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Seated Postural Changes with Foot Position at a Tall Workstation

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Nomenclature

FOF = Feet on the Floor data collection

$FUCh$ = Feet Under Chair data collection

FUT = Feet Under Table data collection

$STAND$ = Standing collection

Tall Workstation= A workstation where feet do not touch the floor

Preferred Posture= A posture that is preferred by clinicians for the health of the spine

1 Abstract

Back pain is a leading cause of disability costing 100 billion in healthcare and missed work in the United States alone[15]. While traditional workstations have been extensively studied, non-traditional workstations have not been as rigorously investigated for ideal settings and possible improvement[4]. The motivation for this project was to investigate an understudied but growing workstation setup—a tall workstation. The aim of this project was to assess tall workstations and the effect of foot position on back posture. Posture is a growing area of research as we understand that the spinal loading of sitting for long periods of time can have long lasting deleterious effects[3,26]. In this study we determined the feasibility of quantifying back posture during two 30-minute data collections and developed methods for analyzing time-varying back posture. This study involved collecting a single dataset from a volunteer who sat a tall workstation setup, where feet are not meant to touch the floor, with two different foot positions. For the first foot position, the subject placed their feet under the table on a bar made for that purpose, and the second position was to place the feet on the circular ring under the chair also designed for this use. The three-dimensional position of 11 retroreflective markers adhered to the spine and back were collected for thirty minutes in each position (60 minutes total). Lastly, two reference posture datasets were collected for one minute—a standing posture and a traditional seated posture. Marker position movement was quantified by taking the absolute distance of each marker position from its own starting

point as the origin. Marker positions along the spine were fit to a 5th order polynomial on each timeframe to investigate changes in the shape of the spine over time and between foot positions. At each marker location, the slope of the 5th order polynomial was determined to assess in which anatomical locations the spine changed shape over time and between foot positions. The slopes along the spine were subtracted from the first timeframe and the preferred postures, and the absolute value was then summed and averaged across all the markers. The plot of marker positions over time showed that the subject moved increasingly farther away from the origin in both foot positions. The 5th order polynomials showed that both foot positions were significantly more curved than the preferred postures and they both curved more overtime though the FUT posture curved slightly more. Overall, this thesis demonstrates the feasibility of quantifying back posture with varying foot position at a tall workstation. Ongoing subject recruitment and data collections will generate results for which statistical comparisons can be made for temporal changes in back posture and foot positions.

2 Introduction

Back pain is the single leading cause of disability worldwide, and the prevalence of back pain is increasing[25,26]. Lower back pain is a major cause of disability costing 100 billion in healthcare and missed work in the United States alone[18,27]. Over 80 percent of the population experiences back pain at some point in their lives[12]. According to the American Chiropractic Association, the majority of cases are caused by poor posture or repetitive mechanical loads, rather than caused by another condition like arthritis, fracture, infection or cancer[3]. Because of the high prevalence of back pain, there has been a large amount of research on the ideal seated posture, and the methods of evaluating it[2,4,5,7,8,10,13,14,18–20,23,24]. This is reflected in the review by E.N Corlett which found that an ideal posture is one with feet on the floor, and a 110 degree backrest angle, along with the weight distribution being transmitted primarily through the pelvis[4]. Additionally, various solutions have been implemented and tested for the traditional workstation to alleviate back pain and create better posture these include saddle chairs, reclining chairs and standing workstations[10,14,15,19,20,23,24]. It is believed that by improving posture, back pain and the development of back pain can be reduced. OSHA even has guidelines on seating to this end[11].

One area of research in ergonomics deals with the spine position as the driving force of the posture. The spine is after all much of the back and many back problems come from the spine. This has driven many to study the spine with a variety of methods to try to develop new technologies to look at posture non-invasively. One such way that has been repeatedly used is by attaching motion capture markers to different vertebra to try to get a sense of the shape of the spine. This improvement in looking at posture is positive, still much of traditional workstation research assumes that there is control over the workstation in question and that ideal conditions are possible with modification. However, there are numerous real-world workstations where the confining factors are not related to the workstation itself. One subset of these is the tall workstation where the feet are not meant to touch the floor or a block. This is seen in a variety of workspaces including public workspaces in coffee shops, libraries, and airports and in jobs such as labs, hospitals, receptionist desks or office jobs. In these workspaces there may be equipment or luggage that needs to fit under the workspace, or it may be so that there is privacy in a larger room. These workstations are a problem in that traditional workstation research does not apply as it often begins getting the feet in a flat position comfortably on the floor or a block. Additionally, because leaving the feet hanging is so uncomfortable that many people would have to get up, tall workstation manufacturers have put forth two main solutions. One is a ring or bar underneath the chair and the other is a bar underneath the table. Neither give the feet a solid place to land and neither position the foot where it would naturally and, according to traditional workstation research, ideally rest. This then effects the knee and hip angles which can cause pain, and can lead to different hip and spinal postures. The aim of this project is to discover if the current ways of coping with a tall workstation are creating healthy posture and if the postures produced by tall workstations change over long periods of time. The aim of this study is to determine if the set of methods of looking at total movement, spine shape, and calculated slopes is an appropriate way of quantifying a posture.

3 Methods

3.1 Study Subject

A single volunteer was used for this initial study. The volunteer was male 27 years old, 63.5 inches with shoes, and 160lbs. The volunteer was told about the purpose of the research and the expectations for the subject.

3.2 IRB Approval

For this project IRB approval was received. A detailed protocol and recruitment documents including phone scripts and email blasts were created and submitted to the IRB for approval. After several rounds of edits the protocol was approved and research began.

3.3 The Workstation

The workstation set up went through several iterations over the course of the project. The first part of designing the workstation included measuring various tall workstations around campus to get a range of appropriate table heights where people's legs would not be able to touch the floor. This ended up being a range of 40" to 58". Various tables were compared including ones that were height adjustable; however, because none of the real-world tables found were adjustable it was decided to go with a fixed height table. The table was found on a major online seller and marketed as a bar table, it had the appropriate foot bar and was designed to be sat at for a good amount of time. The focus on a real world set up made for the lab would continue in the search for a chair. several Several chairs were found and compared for range. The chair with the largest range was chosen for the experiment and fitted to the table to ensure it would make a good workstation. The chair also had the required ring under the seat for the feet of the participants. However, this stool's range was not able to approximate a regular office chair to allow for lordotic seating. Instead a regular office chair with the back removed was used for the preferred seated posture, which is closer to the preferred workstation as well. A laptop was placed at the workstation as many people use laptops at their workstations. At the beginning of data collection the workstation was set up by changing the chair to a height where the participant could not reach the floor with their feet, but could reach both bars under the table and the chair. Then the chair was moved to a comfortable position for them to reach the bars. Both the chair and the table had motion capture markers for calculation of their relative distance in post processing. The elbow angle of the participant was measured so at the start and ensured that it was between 90° and 110° which follows guidelines from OSHA[11].

The preferred postures were a standing posture in which the subject was told to stand comfortably feet hip width apart and stay still for one minute. This was chosen as at least a part time standing desk is a common choice for those who experience back pain. The other preferred posture was determined from a previous study where it was chosen most out of all the postures shown to be the "best" seated posture by clinicians[21]. To achieve this posture the workstation was changed to include a traditional workstation chair that had its back removed. The participant was then shown the image and instructed to sit like the image. The height of the chair was adjusted to ensure their knees were at a 90-degree angle.

