elderly is of a major public health concern and leads to different forms of disabilities (Sadigh et al. 2004), together with psychological impairments that challenges functional independence (Gostynski 1991; Ryynanen et al. 1992; Kiel 1991). It has been reported that about 40% of the elderly population aged ≥65 would fall at least once each year, out of which 1 in 40 would be hospitalised (Rubenstein 2006) and it would account for 35 million disability-adjusted life years worldwide (Murray et al. 2012). Of particular interest is wheelchair falls, with an estimated about 36,599 nonfatal incidents yearly that calls for medical attention (Kirby and Ackroydstolarz 1995). Fall majorly occurs during a shift in the COP while performing tasks. Possible causes of falls include balance impairments, medications, and falls related to muscle weakness have been reported in the elderly population. However, the United States public health service has reported that two-thirds of fall-related deaths are preventable (Rubenstein 2006).

One of the tasks that perturbs balance in the sitting position is reaching for objects. Reaching for objects can be defined as the transportation of the arm and hand in space. A number of studies have reported tests and ways to improve reaching in the standing position in older adults (Newton 2001; DeWaard BP 2002; Rone-Adams SA 2001). These measures are well applicable to individuals who can stand. Individuals who are not able to stand due to conditions such as frailty, stoke, among others cannot perform this task in standing (Duncan et al. 1990). With the awareness that falls from the seated position are a concern, there is a shortage of sitting balance measures for a growing elderly population who spend most of their time in the sitting position. Thus, it is important to come up with better ways to improve functional effectiveness in the sitting position for this population.

Different seat modifications and sitting configurations have been employed to improve seating balance. While performing a forward reaching task, an inclined seat was found to improve the control of trunk and arm displacement (Janssen-Potten et al. 2000). In another study, kinetic chain (open and closed) was utilized to study dynamic balance activity in healthy young adults, and the results showed that the closed kinetic chain improved balance (Kwon et al. 2013). The effect of leg supports, whether anteriorly placed or posteriorly placed was also examined while studying anticipatory postural control in healthy adults (Aruin and Shiratori 2003).

There are however, deficiencies in literature as to how the different seat configuration and seat modification affect functional task such as reaching from the seated positioned. This thesis will focus on studying the effect of chair design while quiet sitting (Chapter 2) and looking at the effect of chair and sitting position on reaching distance (Chapter 3)

CHAPTER II

SITTING POSTURES AND BODY SWAY

2.1 INTRODUCTION

People randomly assume different postures in sitting whether intentionally or unintentionally. The way the body sways in these various sitting postures or positions vary with factors like the amount of sensory inputs the sense organs are able to gather, the amount of support the body is able to get in the assumed posture, individual preferences in terms of how much the body sway in a static sitting posture, angle of inclination or position of the seat and other environmental factors.

In order to maintain balance, coordination of inputs from various sensory systems (vestibular, somatosensory, and visual systems) is essential. (Shumway-Cook and Woollacott 2007). A disturbance to some of these sensory inputs, either by experimental manipulation or as a result of injury, an alteration in postural sway would occur (Diener and Dichgans 1988). Interestingly, a previous study suggested that inappropriate interactions among the three sensory inputs could result in balance deficiencies in people with neurological disorders (Shumway-Cook and Woollacott 2007).

The sitting posture is considered more stable than the standing posture, owing to the biomechanical differences in sitting versus standing (Aruin and Shiratori 2003). The greater stability during quiet sitting is associated with several factors. First, there is a significantly larger base of support in the sitting position compared to the standing position, which makes the task of keeping the center of mass (COM) projection within the limits of stability less challenging (Shephard, 1989). Second, proximity of the center of mass to the base of support in sitting. Third, the lower part of the body is supported as a result of the contact of the feet with the ground in sitting. Finally, the inertia values of the body are different in sitting as compared to standing (Aruin and Zatsiorsky 1984).

Falls have been recorded while performing different tasks in sitting, ranging from defecation (37.8%) to reaching for an object (12.7%) (Okamoto et al. 2011; Watanabe et al. 2014). Falls among the elderly are of immense socioeconomic concern (Moller et al. 2000). Fall itself and the belief of a likelihood of fall in a fall-probable situation can result in limitation of movement and activity, reduced confidence levels, depression, and institutionalization of the person (Tinetti and Powell 1993). The National Health Interview Survey specifies that fall is the single leading cause of restricted activity days among older adults, and accounts for 18% of restricted activity days (Rubenstein 2006). These shows that fall is a major concern, thus, it is pertinent to come up with ways to reduce falls and fall risks.

Center of pressure (COP) parameters derived from ground reaction forces obtained from a force platform have been found to be reliable in measuring postural stability (Cherng et al. 2009) while standing (Rocchi et al. 2002) and also in sitting (Nag et al. 2008). COP parameters have been used while examining postural control during sitting in subjects with brain injury, subjects with cerebral palsy and the sit-to-stand ability of typically developing children. Mean velocity of COP displacement was found to have the least standardized within subject coefficient of variation, i.e. the least reproducibility error (Raymakers et al. 2005) and was found to be the most reliable COP measure (Lafond et al. 2004); (Cornilleau-Peres et al. 2005); (Raymakers et al. 2005). On the other hand, there is an established relationship between the measurements of mean distance and the effectiveness of, or the stability achieved by, the postural control system (Hufschmidt et al. 1980). To understand the postural control in the frontal and sagittal planes separately, COP time series are usually analyzed in the anterior-posterior (AP) and medio-lateral (ML) directions respectively. The relative change in position of a body in the anterior-posterior and medio-lateral directions are governed by an open loop control system to keep the body stable (Chiari et al. 2002).

Comparing sitting postural sway between healthy children with typical development and children with cerebral palsy showed that the children with cerebral palsy had significantly higher spatial components (area of sway, maximum displacement or average velocity) during sitting which was considered as less stable (Reid and Sochaniwskyj 1991). This also indicated that force platform could be used to assess postural control in different sitting postures. COP displacement parameters can be helpful to evaluate seated stability and efficacy of seating components (Lacoste et al. 2006).

Different sitting behaviours and seat components have been found to have various effects on musculoskeletal health (Nag et al. 2013). These sitting behaviours bring about different results of body sway owing to the way the body reacts to each of the sitting conditions. Previous studies have used a wedge (a piece of wooden material used to separate two objects or two portions of an object, lift up an object or hold an object in place) to induce seat inclination either backward or forward (Kim et al. 2014). A backward inclined seat was found to improve head and trunk posture, (Angelo 1993); (Chan A 1999) and was capable of reducing the loading under the buttocks (Hobson 1992); (Vaisbuch et al. 2000) or through the spine (Ham 1998). A forward inclined seat can help preserve lumbar lordosis, reduce posterior pelvic tilt, and decrease the impact of tight hamstring muscles on the position of the pelvis (Bendix and Biering-Sorensen 1983). Nevertheless, the literature on how inclined seat affects postural sway is limited.

Kinetic chain can also be used to categorize sitting conditions in terms of lower limb position while sitting. This term describes how the limbs are positioned while sitting, either in an open kinetic chain (OKC) condition, in which case the limbs are free and not fixed to an object (i.e. footrest), or a closed kinetic chain (CKC) condition in which case limbs are fixed or stationary. The difference between these two conditions is determined by whether the distal end of the limbs are free or fixed; for example, whether the feet are moving against a hard or soft surface (Khademi Kalantari and Berenji Ardestani 2014; Mesfar and Shirazi-Adl 2008). Activity wise, the effects of CKC exercise are remarkable; CKC exercises could activate antagonistic muscle group across multiple joints (Lutz et al. 1993) and the co-contractions and complex actions of lower leg muscles could greatly enhance joint stability (Heller and Pincivero 2003).

