Reliability Evaluation of the BIFMA Chair Measurement Device

by

Hyun Lee

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APPROVED:

Dr. Robert J. Beaton, Chair

Mr. John Deighan

Dr. Albert M. Prestrude

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Committee Chairman: Robert J. Beaton

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(ABSTRACT)

In the last decade, most offices have been equipped with computers, and most office workers spend much of their time sitting in chairs. And recently, as many office workers complain of back pains, the importance of proper sitting and of chair designs that provide comfortable and suitable sitting posture has become recognized widely.

One organization involved in the design of chairs is the Human Factors and Ergonomics Society (HFES) and its ANSI/HFES 100 committee. This committee has established the ANSI/HFES 100 standard for various types of furniture used at computer workstations, including chairs, desks, and tables. This committee also has designed the Chair Measurement Device (CMD) for specific assessments of seat height, seat depth, seat width, backrest height, backrest width, lumbar support, seat to back included angle, seat pan angle, armrest height, and armrest clearance, for the purpose of developing chairs in connection with other related furniture, such as computer desks. The CMD has been developed through the Business and Institutional Furniture Manufacturer's Association (BIFMA).

The purpose of this study was to evaluate the reliability of the CMD, for future use in evaluating chair design. Eight participants made specific measurements of three chairs over three measurement sessions. Six measurements were taken from each chair: lumbar support height, seat height, seat depth, backrest height, seat pan angle, and seat to back included angle. This experiment produced 2,160 data points, and standard deviation and

confidence interval analysis was used to evaluate the inter-evaluator reliability (i.e., consistency across the different evaluators) and the intra-evaluator reliability (i.e., consistency within an evaluator).

All standard deviations and 99% confidence intervals of the measurements were very small, implying that the measurements using the CMD were reliable across the evaluators, as well as within evaluators. The results also show that the procedure established for measurements was adequate for ANSI/HFES 100 compliance evaluations..

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INTRODUCTION

As most offices have been equipped with computers and most office workers spend a considerable amount of time sitting in chairs, the number of workers who complain of back pain has increased rapidly (in some surveys conducted in Europe and North America, up to 80 percent of the sampled population suffered back pain; Helander, 1988), and the importance of proper sitting and of the chair designs that provide comfortable and suitable sitting posture is recognized widely.

One organization involved in the design of chairs is the Human Factors and Ergonomics Society (HFES) and its ANSI/HFES 100 committee. This committee established design specifications for various types of furniture used at computer workstations, including chairs, desks, and tables. This committee also designed the Chair Measurement Device (CMD, Figure 1) for the specific assessments of seat height, seat depth, seat width, backrest height, backrest width, lumbar support height, seat to back included angle, seat pan angle, armrest height, and armrest clearance, for the purpose of developing chairs in connection with other related furniture, such as computer desks. The CMD was designed to ensure that chairs are measured uniformly across manufacturers and laboratories performing compliance measurements with the ANSI/HFES 100 standards.

The purpose of this study was to evaluate the reliability of the CMD, as well as to provide a basis of the chair measurement procedures used in the ANSI/HFES 100 standard.