3.4 Motion Capture

The motion capture system consisted of 10 Vero infrared cameras (Vicon, Oxford, UK). The system was calibrated with an active wand, and the laboratory origin was set at a consistent location marked on the floor. Markers were placed under the supervision and training of a clinician. Marker positions were acquired, stored and reconstructed using Vicon Nexus. Retroreflective 14mm markers were placed on the participant in 11 locations. Ten were placed on the spine, which has been shown to be the number required to get an accurate representation of spinal curvature[16]. The locations of these were C7, T10, T4, T7, T10, L1, Lmid (centered between L1 and L4), L4, L (centered between L4 and SACR), SACR (Centered between LPSI and RPSI) found in previous research[20]. One a rotational marker was placed an inch and a half to the side of T10 to be able to be able to create a sagittal plane in analysis and modify for rotations to detect any major body rotation. Due to limitations with computer memory, marker positions were collected for 10-minute intervals for 30 minutes for the two tall workstation postures and for one minute at the two resting postures— the preferred seated and the standing posture.

3.5 Post Processing

The first part of post-processing was marker labeling. A model template was created for the chair, the table and the spine. The next step was to check that the auto labels were applied correctly and to fill in missing marker locations using the Vicon Nexus software. Only one marker was found to disappear regularly, and it was the farthest from the camera's field of view on the table. The next step was to export the c3d files and organize the data in MATLAB. Because the data was collected in 10-minute increments this needed to be done for each one and then stored in a MATLAB structure. Unfortunately, some of the data was lost in export in the first FUCh data collection due to the size of the file, in later trials the file size will be reduced. After this the sagittal plane was created by using a cross product of the rotational marker and the marker directly above T10, both expressed relative to the T10 marker. The sagittal plane is the plane that goes through the body vertically and anteriorly. Then an origin was created in this plane at the SI joint (base of the spine marker set).

3.6 Spinal Posture

The spinal curve is approximated using a 5th order polynomial which was found to be an appropriate approximation of the curvature, see Figures 1 and 2[22]. For the spinal posture the origin set at the bottom of the spine allows the graphs to be layered over each other and compared. This method of shape creation and setting the sacrum as the origin has been done in previous research as the seat does not move much, it moves significantly less than C7 and only about a millimeter. After the curve was plotted they could also be compared numerically by using the derivative to get the slope. This was done by taking the derivative of two of the curves at the point closest to each marker, this position was taken by finding the shortest distance to the curve and then taking the derivative there and graphing it over the marker location as seen in Figure 3. This must be done in the x direction as the MATLAB function requires only one x-value per y-value and when turned upright they sometimes overlap slightly. The curves and derivative values can now be directly compared at time points of interest and times utilizing this derivative value. For the differences calculation, the difference of the derivatives of the individual markers in the two postures to be compared was taken. Then this value had the absolute value taken of it. This was then either summed or averaged for each comparison to get the total or average absolute value difference for all the derivatives C7 through SACR. For this proof-of-concept study, the 1 minute, 15 minute and 30 minute marks were graphically compared to each other and the two preferred postures.

The beginning and end of each position was compared to each other using the derivatives.

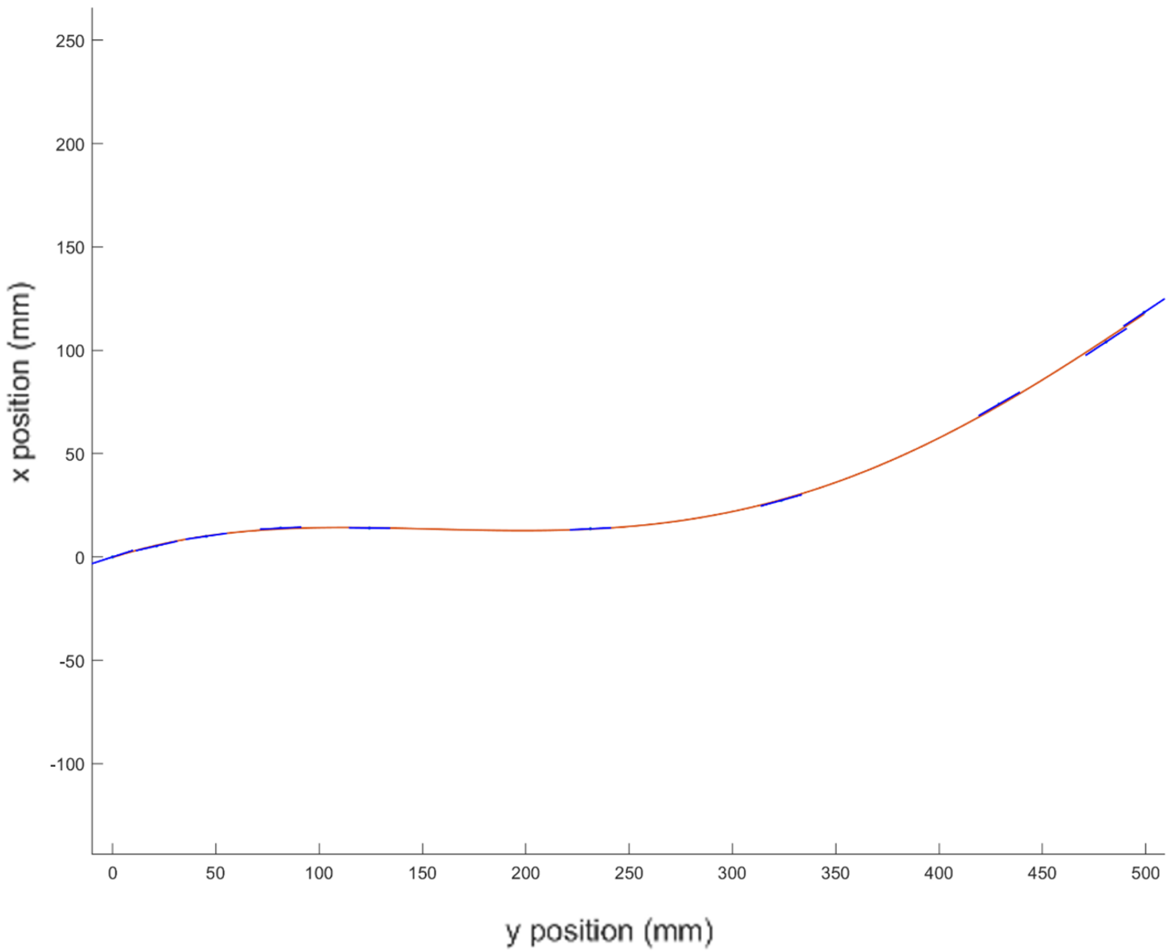

Figure 1: The shape of one of the prefered curves with derivative lines, the sagittal plane is shown with the "head" being on the right and the sacrum on the left