Increased muscle tension along the torso above certain threshold have been found to impair balance in standing subjects (Hamaoui et al. 2011). Additionally, trunk and hip muscle stiffness has been found to increase the possibility of losing balance laterally and/or backwards in standing (Gruneberg et al. 2004). In the sitting posture, degradation of postural control was observed in unstable sitting when there was an increase in trunk muscle coactivation (Reeves et al. 2006). There is limited literature on how muscle stiffness affects body sway in sitting, particularly when the legs are crossed.

To address this gap, we investigated changes in postural sway during sitting. Firstly, this study aimed to focus on how the incorporation of selected sitting modifications (backward and forward inclined seat) and postures (open and closed kinetic chain sitting for the lower limbs), could affect balance in sitting. Secondly, this study aimed to see how the selected sitting modifications differ from each other. We hypothesized that of all the selected sitting conditions, subjects would have the least postural sway in the open kinetic chain sitting condition compared with the closed kinetic chain sitting condition, backward inclined and forward inclined seat conditions.

2.2. METHODS

2.2.1. Participants:

Ten young healthy individuals (6 males, 4 females) with an average age of 24.5 ± 3.5 years, weight 69.0 ± 15.9 kg and height 1.73 ± 0.14 m participated in the study. The study was approved by the University of Illinois at Chicago Institutional Review Board, and each participant provided a written informed consent before data collection.

2.2.2. Instrumentation:

A wooden chair with a height of 81cm and with a sitting base of 41cm by 41cm but had no backrest, was used in the experiments. The chair allowed manipulating sitting positions by using adjustable parts attached to it. Two parts of the plywood connected with a hinge were placed on the seat of the chair and used to create 10° backward or forward inclination of the seat (Fig. 2.1 (a) &(b)).

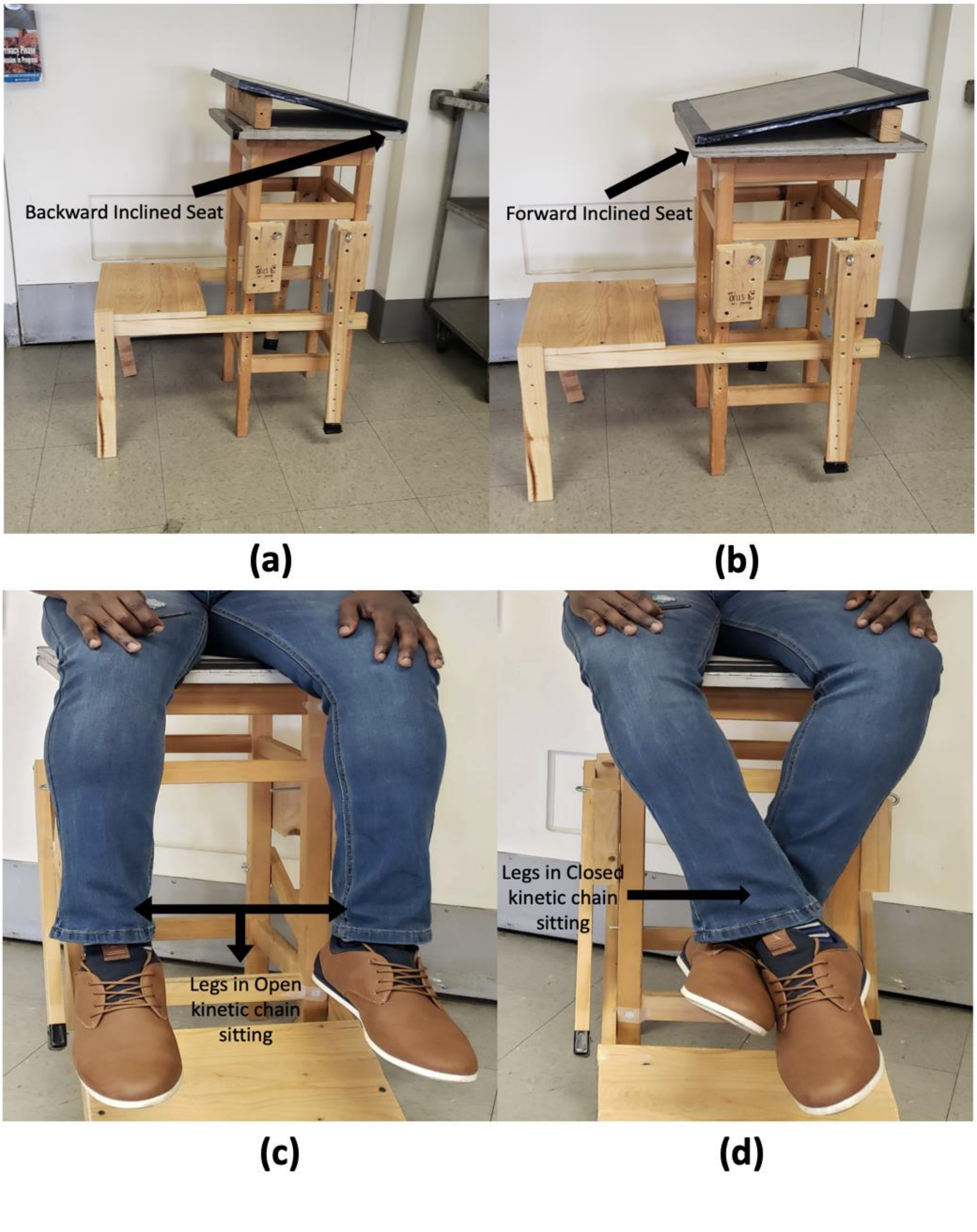


Fig. 2.1. Experimental setup showing: (a) the backward inclined seat (BIS) conditions, (b) forward inclined seat (FIS) condition, (c) the open kinetic chain sitting condition (OpenL) and (d) the closed kinetic chain or leg-crossed sitting condition (CloseL).

The chair was positioned on the top of a force platform (Model OR-5, AMTI, USA). Ground reaction forces and moments of force obtained from the platform were digitized with a 16-bit resolution at 1000 Hz by means of an analog-to-digital converter and a customized LabVIEW 8.6.1 program (National Instruments, Austin TX, USA). Data were stored on a computer for further processing.

2.2.3. Experimental procedures

Subjects were required to sit on the chair with no footrest or leg support. Subjects were asked to keep their back straight, place the hands on the thigh, and keep their head forward with the eyes focused at a point on the wall. The hip and knee were positioned at approximately 90 degrees of flexion and the sacrum at 1cm away from the posterior edge of the seat.

In the inclined seat conditions, subjects were required to sit on a backward inclined seat (BIS) at 10 degrees (Fig. 2.1a) (Kim et al. 2014). Subjects were also required to sit on a 10 degrees forward inclined seat (FIS) with the lower limbs off foot rest and no leg support (Fig. 2.1b).