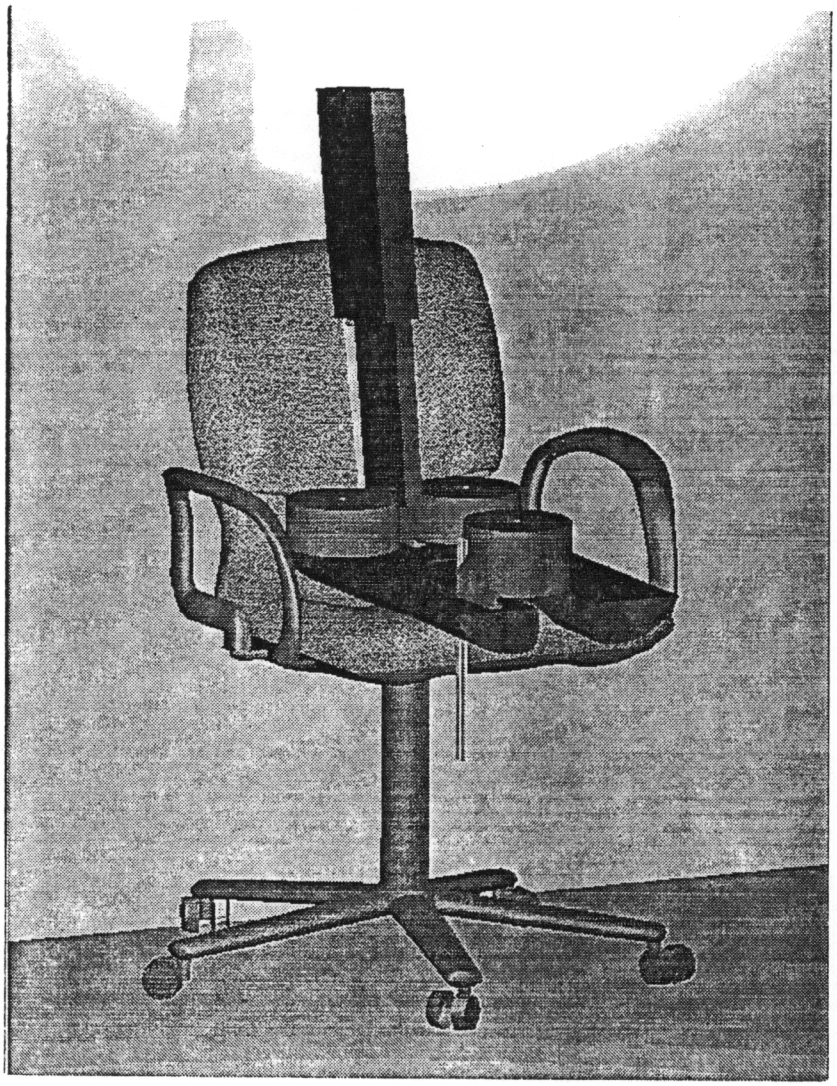

Figure 1. The Chair Measurement Device (the BIFMA /CMD-1-96).

BACKGROUND

Sitting has been defined as a body position in which the weight of the body is transferred to a supporting area mainly by the ischial tuberosities of the pelvis and the surrounding soft tissues (Chaffin, D. B. and Andersson, G. B. J., Occupational biomechanics). Depending on the chair and posture, some proportion of the total body weight also will be transferred to the floor, as well as to the backrest and armrests of the chair (Figure 2).

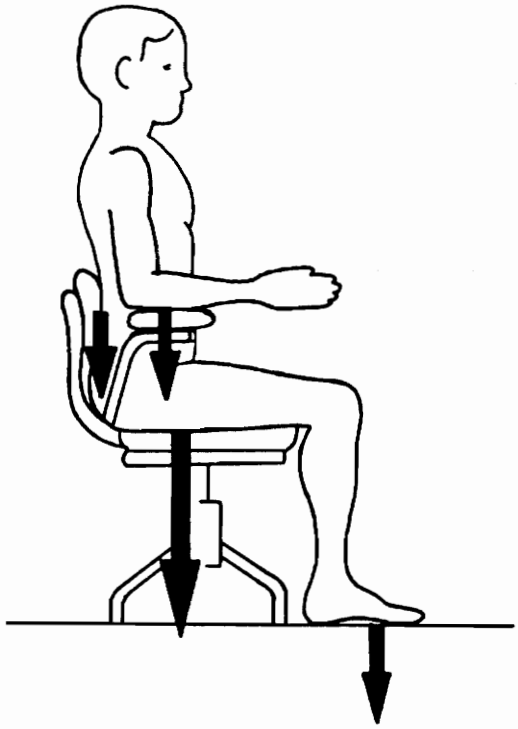

Figure 2. When sitting, the main part of the body weight is transferred to the seat. Some weight also is transferred to the floor, the backrest, and the armrests (Chaffin and Andersson, 1984).