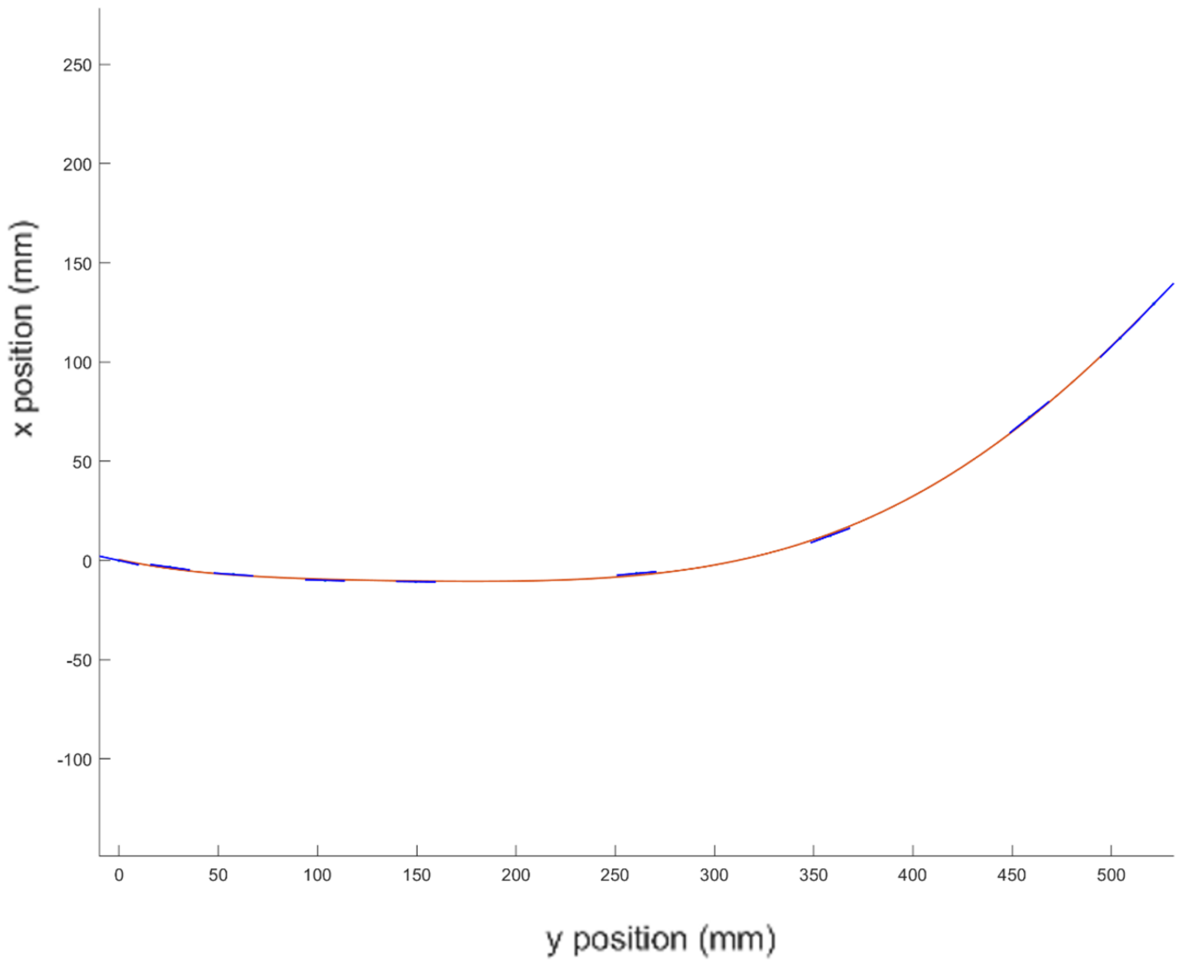

Figure 2: The shape of one of the tall workstation curves with derivative lines, the sagittal plane is shown with the "head" being on the right and the sacrum on the left

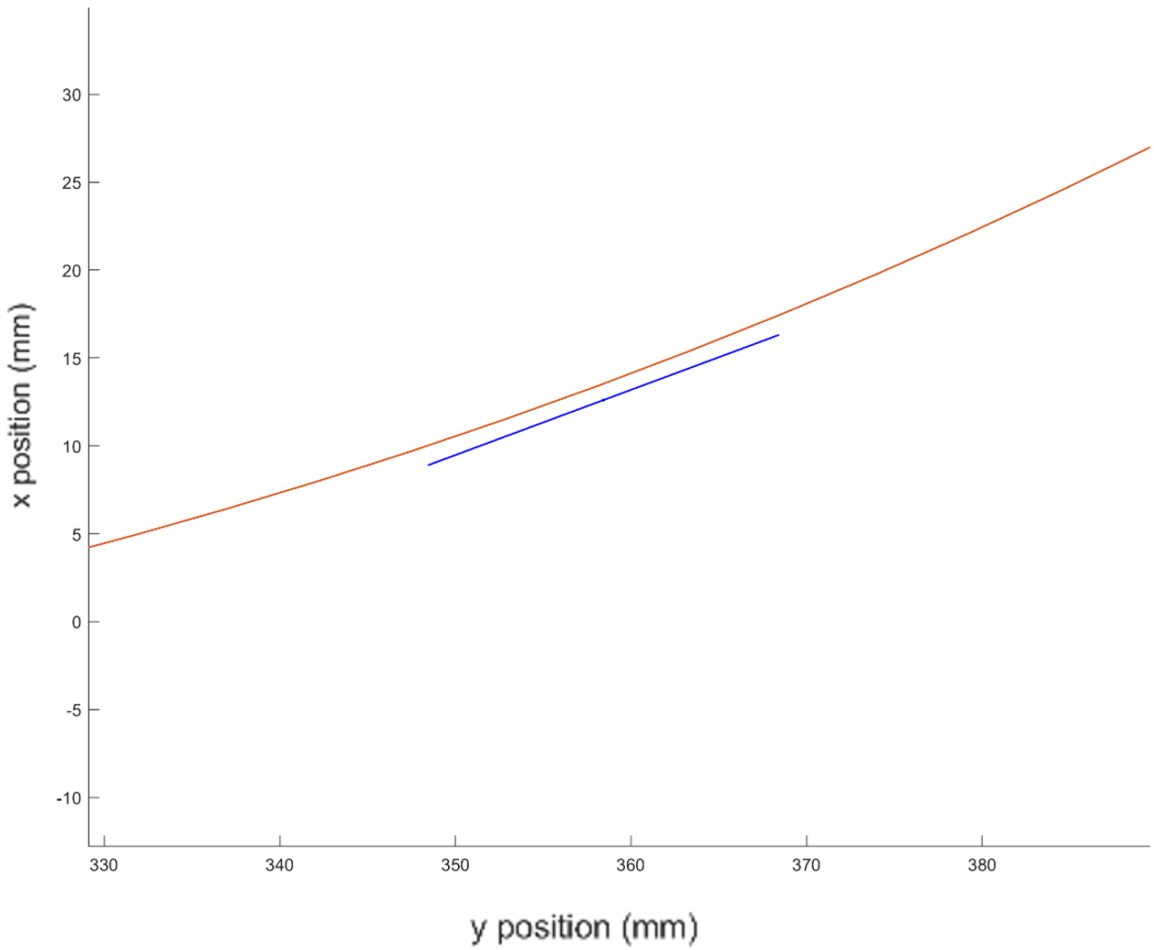

Figure 3: A close up look at a derivative line and the curve it represents

3.7 Spinal Movement

Spinal movement is how much movement there was in the spine over all. Spinal movement, can be shown through the magnitude of how far away the markers were from their starting positions. This could give insight into the shifting caused by discomfort or if a position was settled relatively quickly. This was done by comparing the position over time from its original position.

4 Results

4.1 Movement

The overall movement graphs are compared between the whole of the FUCh and FUT trials in Figures 4 and 5.