In the lower limbs open kinetic chain sitting condition (OpenL), subjects were required to sit on the chair without inclination, hands on the thighs and back straight (Fig. 2.1c). For the lower limbs closed kinetic chain sitting condition (CloseL), subjects sat on the chair with no footrest and have their legs crossed at the level of the distal 1/3 of the tibial bone (Fig. 2.1d). Two trials were recorded for each of the conditions, each trial lasted for 30 seconds and all trials were performed with eyes open. To ensure the safety of participants during the experiments, the subjects were provided with a harness loosely attached to the ceiling.

2.2.4. Data Processing

MATLAB software R2016a (MathWorks, Natick, MA, USA) was used for offline data processing of signals from the force platform. The vertical component of the ground reaction force (F_z), the horizontal components in the anterior-posterior (AP) direction (F_y) and in the medial-lateral (ML) direction (F_x) and the moments of force around the frontal axis (M_x) and the sagittal axis (M_y) were filtered with a 20Hz low-pass, 2nd order, zero-lag Butterworth filter. Time-varying COP displacements in the AP direction (COP_{AP}) and ML direction (COP_{ML}) were calculated using equations described in the literature (Winter et al. 1996) as:

$$COP_{AP} = \frac{M_x - F_y \cdot dz}{F_z} \quad and \quad COP_{ML} = -\frac{M_y + F_x \cdot dz}{F_z}$$

Equation 2.1. Calculation for center of pressure displacement in AP and ML direction.

where *dz* represents the distance from the surface to the platform origin (0.038m). Means were removed from the COP_{AP} and COP_{ML} time series respectively for further calculation.

Mean distance in mm and the mean velocity in mm/s were calculated in the AP and ML directions using equations described in the literature (Prieto et al. 1996).

$$MDIST_{AP} = \frac{1}{N} \sum |\mathrm{AP}[n]|$$

$$MDIST_{ML} = \frac{1}{N} \sum |\mathrm{ML}[n]|$$

Equation 2.2. Calculation for Mean distance of sway in the AP and ML direction.

$$Velocity_{AP} = \frac{\sum_{n=1}^{N-1} |COP_{AP}[n+1] - COP_{AP}[n]|}{T}$$

$$Velocity_{ML} = \frac{\sum_{n=1}^{N-1} |COP_{ML}[n+1] - COP_{ML}[n]|}{T}$$

Equation 2.3. Calculation for velocity of sway in the AP and ML direction.

where N is the number of data points included (30,000) and T is the length of the trial (30 seconds).

2.2.5. Statistical Analysis:

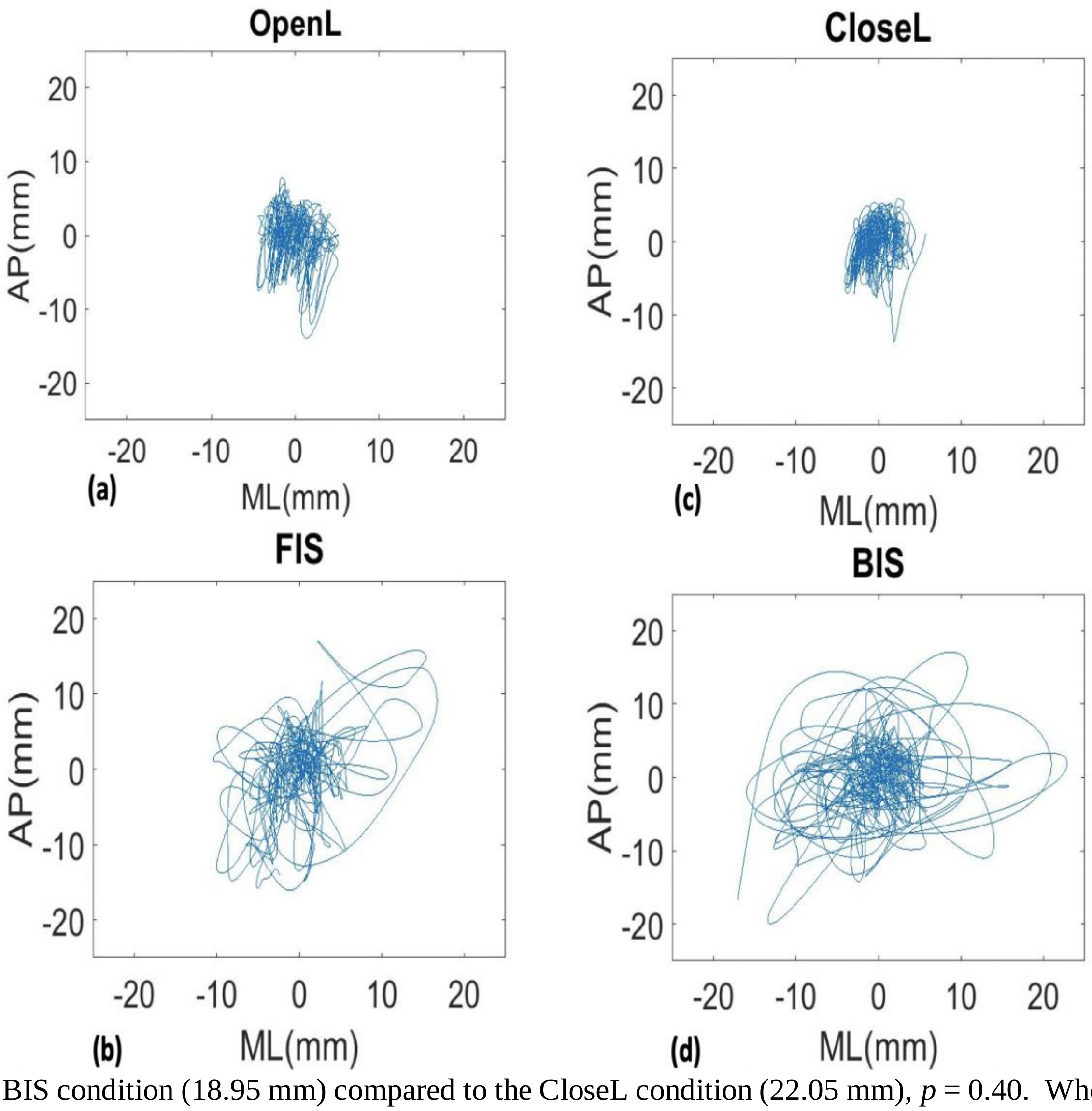
Mann Whitney test was utilized to compare the difference in each study outcome between the selected sitting conditions (OpenL, CloseL, BIS, FIS). SPSS software (IBM, Armonk, NY, USA) was used. Significance was set at $p<0.05$.

2.3. RESULTS

The raw results of how subjects swayed in the selected sitting conditions is depicted by a representative subject in Fig 2.2. As represented, there are observable differences in the center of pressure displacement parameters in each of the selected sitting conditions.

The results of the mean distance of sway in the AP direction (MDIST-AP) are shown in Fig 2.3 (a). Subjects were more stable in the OpenL condition (17.45 mm) compared to the BIS condition (23.55 mm), $p = 0.099$. Similarly, subjects experienced a significantly lesser sway in the OpenL condition (16.85mm) when compared with the FIS condition (24.15 mm), $p < 0.05$. There was no significant difference in the MDIST-AP when the OpenL condition (19.15 mm) was compared with the CloseL condition (21.85 mm) $p = 0.465$. In the CloseL condition (18.50 mm), subjects had no significant difference in sway compared to the BIS condition (22.50 mm), $p = 0.29$. There was no significant difference when we compared the CloseL condition (18.40 mm) with the FIS condition (22.60 mm), $p = 0.256$. So also, there was no significant difference in the MDIST-AP in the BIS condition (20.35 mm) compared to the FIS (20.65 mm). $p = 0.935$.