When considering biomechanical aspects of sitting, the spine is important, but the lower and upper extremities should not be disregarded. Even though there are large individual variations among people in the shape of the spine when assuming different

standing and sitting postures and when using different chairs, there are some common aspects. To understand these aspects, a basic knowledge of the gross anatomy of the spine is needed.

Functionally, the vertebral column consists of four parts (Figure 3). Two mobile segments , the cervical and lumbar spine, are below and above the relatively immobile thoracic spine. The lumbar spine is attached to the sacrum, which is fixed to the pelvis.

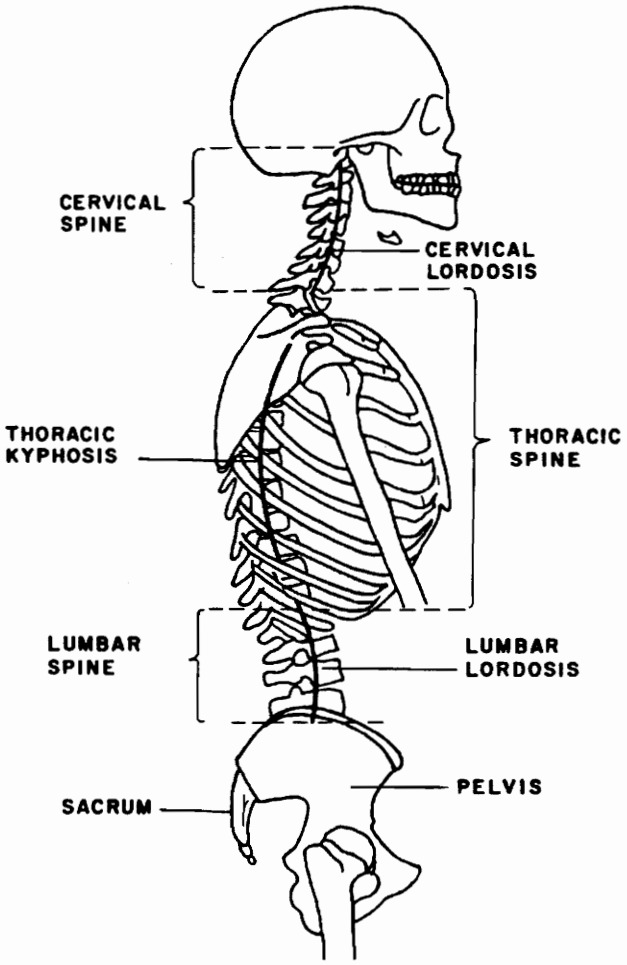

Figure 3. The spine is divided into four segments - the cervical, thoracic, and lumbar segments, and the sacrum. In the lateral view, there is a lumbar lordosis, a thoracic kyphosis, and a cervical lordosis (Chaffin and Andersson, 1984).

When a person stands erect, the vertebral column is straight in the anteroposterior aspect and curved in the later aspect, producing a compound curvature referred to as cervical lordosis, thoracic kyphosis, and lumbar lordosis. The lumbar curve is lordotic partly because the vertebrae and discs are thicker anteriorly than posteriorly and partly because the upper surface of the sacrum is at an angle to the horizontal plane. As the sacrum is fixed to the pelvis, it follows that a rotational movement of the pelvis influences the shape of the lumbar spine.

A forward rotation of the pelvis causes the lumbar spine to move toward increased lordosis in order to maintain an upright trunk posture. When the pelvis is tilted backward, on the other hand, the lumbar spine tends to flatten, and sometimes a kyphosis can develop. When the knees and hips are flexed in sitting, the pelvis is rotated backward and the lumbar lordosis flattens.