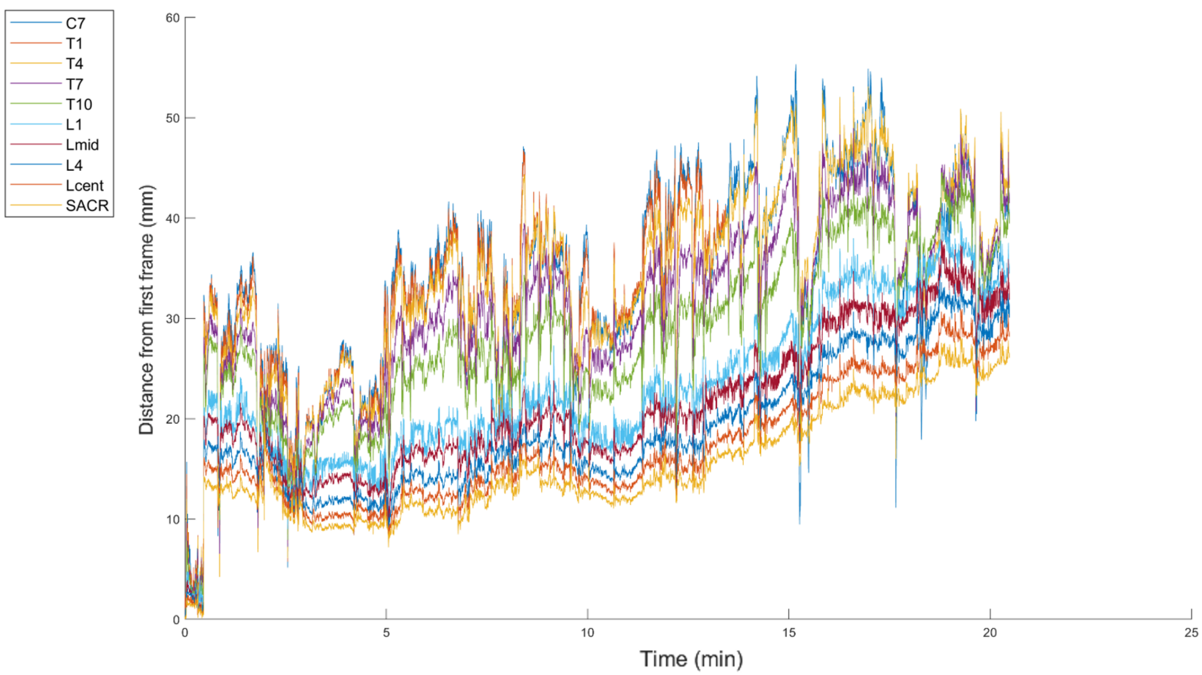

Figure 4: Visualization of the movement for Feet Under the Chair

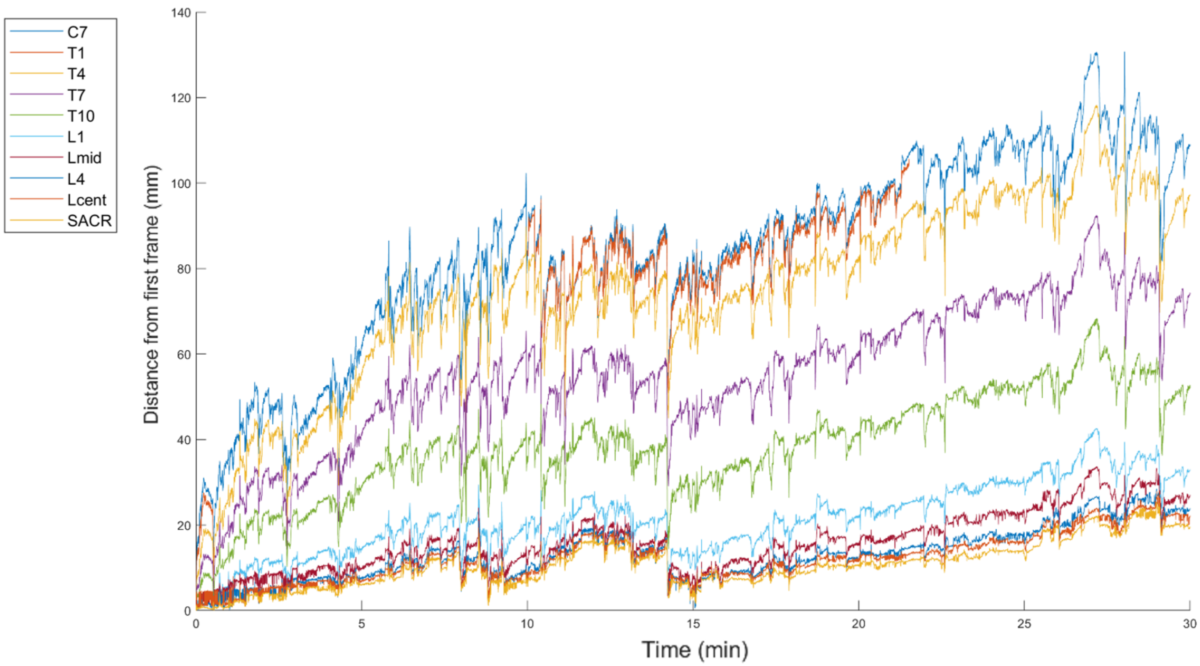

Figure 5: Visualization of the movement for Feet Under the Table

Both graphs demonstrate that the closer to the top of the spine the more movement was seen in the spine. It should also be noted that it would appear that the data lost from the FUCh collection was likely in the middle of that collection as that is where the larger jump is in the position.

4.2 Spinal Positions

Figures 6 and 7 show the posture at the times the 0 minute the 15 minute and the 30 minute. The data was down sampled so that one spinal shape was extracted for every 10 seconds as well as the actual time itself meaning there were a total of 7 samples taken across one minute. These were then averaged into the three spine shapes shown for each minute of data.

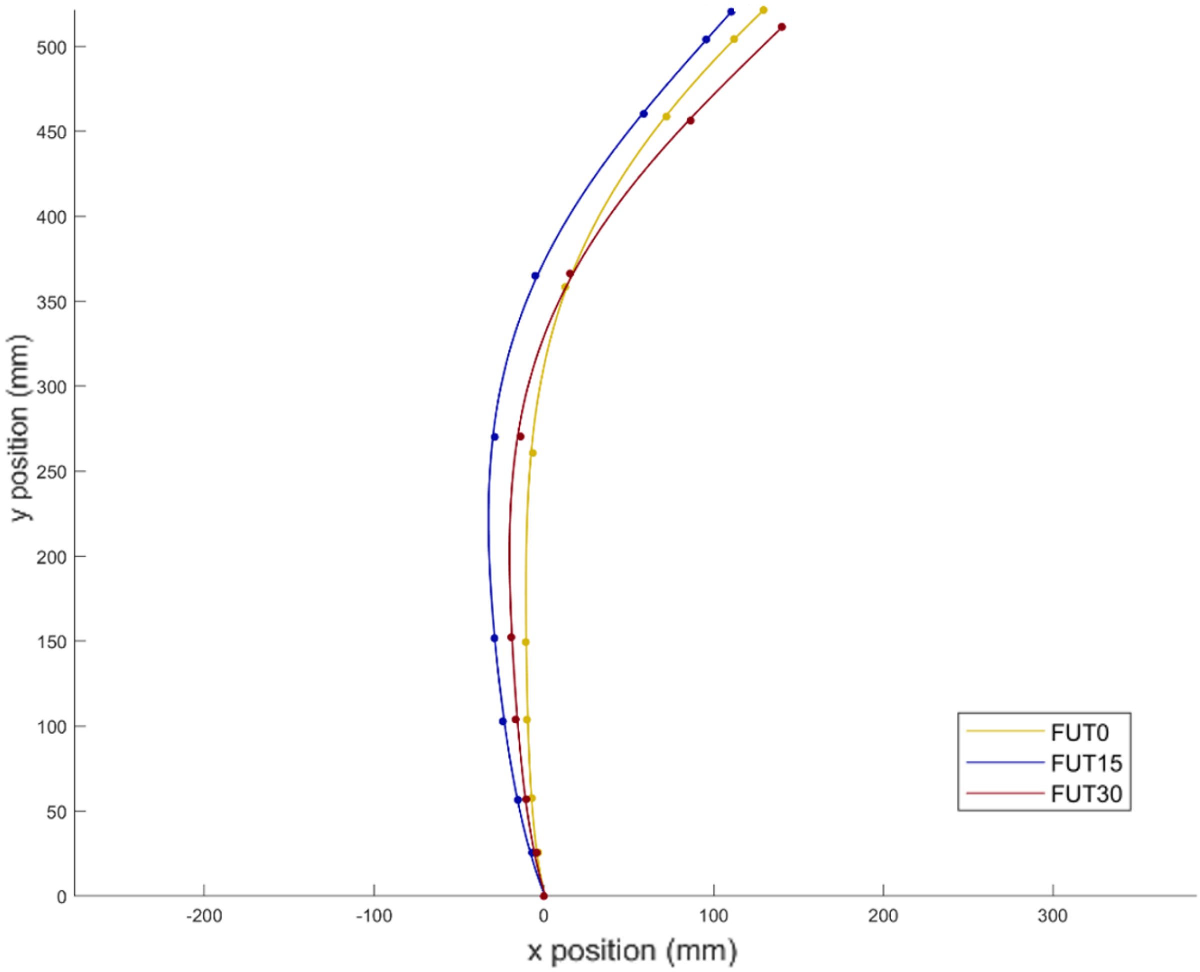

Figure 6: Visualization of the spine curve shape for Feet Under the Table, the sagittal plane with C7 at the top and the Sacrum at the origin