The results of the mean distance of sway ML direction (MDIST-ML) are shown in Fig. 2.3 (b). Subjects had no significance in sway when OpenL condition (19.10 mm) was compared with the CloseL condition (21.90 mm), $p = 0.45$. Similarly, there was no significant difference in the BIS condition (19.85 mm) when compared with the OpenL condition (21.15 mm), p = 0.73. When the FIS condition (20.10 mm), was compared to the OpenL condition (20.90 mm), subjects had no significant difference in MDIST-ML, p = 0.83. A comparison between the FIS condition (20.25 mm) and the CloseL condition (20.75 mm) showed no significant difference (p = 0.89) in subjects' sway distance. Similarly, subjects had no significance in sway in the



BIS condition (18.95 mm) compared to the CloseL condition (22.05 mm), p = 0.40. When the FIS condition (22.60 mm) was compared with the BIS condition (18.40 mm), there was no significant difference in their MDIST in the ML direction, p = 0.26.

Fig 2.2: Raw COP displacement parameters of a representative subject in the OpenL – Open Kinetic chain sitting for the lower limbs, CloseL- closed kinetic chain sitting condition for the lower limbs, BIS – backward inclined seat, FIS - forward inclined seat conditions.

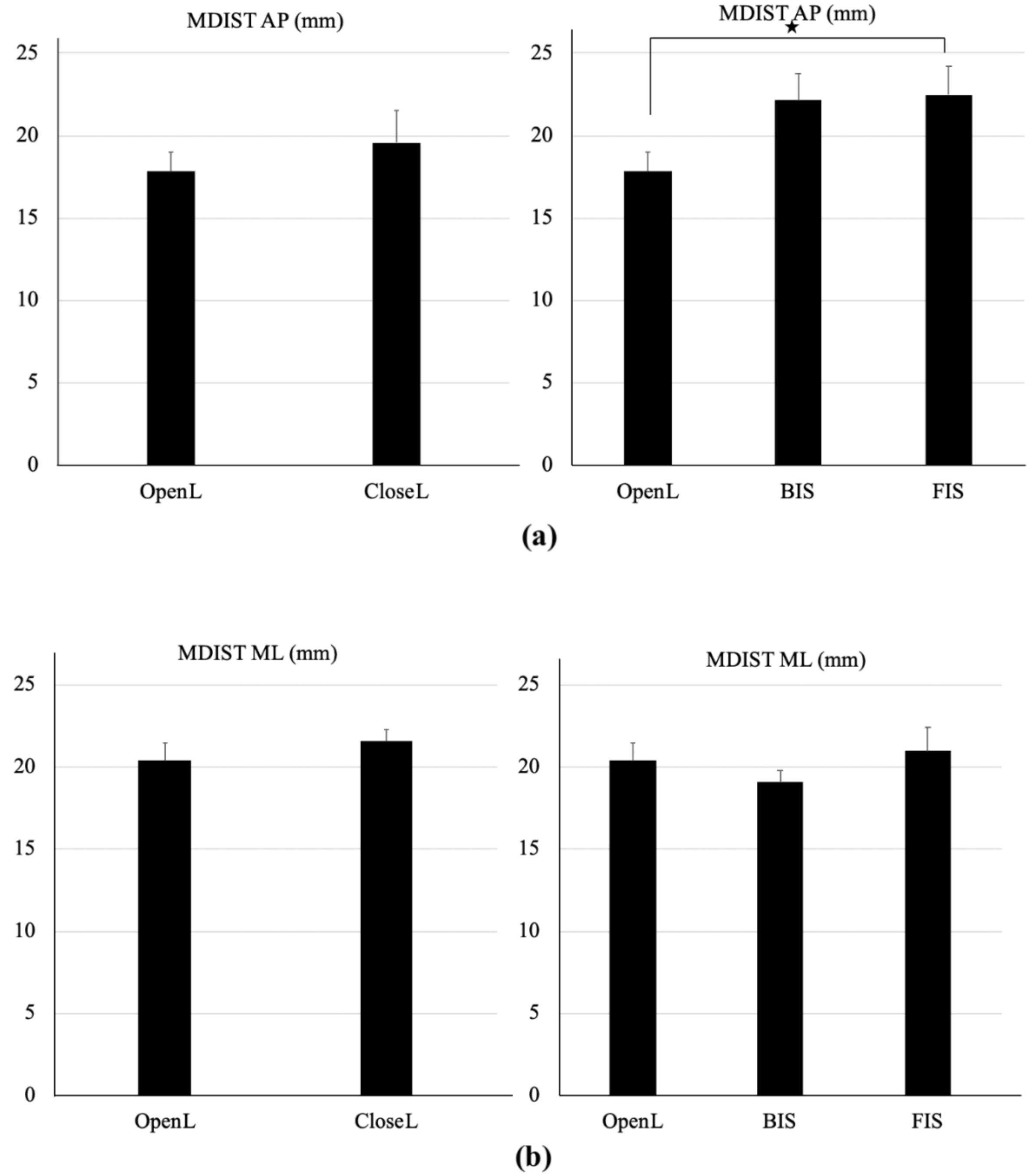
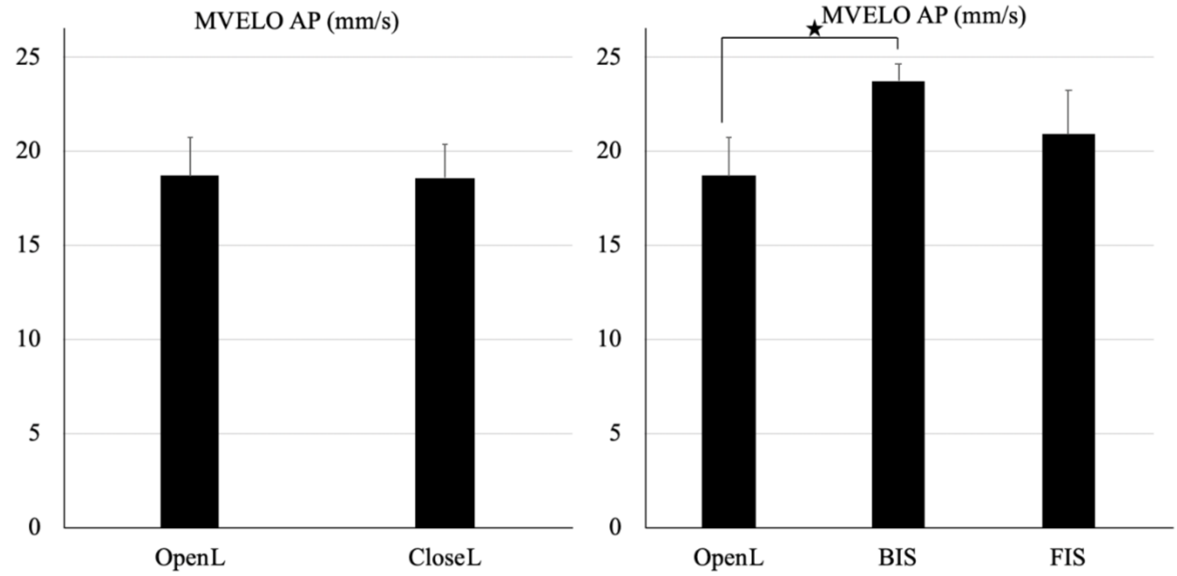