The proper way to sit is with the normal lordosis present in the erect standing position. Prolonged sitting with a flat or flexed lower back, as opposed to a lordotic posture, will stretch the posterior fibrous wall of the discs, as well as cause a greater pressure increase within the discs.

Nachemson and Morris (1964) published data on *in vivo* disc pressure measurements of subjects standing and sitting without support. The pressures measured when standing were found to be about 35% lower than those when sitting. These findings were later confirmed by Okushima (1970), Nachemson and Elfstrom (1970), and Tzivian et al. (1971). In the early 1970's, a series of studies were completed in which disc pressures were measured in the third lumbar discs of subjects standing and sitting in different chairs, and with different back supports. These studies confirmed that the disc pressure is lower in standing than in unsupported sitting. In different unsupported sitting postures, the lowest pressure was found when sitting with the back straight. When supports were added to the

chair, disc pressure was found to be influenced by several of the support parameters studied. For example, inclination of the backrest resulted in a decrease in disc pressure especially when tilting the backrest from vertical to 110 degrees, and increase in lumbar support resulted also in a decrease in disc pressure. Studies performed in an office chair placing the back support at different lumbar levels showed a slightly lower pressure when the support was at the level of the fourth and fifth lumbar vertebrae compared with the first and second. The use of armrests always resulted in a decrease in disc pressure.

While disc pressure has been found to be larger in sitting than standing, the advantage of providing a regular sitting posture are:

1. it provides stability required on tasks with high visual and motor control,
2. sitting is less energy consuming than standing,
3. it places less stress on the lower extremity joints, and
4. it lowers the hydrostatic pressure on the lower extremity circulation.

When work is performed in sitting posture, the location and slope of the work area have a major influence on the posture of the neck, shoulders, and upper extremities. Thus, the seat should not be considered without taking the work to be performed into account. In general, the posture of a seated person depends on the design of the chair, individual sitting habits, and the task being performed. Anterior sitting postures are adopted most often when desk work is performed, while posterior positions are assumed in chairs with large backrests that incline and are often preferred for resting. The height and inclination of the seat of the chair, combined with the position, shape, and inclination of the backrest and the presence of other types of support, combine to influence the resulting posture. Obviously, it is important to provide a good chair that is adapted functionally to the task of the occupant. And, since it is unlikely that there is a single ideal posture, and

furthermore, no body posture can be maintained indefinitely, it becomes important that the chair design should allow alterations in one's posture.

In this regard, the Chapter 6 of the ANSI/HFES 100 standard presents design specifications for various types of furniture used at computer workstations, including chairs, desks, and tables. Some of the furniture design specifications were established in ANSI/HFS 100-1988 standard. However, in that just edition of the standard, only one reference posture of a seated operator was used to derive the design specifications. To avoid representing that seated posture as a recommendation for computer workstation users, the pending ANSI/HFES 100 standard extends the design specifications to four reference postures: reclined sitting, upright sitting, declined sitting, standing (Figure 4). The additional postures considered in the pending ANSI/HFES 100 standard points up a need for computer workstation furniture to support a variety of user postures and movements.

The pending ANSI/HFES 100 standard requires that the anthropometric considerations include the 5th percentile female and the 95th percentile male, and the specifications of chairs include:

1. Seat height

   The seat height should allow the user's feet to rest flatly on the floor when the user is in at least two of the three sitting reference postures. The seat height should be user adjustable at least in the range of 38cm to 56cm, with the minimum adjustable range of 11.4cm.

2. Seat depth

   The seat depth should be such that the user's back can be in full contact with the backrest when seated, without experiencing any contact between the back of the knee and the front of the seat pan. Adjustable seat pan depth should include 43cm. If

not adjustable, it should be less than 43cm to accommodate a 5th percentile female.

3. Seat width

The seat pan width should be at least as wide as the user's thighs, including clothing. The seat pan width should be at least 45cm.