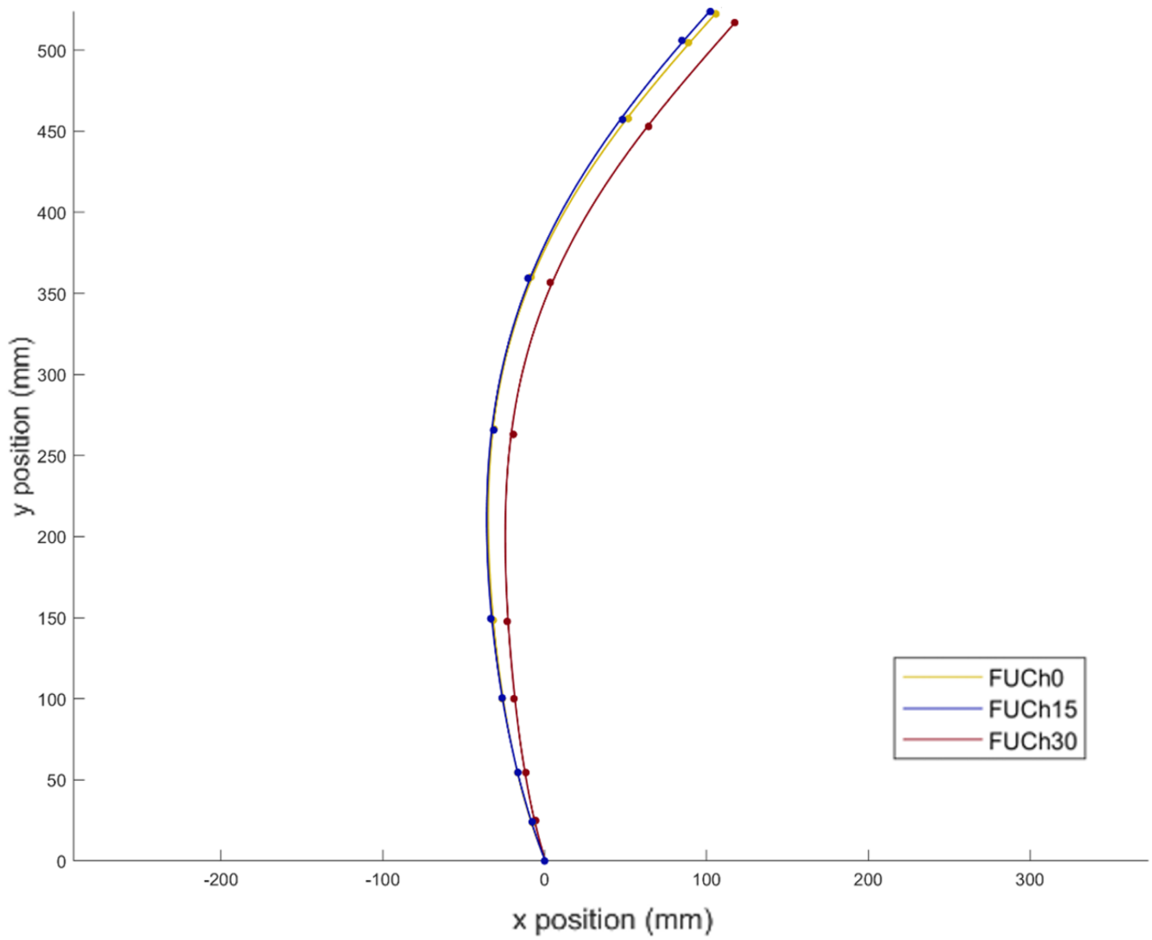

Figure 7: Visualization of the spine curve shape for Feet Under the Chair, the sagittal plane with C7 at the top and the Sacrum at the origin

The 5th order polynomial fit was also applied to the preferred postures and these were graphed separately and with the tall workstation postures.

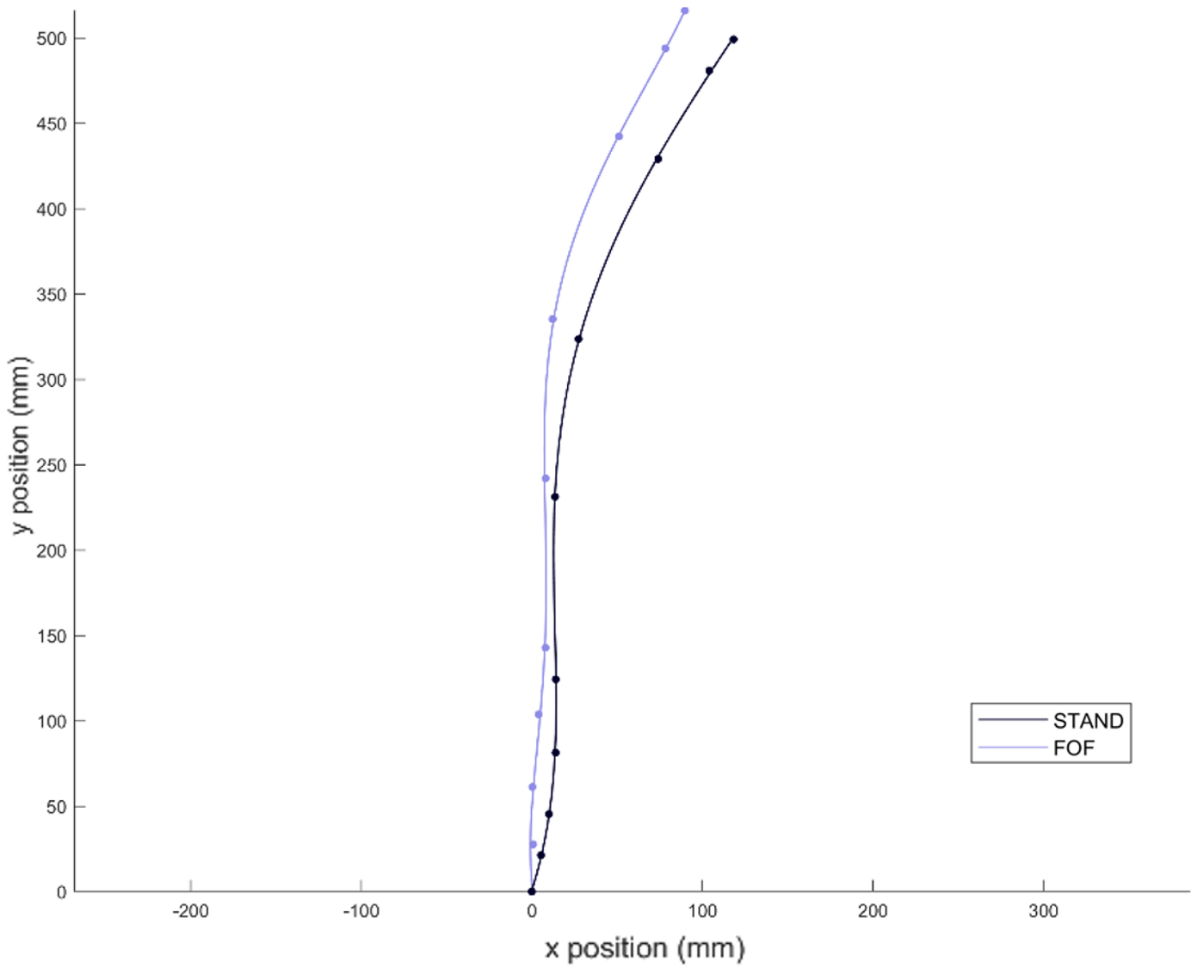

Figure 8: Visualization of the spine curve shape for the preferred postures, the sagittal plane with C7 at the top and the Sacrum at the origin