Fig. 2.3: Mean and standard deviation of sway distance in the (a) anterior-posterior and (b) mediolateral direction. OpenL – Open Kinetic chain sitting for the lower limbs, CloseL- closed kinetic chain sitting

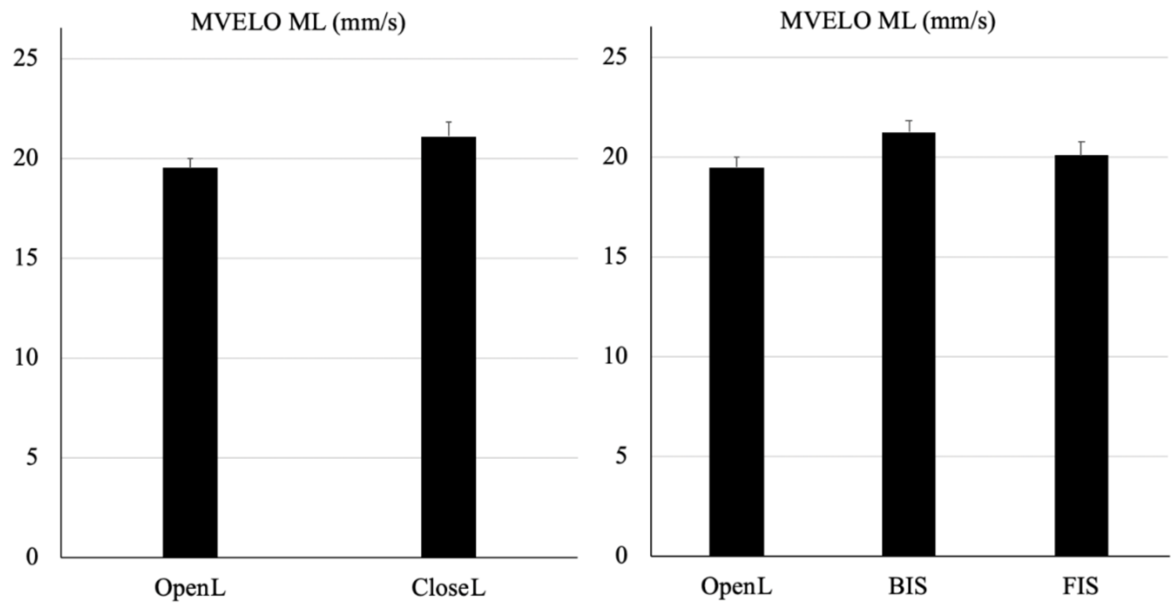
condition for the lower limbs, BIS – backward inclined seat, FIS - forward inclined seat. * shows significant difference ($p<0.05$).

The results of the mean velocity of sway (MVELO) in the anterior-posterior (AP) direction are shown in Fig. 2.4 (a). There was a significant difference in the subject sway when the OpenL condition (18.65 mm/s) was compared with the BIS condition (24.30 mm/s), $p < 0.05$. Similarly, subjects had significantly lesser sway in the CloseL condition (16.75 mm/s) compared to the BIS condition (24.25 mm/s), $p < 0.05$. Subjects had no significant difference in the comparison between the OpenL condition (20.75 mm/s) and the CloseL condition (20.25 mm/s), $p = 0.89$. Similarly, a comparison between the OpenL condition (18.65 mm/s) and the FIS condition (22.35 mm/s) showed no significant difference, $p = 0.32$. Subjects had no significant difference in the CloseL condition (18.25 mm/s) compared to the FIS condition (22.15 mm/s), $p = 0.37$. In the BIS condition (22.75 mm/s) compared to the FIS condition (18.25 mm/s), $p = 0.22$, there was no significant difference in the mean sway velocity.

The results of the mean velocity of sway (MVELO) in the mediolateral (ML) direction are shown in Fig. 2.4 (b). There was no significant difference in the mean sway velocity between the OpenL condition (19.30 mm/s) and the CloseL condition (21.70 mm/s) $p = 0.52$. Similarly, there was no significant difference in the OpenL condition (19.15 mm/s) compared to the BIS condition (21.85 mm/s), $p = 0.47$. The OpenL condition (20.10 mm/s) showed no significant difference from the FIS condition (20.90 mm/s), $p = 0.83$. Similarly, there was no difference in subjects sway in the CloseL condition (20.30 mm/s) compared to the BIS condition (20.90 mm/s), $p = 0.91$. Subjects had no significant difference in MVELO-ML between the FIS condition (19.65 mm/s) and the CloseL condition (21.35 mm/s), $p = 0.65$. So also, subjects were no significantly different sway in the BIS condition (19.75 mm/s) compared to the FIS condition (21.25 mm/s), $p = 0.69$.



(a)



(b)

Fig. 2.4: Mean and standard deviation of sway velocity. OpenL – Open Kinetic chain sitting for the lower limbs, CloseL - closed kinetic chain sitting condition for the lower limbs, BIS – backward inclined seat, FIS - forward inclined seat. * shows significant difference (p<0.05).

2.4. DISCUSSION

Postural sway varied among the different sitting conditions. The lower-limb open kinetic chain sitting condition had the least mean velocity and mean distance of sway compared to the other sitting conditions. The result of the experiment supported our hypothesis that the subjects would have the least sway in the OpenL condition when compared to the CloseL, BIS and FIS condition.

2.4.1. Open kinetic chain sitting and backward inclined seat

Sitting stability on an unstable seat is dependent on the individual’s ability to bring the projection of the center of mass to line with the center of rotation of the support surface; additionally, trunk movements produce inertial forces which are controlled by the CNS (Lanzetta et al. 2004). Increased COP displacement is the indication of an increase in postural instability. In terms of the mean distance of sway and mean velocity of sway, subjects experienced lesser sway in the OpenL condition compared to the BIS condition in the AP direction. Increased muscular effort has been attributed to the sitting posture in backward inclined seat (Hadders-Algra et al. 2007), as such that the increase in the muscular activity of the back muscles and the abdominals could help to avoid falling backwards. However, this increased muscular activity could lead to postural instability (Hamaoui et al. 2007). In the ML direction, we observed a decrease in postural sway in the BIS condition, though the difference was insignificant. Prior literatures suggested that this decrease could be useful in training balance control (Marigold and Eng 2006b); (Tessem et al. 2007); (Cherng et al. 2009).

2.4.2. Open kinetic chain sitting and forward inclined seat

The forward slopping seat has been found to change the center of gravity with respect to the seat top, which induced a sliding effect on the pelvis (Hamaoui et al. 2015). To compensate, subjects apply pressure on the contact area of the body to avoid slipping off. In so doing, there was an increase in body sway due to muscular activity in the thigh and buttocks against the seat (Silfies et al. 2003). Insightfully, Newton's first law has made it known that, the force responsible for this sliding down effect must be balanced by another force with the same magnitude acting in the opposite direction to keep the body balanced. Thus, subjects in the process of trying to balance these forces out, had an increase in body sway in the forward inclined seat condition compared to the open kinetic chain sitting condition in the anterior-posterior direction. However, we cannot neglect the fact that the forward inclined seat encouraged a straight sitting posture.