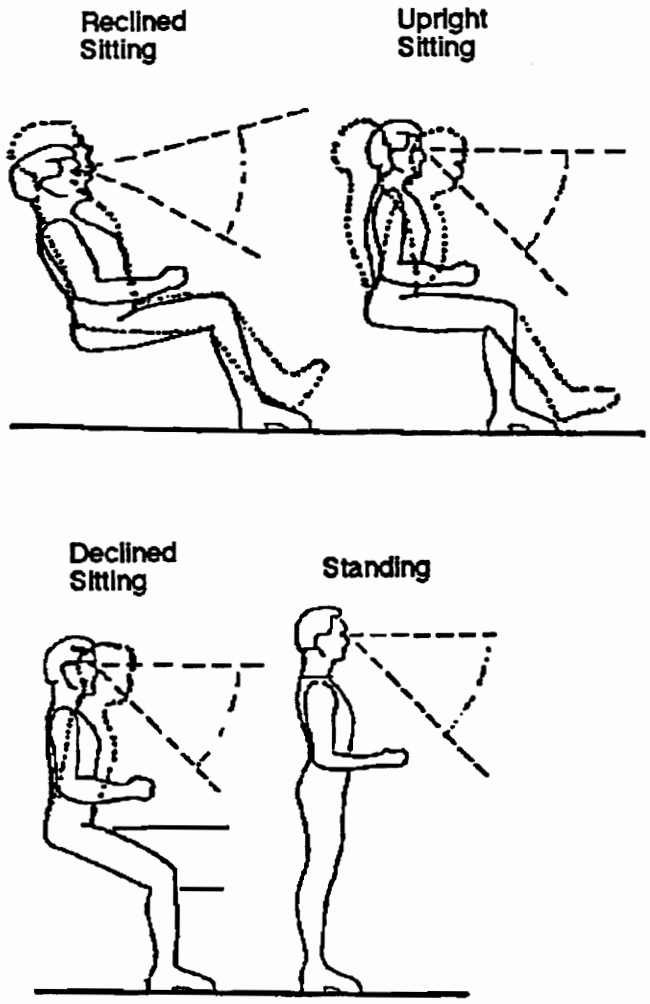

Figure 4. Reference postures (ANSI/HFES 100 standard).

4. Seat angle

The seat pan shall tilt so that it can backward-recline and/or forward-decline from the default setting. The seat pan shall have a user adjustable range of at least 6 degrees that includes a position within 2 to 5 degrees reclined.

5. The angle between seat pan and backrest

The angle between the backrest and seat pan shall be more than 90 degrees, self-adjust to more than 90 degrees, or be adjustable to more than 90 degrees.

6. Backrest height and width

The backrest should provide support in the thoracic region. The height of the top of the backrest should be at least 45cm above the compressed seat height. The width of the backrest should be at least 36cm.

Lumbar support should be provided and should be user adjustable. The lumbar support area of the backrest should be located about 15cm and 25cm above the compressed seat height.

7. Armrests

Armrests should be available if requested by the user. Armrest should be between 1cm below and 2.5cm above the elbow height when the user is in the upright reference posture. Armrest should be close enough to allow the user's arm to rest on them with no more than 15 degrees of shoulder abduction. The clearance between armrests shall be wide enough to allow the user to enter and exit the seat without interference.

Armrests height and the space between armrests should be adjustable, and the adjustment range of armrests height should include some portion of the range 18cm to 27cm above the compressed seat pan height. Armrests should be at least 46cm apart.

The purpose of this study was to evaluate the reliability of the CMD for the evaluation of chairs, as well as to provide a test of the measurement procedures used in the ANSI/HFES 100 standard.

METHOD

Participants

Participants were paid volunteers from the university population. Eight participants (six males; 26-36 years of age) completed the experiment. None of the participants were familiar with the CMD before experiment. Instructions were given to all participants regarding the procedures of measurements and the CMD apparatus. Demonstration of measurements also were given. All participants passed the screening test that was given after the instructions to determine their understanding of the instructions and the CMD measurement procedures.