It is also possible to compare these spinal postures by directly overlapping the graphing making the differences in the curvatures more obvious (Figures 9 and 10).

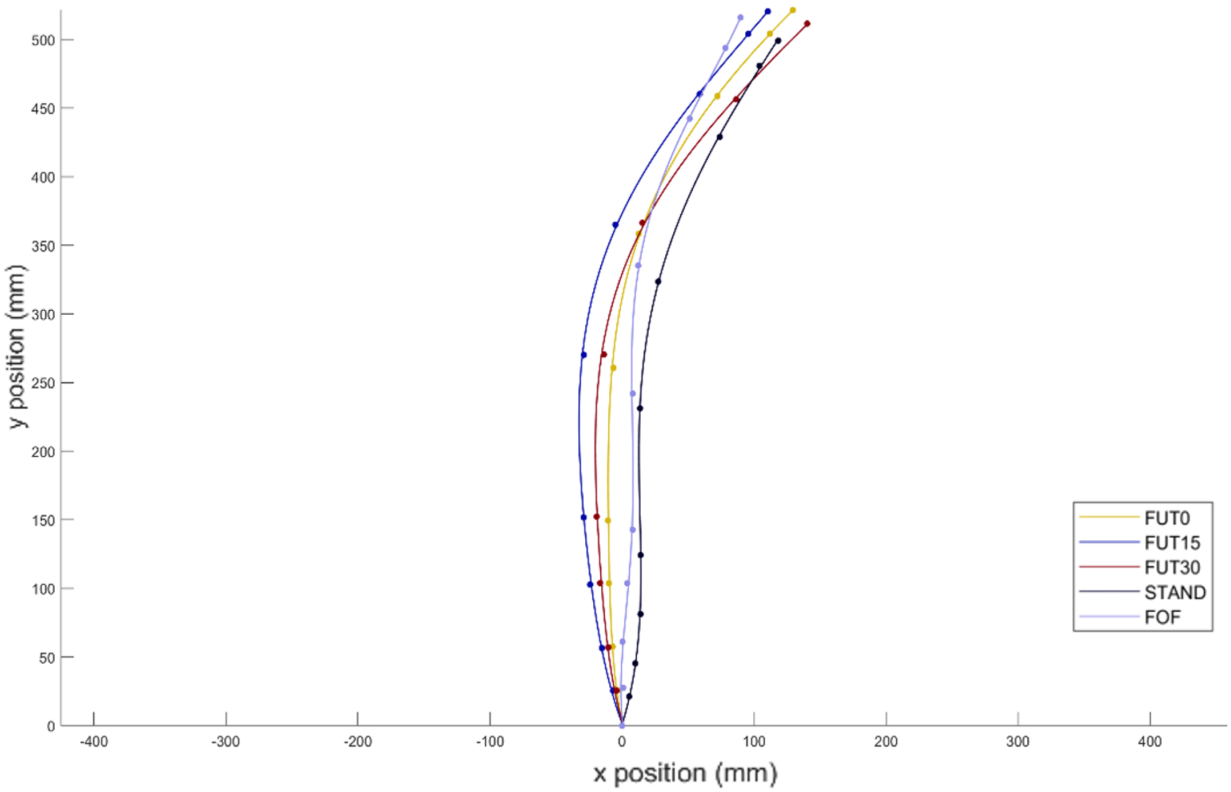

Figure 9: Visualization of the spine curve shape for Feet Under the Table with preferred postures, the sagittal plane with C7 at the top and the Sacrum at the origin

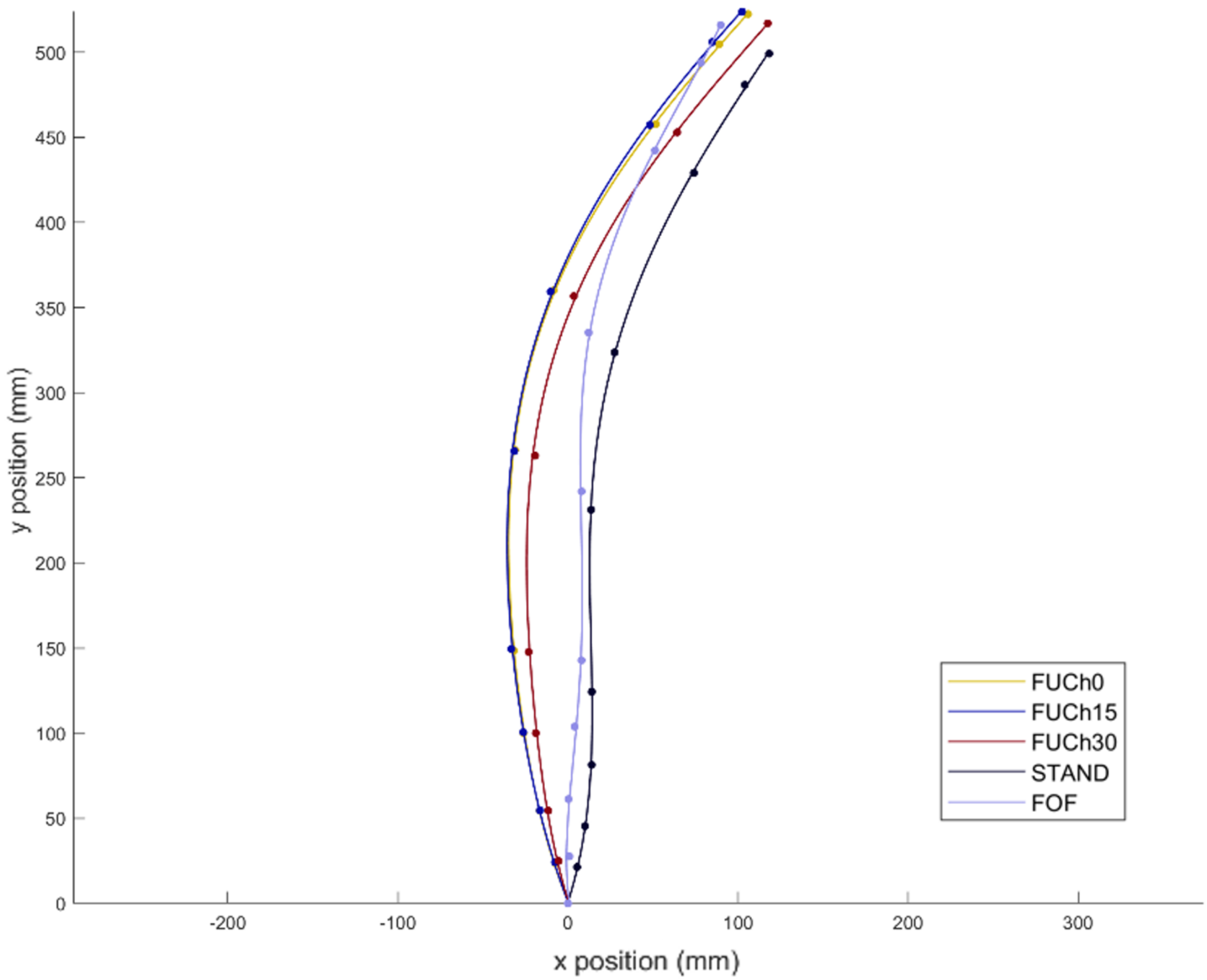

Figure 10: Visualization of the spine curve shape for Feet Under the Chair with preferred postures, the sagittal plane with C7 at the top and the Sacrum at the origin

The two different foot positions can also be directly compared with this method. For this subject they are relatively similar with FUT being slightly more curved than FUCh.