2.4.3. Open kinetic chain and legs crossed

Balance in sitting can be maintained as long as COM is kept within the limits of stability, which in healthy subjects is bordered by the buttocks and feet (Janssen-Potten et al. 2002). While sitting in the OpenL condition (sitting with legs off the ground), subjects had lesser values in the mean distance of sway and the mean velocity of sway compared to the CloseL condition (legs crossed). This outcome could be explained by the fact that subjects felt more relaxed when having the legs hang freely compared to that they had to stiffen the leg muscles when crossing the legs. It was described in the literature that increased muscle tension could impair balance (Hamaoui et al. 2007).

2.5. STUDY LIMITATIONS

Possible limitations of this study were the small sample size that we had; only two angles of inclination were taken into consideration; there were also limited number of conditions.

2.6. CONCLUSION

Sitting is an important daily activity and as such improving balance in sitting is essential. The results of this study showed that seat inclination (forward and backward) increased postural instability in the sitting position. We also found that crossing the legs with the legs off a footrest or leg support could help reduce postural sway during unsupported sitting. The results further showed that sitting with no leg support nor footrest appeared to be easier for subjects to achieve stability, which is associated with the lesser effort utilized in attaining stability in this condition. Findings from this study would add to the body of literature and offer a background for future studies of sitting balance.

CHAPTER III

EFFECT OF MODIFIED SITTING POSTURES ON REACHING DISTANCE

3.1. INTRODUCTION

People spend substantial part of their active time sitting because it is a common and well-known position from which motor activities are performed in everyday life. People learn sitting before they learn standing. Certain individuals with neurologic impairments who are unable to stand spend most of their active time in the sitting position (Lanzetta et al. 2004). Thus, improving comfort of sitting as well as optimization of the chair design allowing for better balance needed for performance of daily tasks in seating could be invaluable for such individuals. There is a consensus in the literature that altering postural habits together with seating options such as providing supports to the lumbar, neck, the use of arm rests and seat surfaces could improve sitting (Makhsous et al. 2009).

Balance control in sitting encompasses ability to maintain the seated posture without falling over and maintaining the body's center of mass within the limits of stability while performing a variety of self-initiated actions (Carr and Shepherd 1987). Balance and postural impairments affects individual performance of activities of daily living in sitting (Dean and Shepherd 1997). For example, people with neurological impairment, individuals with spinal cord injury and individuals with cerebral palsy who frequently have balance problems in seating, demonstrate limitations in performance of daily tasks (Field-Fote and Ray 2010; Lee et al. 2013; Saavedra et al. 2010; Tessem et al. 2007). Sitting balance recovery is important in obtaining independence while performing other important functions such as reaching, rising to stand and sitting (Morgan, 1994).

Reaching to targets beyond arm's length, for instance when answering the telephone or picking up an object situated by the side, is a common activity that challenges balance.

Reaching movements in sitting involve multifarious communications between the arm and the upper body, taking into consideration the dimensions of the BOS (the pelvis, thighs and the feet) (Friedli et al. 1984). The ability to perform reaching tasks in sitting is necessary for an individual's functional independence and quality of life. Persons with movement disorders, as a result of stroke for example, often face challenges while coordinating body movements and balance while performing reaching tasks (Dean and Mackey 1992).

It is estimated that over 2 million Americans depend on wheelchairs to make up for mobility impairments and a large number of them are over 65 years old (Gavin-Dreschnack et al. 2005). Additionally, over 36,000 nonfatal, wheelchair-related accidents (usually during dynamic activities) necessitate emergency department attention yearly in the United States (Xiang et al. 2006). It is reported that about 30% of individuals with stroke experience a fall while sitting in a wheelchair (Czernuszenko and Czlonkowska 2009; Teasell et al. 2002). Given that wheelchairs are normally used for about 16 hours per day throughout the year (Kirby et al. 1995), falls from the seated position are a concern.

Different chair designs and sitting manipulations have been used to minimize the probability of a fall and to provide body support needed in carrying out daily activities. Thus, the wedge (a piece of wooden material used to separate two objects or two portions of an object, lift up an object or hold an object in place) has been used to induce seat inclination (Kim et al. 2014). Experimentally, the wedge has been used in sitting in different ways – forward inclined or backward inclined. It was found that the use of a padded inclined seat at 10 degrees did not greatly affect internal spinal fixation implant loads during sitting, but had a significant effect on back shape (Rohlmann et al. 2001). Moreover, the ability to control displacement of arms and trunk during reaching was improved while sitting in chairs with backward tilted seat as compared to a standard chair configuration (Janssen-Potten et al. 2000). However, the literature on the effect of an inclined seat on reaching distance from the sitting position is limited.

Another way in which balance control in sitting could be enhanced involves using body positions that utilize the effects of a closed kinetic chain (CKC). For example, such a lower legs CKC is utilized when sitting with the feet on the ground or crossing the legs while sitting with the feet off the ground. Sitting in a position involving lower leg CKC (that is associated with the stiffening of muscles in the lower extremities) differs from sitting with feet off the ground and not crossed as the terminal ending of the limb is free or fixed (Khademi Kalantari and Berenji Ardestani 2014; Mesfar and Shirazi-Adl 2008). However, not much has been studied on how reaching is affected by stiffening muscles that could be achieved using CKC. Using closed kinetic chain for the upper limb also can enhance sitting balance control. For example, better body stability could be achieved while sitting with the hands holding the edge of the seat (closed kinetic chain) as compared to sitting with both hands by the side (open kinetic chain (OKC) for the upper limb). While it was demonstrated that CKC exercise has been more successful in improving the dynamic balance ability than OKC exercise (Kwon et al. 2013), no studies on the role of closed kinetic chain posture in balance control during reaching were conducted.

It was shown that providing external supports to the lower legs anteriorly or posteriorly could help to improve postural control by decreasing the load on the muscles while performing tasks involving arm manipulations (Aruin and Zatsiorsky 1989; (Shenoy and Aruin 2007). In addition, enhanced muscle activity was observed in the rectus femoris and biceps femoris muscles when anterior and posterior supports were used to support the lower legs in the sitting position. (Aruin and Shiratori 2003).

This study was aimed to investigate how difference in the chair design and selected sitting manipulations could influence reaching distance in sitting. We hypothesized that reaching distance would be affected by the different sitting manipulations or seat features. Particularly, sitting with the lower limbs support, contralateral hand support and sitting on an inclined seat would allow a greater reaching distance as compared to reaching from a traditional seated position.

3.2. METHODS

3.2.1. Participants

Ten healthy subjects (4 males, 6 females) with the average age of 26 ± 7 years, height 1.63 ± 0.17m and weight 62.77 ± 20kg participated in the study. Nine of them were right-hand dominant and one was left-hand dominant. The study was approved by the University of Illinois at Chicago Institutional Review Board and all the subjects provided a written informed consent.

3.2.2. Instrumentation

A wooden chair with no backrest, with a height of 81cm and with a sitting base of 41 cm by 41cm, was used in the experiments. The chair allowed manipulating sitting positions by using adjustable parts attached to the chair. Thus, two parts of the plywood connected with a hinge were placed on the seat of the chair and used to create 10° forward and backward inclination of the seat. A height adjustable and detachable footrest was used to study the effect of footrest. Two height adjustable removable sidebars were used to study the effect of the anterior and posterior leg support on reaching distance (Fig. 3.1).

To ensure safety of participants during the experiments, the subjects were provided with a harness loosely attached to the ceiling. In addition, a stopper attached to the footrest portion of the chair and a rope connecting the rear end of the chair with the floor were used to prevent the chair from tilting. A wooden ruler positioned horizontally at the shoulder level was used to measure the reaching distance.