Participants received one trial measurement as training before they began experiment. When they finished the experiment, the participants were asked to write down their comments and suggestions concerning the CMD device.

Apparatus

CMD. The CMD is composed of three main parts: base, up-right, and weights (Figure 5: Photograph of the CMD, and Figure 6: Top and side view of the CMD). The CMD weighs 150 pounds, and its functional design mimics the certain aspects of a person sitting in a chair.

The CMD base is made of wood, in the approximate shape of a person's hips and thighs. It is 56cm long, 34cm wide, and 6cm thick. One steel plate of 15cm diameter and 2cm height is on the front side of the CMD, with the front pin installed in the center of it. The front weight is laid on the plate, letting the pin slide into the hole of the weight. One clevis and pin lock is on the rear side of the CMD, which locks the CMD up-right. Seat depth slots are on both front sides of the CMD base. The CMD base weighs about 42

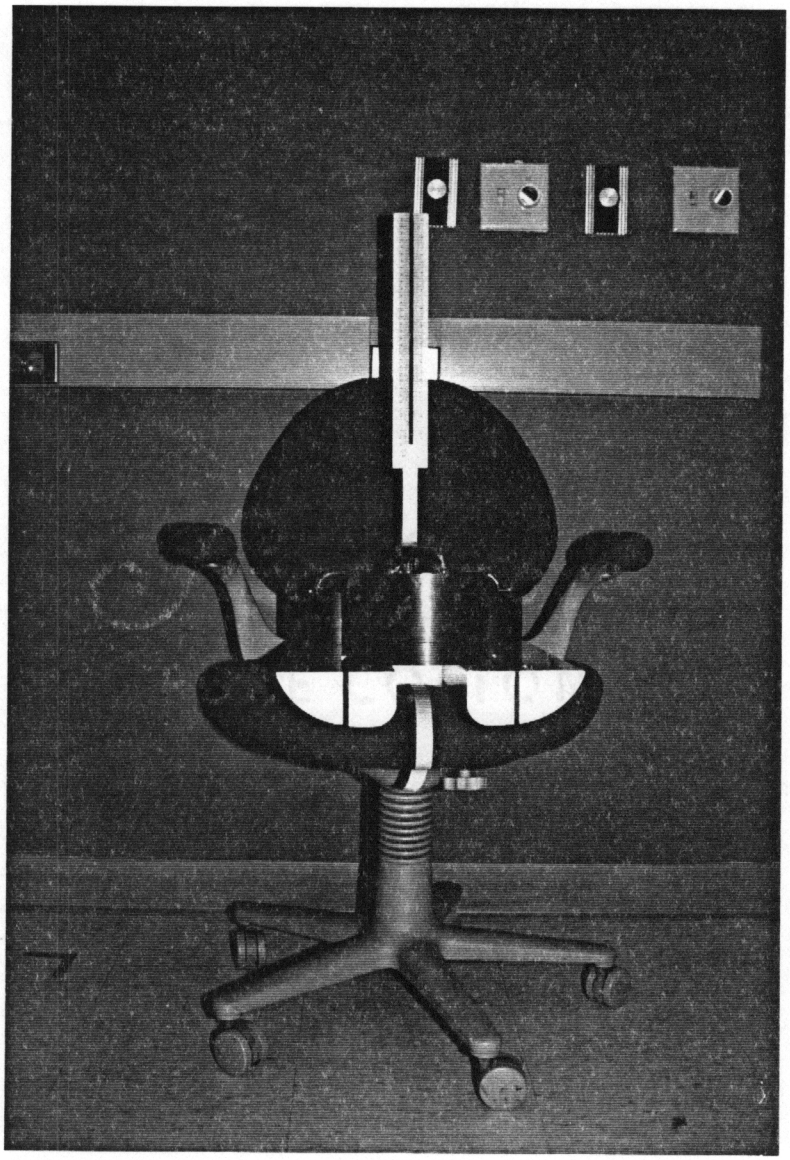

Figure 5. Photograph of CMD.