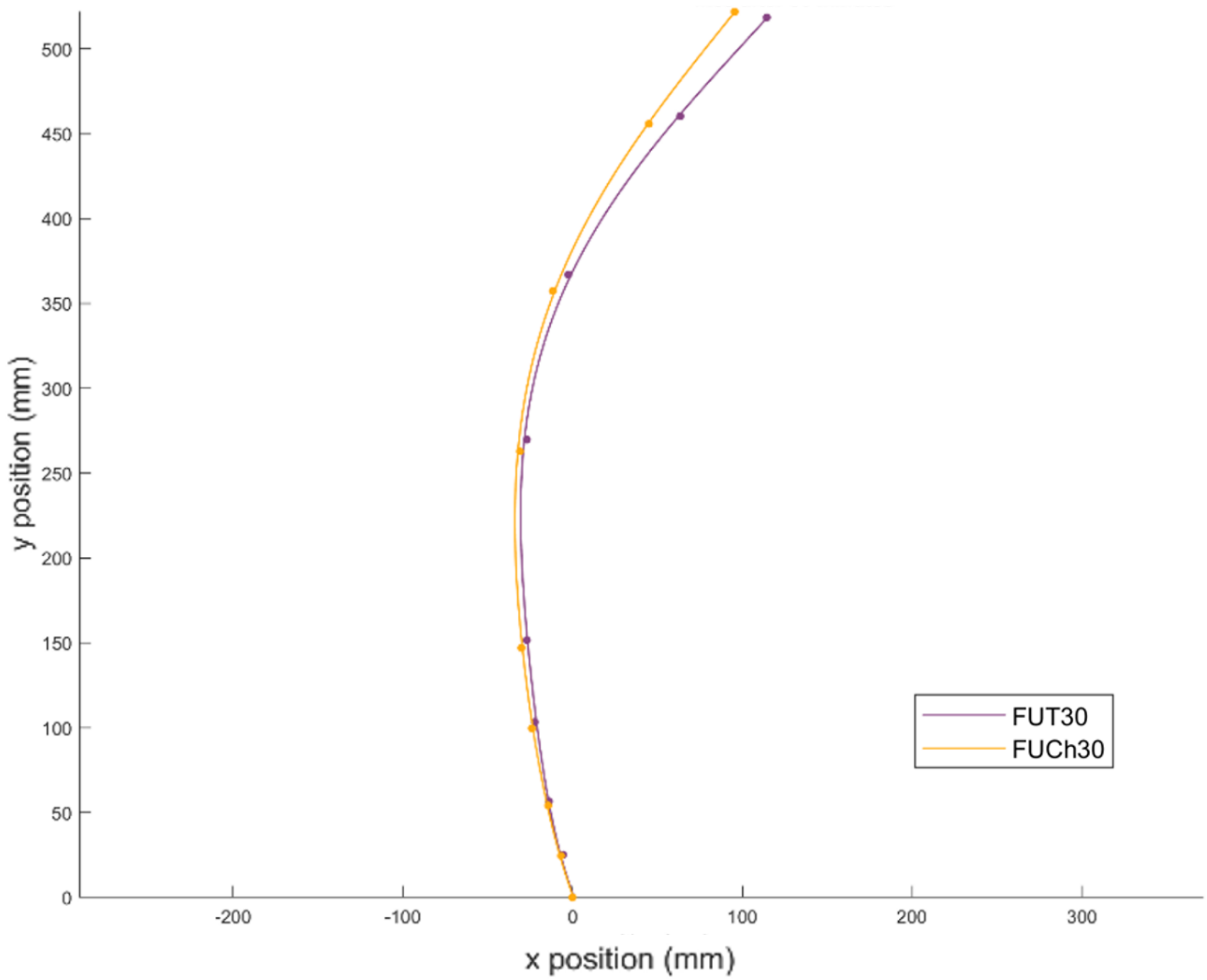

Figure 11: Visualization of the spine curve shape for the final minute of collection for the tall workstation postures, the sagittal plane with C7 at the top and the Sacrum at the origin

4.3 Derivatives

Table 1 shows the sum and average differences between the derivatives of the spine shapes.

The derivatives themselves for each spine shape are listed in Table 2. Because T1 dropped out of view or was not recorded for a section near the end of both collections it returns no value.

All values in mm/mm	Sum Difference	Average Difference
FUT30-FUCh30	0.57	0.06
FUT15-FUCh15	0.29	0.03
FUT0-FUCh0	1.09	0.11
FUT0-Standing	2.26	0.23
FUCh0-Standing	2.82	0.28
FUT0-FOF	2.16	0.26
FUCh0-FOF	2.72	0.27
FUT30-Standing	2.63	0.29
FUCh30-Standing	2.28	0.25
FUT30-FOF	2.40	0.27
FUCh30-FOF	2.06	0.23

Table 1: the differences summed and averaged in the derivatives for each time point and location

Positions (mm)	C7	T1	T4	T7	T10	L1	Lmid	L4	Lcent	Sacr
Standing	0.67	0.66	0.57	0.28	0.048	-0.01	0.05	0.15	0.23	0.32
Feet on Floor	0.46	0.53	0.52	0.17	-0.02	0.04	0.09	0.09	0.007	-0.14
0minute FUT	1.03	0.98	0.80	0.37	0.09	-0.012	-0.029	-0.07	-0.14	-0.22
15 minute FUT	0.89	0.89	0.82	0.46	0.11	-0.093	-0.14	-0.21	-0.29	-0.39
30 minute FUT	1.03	NaN	0.94	0.55	0.16	-0.05	-0.08	-0.13	-0.21	-0.31
0 minute FUCh	0.90	0.88	0.77	0.42	0.12	-0.09	-0.16	-0.24	-0.32	-0.41
15 minute FUCh	0.90	0.87	0.74	0.40	0.12	-0.10	-0.17	-0.25	-0.32	-0.39
30 minute FUCh	0.88	NaN	0.78	0.43	0.13	-0.06	-0.11	-0.17	-0.23	-0.31

Table 2: the derivatives at each location and time point

5 Discussion

The purpose of the project is to determine if current methods of mediating the effect of not being able to have feet on the floor are effective for creating a healthy posture and to look at these postures overtime. In this study the total movement, spine shape, and calculated slopes were evaluated as methods of categorizing and assessing postures. This was achieved through the course of this study. The overall movement graphs showed themselves to be an appropriate way to visualize total movement, though it does not take direction into account, it can show where the movement was. For the most part it shows the peaks in movement at the same time for different vertebrae, meaning it can capture whole spine movement. This means that it can show the spinal motion as a whole as well as more individual changes and be used to show any potential differences in the spinal motion trends over time between the postures.