3.2.3. Experimental procedure

Subjects were required to sit on the chair with no back support, with the sacrum at 1cm from the posterior edge of the seat, and their back straight and head forward and reach forward as far as they could using their dominant hand and placed the other arm by the side except in the CKC for the upper limb condition. Functional reach was measured using a ruler placed on the wall by the dominant side of the participants at the height of the acromion. Subjects were required to lift the arm forward at approximately 90° and to make a fist around a pencil held vertically upwards (Figure 3.1). The point of the pencil along the ruler was documented as point 1. The subjects were asked to lean forward as much as they could while remaining seated. The location of the pencil was recorded again as position 2. Each task was repeated 3 times and the mean reach distance was obtained. Reaching was defined as the difference between position 1 and position 2 and it was averaged over 3 trials (Duncan et al. 1990). All reaches were performed with full vision.

Fig. 3.1. Experimental setup showing different parts of the chair and body position.

Nine experimental conditions were implemented. First, the subjects were required to reach forward while sitting with the legs on the footrest (just as in a normal everyday sitting with the legs on the ground) and the other hand by the side: this condition will be referred as baseline reach (BR)**.** To study the effect of body's closed/open kinetic chain on reaching distance, the subjects were required to reach forward while sitting with no footrest and legs either hanging (open kinetic chain, OpenL_NoFR) or with their legs crossed at the level of the distal 1/3 of the leg (closed kinetic chain, CloseL_NoFR); whilst sitting and reaching concurrently with holding the edge of the seat with the other hand, and the legs on the footrest (closed kinetic chain, CloseH_FR) or the legs hanging (open chain, OpenH_NoFR). To study the effect of leg support, a support was placed across the distal one third of the legs anteriorly (ATL_FR) and across the distal one third of the legs posteriorly (PTL_FR) (Aruin and Shiratori 2003) and the footrest was available in both the conditions. Finally, to study the effect of seat inclination on reaching distance, subjects sat with no footrest, at an angle of 10° inclination on a backward inclined seat (BIS_NoFR) or forward inclined seat (FIS_NoFR) (Kim et al. 2014). The experimenter checked the verticality of the trunk while sitting.

3.2.4. Statistical analysis

Repeated measures one-way ANOVA was employed to compare difference between the reach distances measured in different sitting conditions. SPSS software (IBM, Armonk, NY, USA) was used. Significance was set at $p<0.05$.

3.4. Results

Mean reach distances measured while sitting in different experimental conditions are shown in Fig. 3.2. When sitting in the baseline condition (feet on footrest) the reach distance was 37.2 ± 9.5 cm. When the subjects were sitting in other experimental conditions, the maximal reach distance decreased or increased, and the effect of condition was statistically significant ($F_{(1,9)} = 270.06$, $p<0.05$).

Reaching while sitting with the lower limbs in the open and closed kinetic chain condition resulted in a decrease of the reaching distance to 33.5 ± 6.6 cm and 33.2 ± 6.2 cm respectively ($p<0.05$). Thus, sitting in open kinetic chain condition for the lower limb (OpenL_NoFR), brought about a decrease of 3.7 cm in reaching distance and reached from the closed kinetic chain condition (CloseL_NoFR) resulted in a 4.0 cm decrease as compared to reaching in the baseline condition ($p<0.05$).

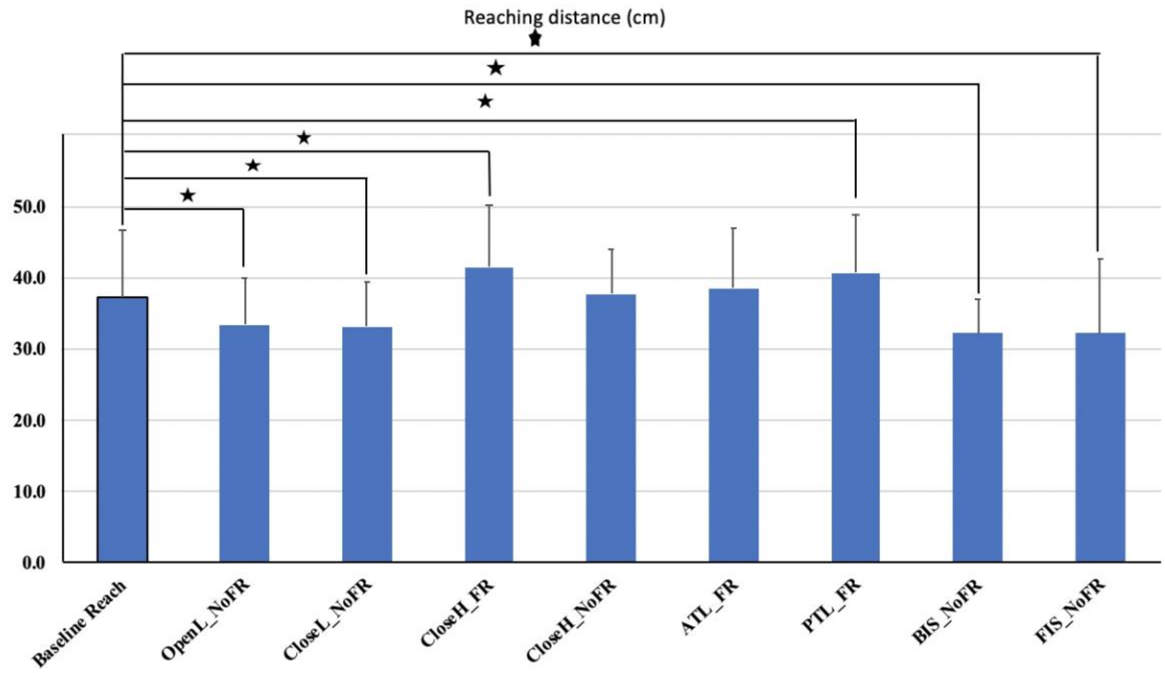


Fig. 3.2. Mean and standard deviation of reach distances measured while sitting in different experimental conditions. Abbreviations: OpenL– Open kinetic chain sitting for the lower limbs; CloseL – Closed kinetic chain sitting for the lower limbs; CLoseH - Closed kinetic chain sitting for the upper limbs; FR – foot rest; NoFR – No foot rest; ATL – anterior leg support; PTL – Posterior leg support; BIS – backward inclined seat; FIS – forward inclined seat. (*) – shows significance.

While sitting and holding the edge of the seat with the contralateral hand, and the legs on the footrest (upper limb closed kinetic chain) (CloseH_FR) the reaching distance increased to 41.5 ± 8.6 cm, 4which was 4.3 cm more than the reaching distance from baseline condition and it was the largest among all experimental conditions. The difference between the baseline condition and CLoseH_FR condition was statistically significant ($p<0.05$). While sitting and holding the edge of the seat with no footrest (CloseH_NoFR), the reaching distance was 37.8 ± 6.1 cm and it did not significantly differ from the baseline sitting condition ($p>0.05$).

While sitting with an anterior leg support, the reaching distance was 38.6 ± 8.3 cm, however, this distance was not statistically significant from the reaching distance in the baseline conditions ($p>0.05$). While in conditions with the posterior leg support, subjects were able to reach 40.7± 8.0 cm more and the reach distance was statistically significant from the reach distance achieved in the baseline conditions ($p<0.05$).