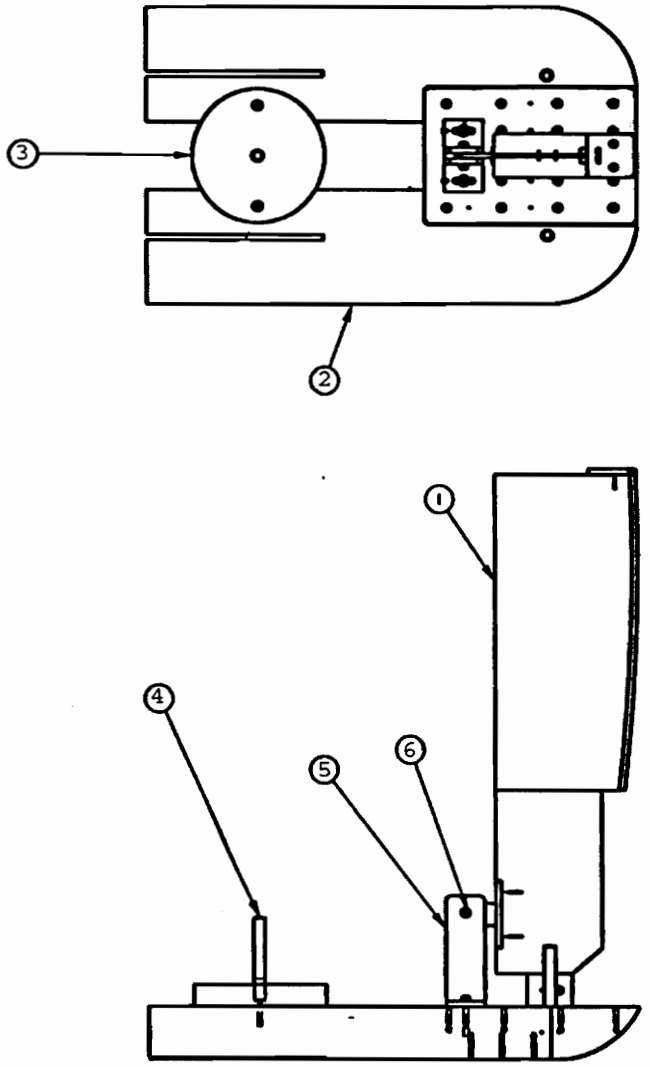

Figure 6. Top and side views of the CMD (above: top view, below: side view). 1.up-right 2.base 3.steel plate 4.pin-front weight 5.clevis 6.pin-lock (the BIFMA /CMD-1-96).

pounds. The CMD base was used when measuring seat height, seat depth, seat pan angle, and seat to back included angle.

The CMD up-right is also made of wood, and stands on the CMD base perpendicular to the CMD base when it is locked to the clevis on the CMD base. When unlocked, the CMD up-right rests against the backrest resembles the functional shape of idealized human back. The lumbar support height scale and backrest height scale are on CMD up-right.

The CMD has three weights, made of steel, one front weight and two rear weights. The front weight weighs 38 pounds, and the rear weights weigh 35 pounds each. The front weight is 15cm diameter and 8.5cm height, and the two rear weights are 15 cm diameter and 7.5cm height each.

Chairs. Three chairs numbered as Chair 1, Chair 2, Chair 3 were measured in the experiment. Chair 1 (Steel Case Inc., Model 239) was the simple office chair (Figure 7), which had 4 fixed legs, a fixed seat pan, and a fixed backrest. Chair 2 (Haworth Inc., Model S 151-224) was an intermediate type of chair 1 and chair 3 (Figure 8), which had casters on the legs, fixed armrest, contoured seat pan and backrest adjustable and designed ergonomically. Chair 3 (Steel Case Inc., Model S 2670) represented a contemporary "ergonomically designed" chair (Figure 9) used for office applications, which had casters on the legs, and adjustable seat pan, backrest, and armrests.