In the spinal position data, the first minute of data for the feet under table was shown to be less curved than the other two, while the posture changed relatively little between 0 and 15 for the FUCh collection, though this could be because of data loss . Still in both, the 30 minute mark shows a more rounded spine, a progression backed by the movement data. This shows that utilizing a 5th order polynomial fit is an effective method of looking at the spine. It can also be seen to follow and align with the markers well over several different spine shapes. For the preferred postures, it is clear these postures possess the double curved structure that is expected out of a spine. The standing spin with a bit more curve than the lordotic seated posture. This is an appropriate way to look at these spines and the methodology achieved the lordotic shape clinicians prefer for a healthy spine posture. Overlapping these curves onto the FUT and FUCh curves effectively demonstrates the differences in shape. In the numerical data, looking at the magnitude and the direction of the derivatives one can get a clear understanding of the curve and if it is lordotic or not. This indicates that the derivative is a valuable numeric method of understanding the shape of the spinal curve. The numbers in table are partially explained by the fact that there are 10 markers for the majority of the sets, meaning that the average is a factor of 10 less than the sum. Interestingly, the smallest difference is between the long collections at the 15 minute mark. The largest difference is between the FUCh at the 0 time point and the standing collection. It should be noted though that the largest average difference is between the FUT at time 30 minutes and Standing collections. This could indicate that when a marker is dropped the average may be a more important value than the total. It is not yet possible to tell if this is statistically relevant. This method does provide different information than the graphical as it shows more than just the distance and instead gives an idea of the total difference in shape numerically. These findings are congruent with and expand on other findings in previous research. The fit of the 5th order polynomial was effective in visualizing the spine as well as utilizing it for numerical categorization via the derivative. Additionally, the trend in the data to show that postures created by a non-preferred workstation are different from the preferred postures was also affirmed. There are limitations to this study. This includes the small sample size, the larger project will provide more data as well as the ability to statistically determine if differences are significant. While the 10 marker system has been shown to be effective, it is still an approximation and placing the markers may not be fully accurate. This was mitigated by training and practicing the placement with a clinician and by only having one time of collection for each subject, meaning any placement error would be consistent and should not effect the shape. However, it could be a source of error when comparing subjects to each other, even with clinician training.

6 Conclusion

It was possible to analyze and determine good methods for analysis for this project moving forward. Among these methods is a total movement graphical representation that is able to show the magnitude and trends in the movement of each marker individually as well as showing the trends of the spine as a whole. This is excellent for validating the changes in shape that might be seen as well as locating any missing data or markers.

The 5th order polynomial with the origin at the SACR marker worked well for depicting the shape of the spine and was able to be fit to a variety of spine shapes. This allowed the spines to be visualized so the progression over time could be clearly seen. It also allows for the derivatives to be created and compared. The derivatives were able to represent distinct spinal shapes and to be used to compare these shapes. The comparison is best done as an average in case a marker drops out during collection.

7 Continuing Work

In future work we will recruit and image more participants. As specified in the IRB protocol, multiple T-Tests will be preformed on the derivative data to determine statistical relevance for the differences in positions. Positions and derivative values will not be directly compared between participants due to anatomical differences only the differences between positions like those in the results. The distance of movements for each person that exceeds a threshold will also be recorded to be able to numerically ascertain if and when participants are moving more as a measure of their potential discomfort. This will also be evaluated with a T-Test. Additionally, some data smoothing will occur to remove noise from the movement graph, something which is apparent in this iteration. In later work the differences across markers might need to be found and evaluated separately from the whole shape data yielded by the totals. Additionally, through this work the average total difference in the derivatives was chosen above the total sum as it can account for a single marker loss. The data collected in this study will be used to evaluate the solutions provided for tall workstations, comparing both feet positions to the preferred postures. At the end of the study the goal will be to provide a recommendation about the construction of tall workstations based on the evidence gathered.

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9 Appendices

9.1 Appendix 1: Tables

Differences	C7	T1	T4	T7	T10	L1	Lmid	L4	Lcent	Sacr
FUT30-FUCh30	0.15	NaN	0.16	0.12	0.03	0.01	0.03	0.04	0.03	0.01
FUT15-FUCh15	-0.01	0.03	0.08	0.06	-0.01	0.01	0.03	0.04	0.03	-0.003
FUT0-FUCh0	0.13	0.10	0.03	-0.05	-0.03	0.08	0.13	0.17	0.19	0.19
FUT0-Standing	0.37	0.32	0.22	0.09	0.04	0.001	-0.08	-0.22	-0.37	-0.55
FUCh0-Standing	0.23	0.22	0.19	0.14	0.07	-0.08	-0.21	-0.38	-0.55	-0.73
FUT0-FOF	0.57	0.45	0.28	0.20	0.11	-0.06	-0.12	-0.16	-0.14	-0.08
FUCh0-FOF	0.43	0.35	0.25	0.25	0.13	-0.14	-0.25	-0.32	-0.33	-0.27
FUT30-Standing	0.36	NaN	0.37	0.27	0.11	-0.04	-0.13	-0.28	-0.44	-0.63
FUCh30-Standing	0.22	NaN	0.20	0.16	0.08	-0.05	-0.16	-0.32	-0.47	-0.64
FUT30-FOF	0.57	NaN	0.42	0.38	0.17	-0.10	-0.17	-0.22	-0.21	-0.17
FUCh30-FOF	0.42	NaN	0.26	0.26	0.14	-0.11	-0.20	-0.26	-0.24	-0.17
0 minute FUCh	0.90	0.88	0.77	0.42	0.12	-0.09	-0.16	-0.24	-0.32	-0.41
15 minute FUCh	0.90	0.90	0.74	0.40	0.12	-0.09	-0.17	-0.25	-0.32	-0.39
30 minute FUCh	0.88	NaN	0.78	0.43	0.13	-0.06	-0.11	-0.17	-0.23	-0.31

Differences Abs Value	C7	T1	T4	T7	T10	L1	Lmid	L4	Lcent	Sacr
FUT30-FUCh30	0.15	NaN	0.16	0.12	0.03	0.01	0.03	0.04	0.03	0.01
FUT15-FUCh15	0.01	0.03	0.08	0.06	0.01	0.01	0.03	0.04	0.03	0.00
FUT0-FUCh0	0.13	0.10	0.03	0.05	0.03	0.08	0.13	0.17	0.19	0.19
FUT0-Standing	0.37	0.32	0.22	0.09	0.04	0.00	0.08	0.22	0.37	0.55
FUCh0-Standing	0.23	0.22	0.19	0.14	0.07	0.08	0.21	0.38	0.55	0.73
FUT0-FOF	0.57	0.45	0.28	0.20	0.11	0.06	0.12	0.16	0.14	0.08
FUCh0-FOF	0.43	0.35	0.25	0.25	0.13	0.14	0.25	0.32	0.33	0.27
FUT30-Standing	0.36	NaN	0.37	0.27	0.11	0.04	0.13	0.28	0.44	0.63
FUCh30-Standing	0.22	NaN	0.20	0.16	0.08	0.05	0.16	0.32	0.47	0.64
FUT30-FOF	0.57	NaN	0.42	0.38	0.17	0.10	0.17	0.23	0.21	0.17
FUCh30-FOF	0.42	NaN	0.26	0.26	0.14	0.11	0.20	0.26	0.24	0.17
0 minute FUCh	0.90	0.88	0.77	0.42	0.12	0.09	0.16	0.24	0.32	0.41
15 minute FUCh	0.90	0.87	0.74	0.40	0.12	0.10	0.17	0.25	0.32	0.39
30 minute FUCh	0.88	NaN	0.78	0.43	0.13	0.06	0.11	0.17	0.23	0.31