When the subjects were sitting in the forward and backward inclined sitting condition, the reach distance decreased to 32.2 ± 4.8 cm and 32.2 ± 10.5 cm respectively. The difference between the baseline reach and reach while sitting on either forward inclined or backward inclined seat was statistically significant ($p<0.05$). The difference in reach distance between the two wedge conditions was not significant ($p>0.05$).

3.5. Discussion

The reaching distance increased and decreased depending on the effect of each of the selected sitting conditions while subjects performed the reaching task. The results of the experiment supported our hypothesis that reaching distance would be affected by the different sitting manipulations or seat features.

3.5.1. Effect of kinetic chain

Performing the reaching task without the use of footrest, no leg support or upper limb support (an open kinetic chain sitting) brought about a 3.7cm decrease in reaching distance as compared to sitting with footrest. This can be related to the fact that lower limbs are not able to key to the ground or footrest for needed physical and psychological support to reach farther. Foot support have been found to play an active role while performing tasks beyond arm's length (Dean et al. 1999). Performing reaching task while the legs were in closed kinematic chain and no footrest brought about the same (4.0cm) reduction in the reaching distance. This decline in maximal reach could be related to the fact that increased muscle tension impaired balance (Hamaoui et al. 2007). Thus, it could be explained that subjects were caught between reaching further and maintaining balance (while expending energy in doing so), from the law of priority setting, the individual would tend to aim at achieving balance rather than reaching farther.

Furthermore, the results of this study showed that individuals could reach farther with the support of the contralateral arm, irrespective of the hand dominance. We can say that using arm support could help increase the body's stability in the sagittal plane and encourage reaching further. Holding the seat while reaching could also be associated with the increased ability of the subjects to obtain information about the position of the body during reaching. The possibility of this to happen was supported by the literature. Thus, healthy individuals were found to improve their stability of upright standing in the sagittal and frontal planes when using light finger touch contact with a stationary surface (Clapp and Wing 1999). Moreover, somatosensory information to any part of the body in contact with a stable external surface is able to influence the orientation of the body (Lackner 1981).

3.5.2. Role of leg supports

The use of anterior leg support together with footrest brought about a 1.4 cm increase in reaching distance as compared to the baseline reach distance. Similarly, the posterior leg support enabled subjects to reach 3.5cm farther than the baseline reach distance. This can be attributed to the fact that leg supports have been implicated in the optimization of sitting postural control, whereby decreasing the load on muscles while performing tasks that involved arm manipulations. (Aruin 1989). Furthermore, anterior or posterior leg supports were found to enhanced muscular activity in biceps femoris and rectus femoris muscles while sitting respectively (Aruin and Shiratori 2003) that helped in the stabilization of the body. The impact of the foot rest was also important as it was described in the literature that individuals were able to reach further with their feet on the ground than when they were off the ground (Chari and Kirby 1986). So also, healthy subjects were able to reach farther due to the influence of the lower legs in maintaining sitting balance while performing forward reaching tasks whereby supports to the thighs and feet permitted larger forward excursions of the center of gravity (Son et al. 1988).

3.5.3. Effect of the inclined seat

Trunk stability bank on the correct acuity of the orientation of the body and on the development of adequate muscular responses. The visual and vestibular systems utilize the information derived from somatosensory receptors to constantly modify the orientation of the body (Massion 1992); this modification requires further muscular response to maintain stability and balance. Sitting stability on an unstable seat is dependent on the individual ability to bring the projection of the center of mass to line with the center of rotation of the support surface; additionally, movements generated by trunk muscles produce inertial forces which are controlled by the CNS (Lanzetta et al. 2004). Sitting on a backward inclined seat packs the pelvis, thereby ensuring more stability of the body. However, there is a tradeoff – increased stability results in reduced the reaching distance. Quite the opposite, sitting on a forward inclined seat (induced by a wedge posteriorly placed) diminished body stability when the subject reached forward. This result of reduced reaching distance which could be attributed to the fact that the subject developed a protective response in order to avoid slipping off the seat. As such, it was likely that fear of falling due to the increased instability of the body in such a position could influence sitting functional reach performance (Thompson and Medley 2007).

3.6. STUDY LIMITATIONS

We only studied forward reach; the experiment had a small sample size; the fear of falling could affect individual performance during the reaching task.

3.7. Conclusions

The results of the study showed that contralateral arm supported reach, reaching while using footrest and posterior leg support increases the reaching distance, while seat inclination, open and closed kinetic chain for the lower limb reduced reaching distance in sitting. The outcome of the study provided foundation for future investigations of the effect of sitting positions on reaching distance in patient population or individuals with impairments who spend most of their time in sitting position. This information could be used while designing and optimizing assistive technology to allow people with disability achieve enhanced functioning and quality of life.

CHAPTER IV

4. CLINICAL APPLICATIONS

The results of the study on sitting postural sway suggest that crossing the legs while sitting with legs off the ground could help reduce postural sway in the sitting position.

The outcome of the study on sitting reach distance suggests that clinicians can systematically manipulate several factors during the intervention focused on retraining sitting balance and reaching to optimize a client's performance. Thus, the use of the contralateral arm to hold the edge of the seat while performing reaching task in individuals with disability with substantial strength in the upper limb can help them reach farther. Individuals who have limited strength in the upper limb can potentially increase reach distance with the help of a leg support placed or attached to the base of their seat. Moreover, using advances of optimal chair design could assist individuals with disability in performance of daily tasks in seating.

CHAPTER V

5. CONCLUSIONS

The outcome of the first study (Chapter 2) showed that seat configurations and sitting modification influenced the way subjects sway based on the challenges faced in the control of their center of mass within the limits of their stability. We could draw the conclusion that seat inclination brought about a shift in the center of mass and as such, subjects tried to find a more comfortable position within the limits of stability. In so doing, there was an increase in the COP displacement. Subjects sway lesser in the legs crossed condition than the inclined seat condition. Crossing the legs could be a form of self-support during unsupported sitting in everyday life. Having the legs hang freely resulted in the least amount of sway recorded for subjects in the experiment. In other words, sitting unsupported without having to apply so much effort to maintain the posture appeared to be easier to perform for the subjects.

The outcome of the second study (Chapter 3) demonstrated that seat modification and sitting postures affected reaching distance in the seated position. Subjects exceeded their initial reach distance when they reached with the hand by the side and the legs on the footrest; we also recorded similar values when subjects reached with the posterior leg support in place and the legs placed on the footrest. The forward and backward inclination of the seat most likely stimulated a sense of dual tasking (maintaining balance and reaching farther), which in this case sparked the fear of slipping off the seat and falling backwards respectively. This in turn reduced the reach distance in these conditions. Findings from this study could potentially be an emerging way in which individuals who spend most of their time in the seated position can functionally reach better.

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VITA

Name:	Adeolu Ademiluyi
Education:	B.M.R. in Physiotherapy, Obafemi Awolowo University, Ile Ife, Nigeria
Honors:	College of Applied Health Sciences Board of Trustees tuition waiver Sprig 2019, Graduate College tuition full-time tuition waiver
Publications:	Obembe AO, Ademiluyi AA, Olaogun MOB, 2014. Impact of an educational package on stroke survivors' knowledge of stroke rehabilitation. International Journal of Stroke. Suppl. 3: 268), 2014.
Memberships:	Member of Medical Rehabilitation Therapists Board of Nigeria