Table 1 compares the adjustability of the three chairs.

TABLE 1.

Comparison between the Chairs

	Lumbar support	Seat height	Seat depth	Backrest height	Seat pan angle	Seat to back angle
Chair 1	fixed	fixed	fixed	fixed	fixed	fixed
Chair 2	adjustable	adjustable	fixed	adjustable	fixed	fixed
Chair 3	adjustable	adjustable	adjustable	adjustable	adjustable	adjustable

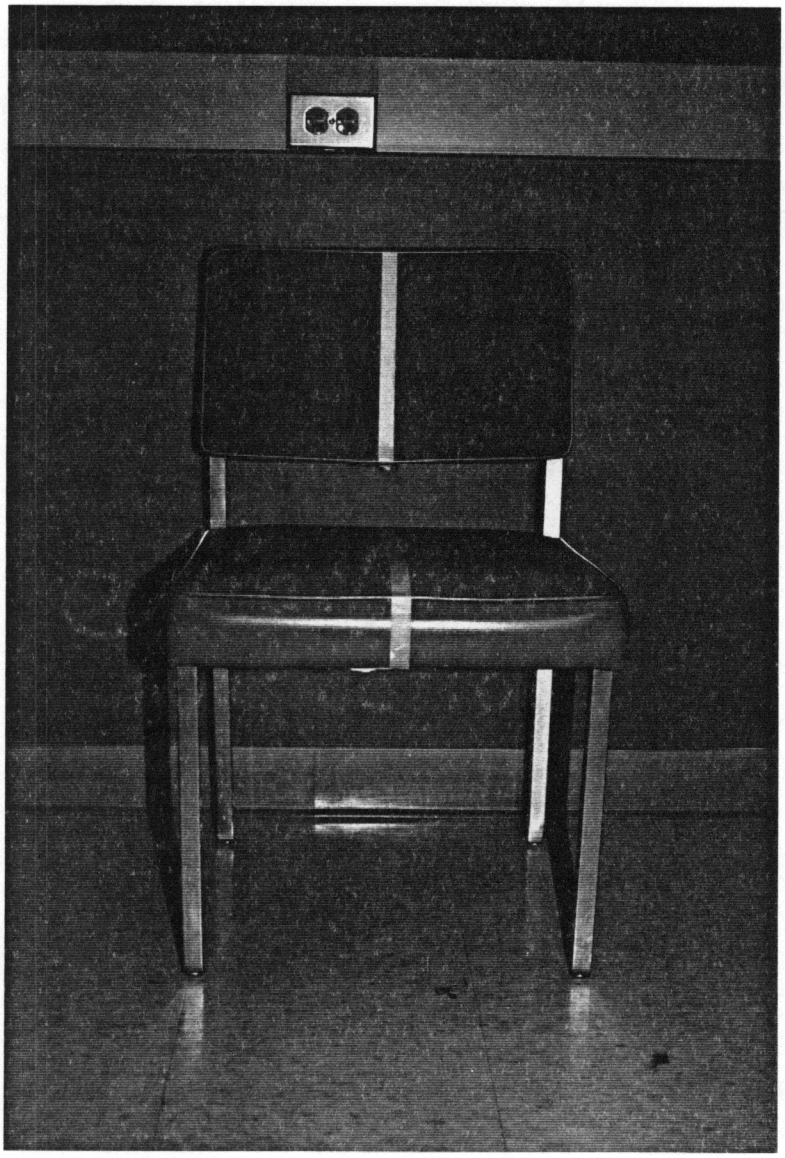

Figure 7. Chair 1 (Steel Case Inc., Model 239).

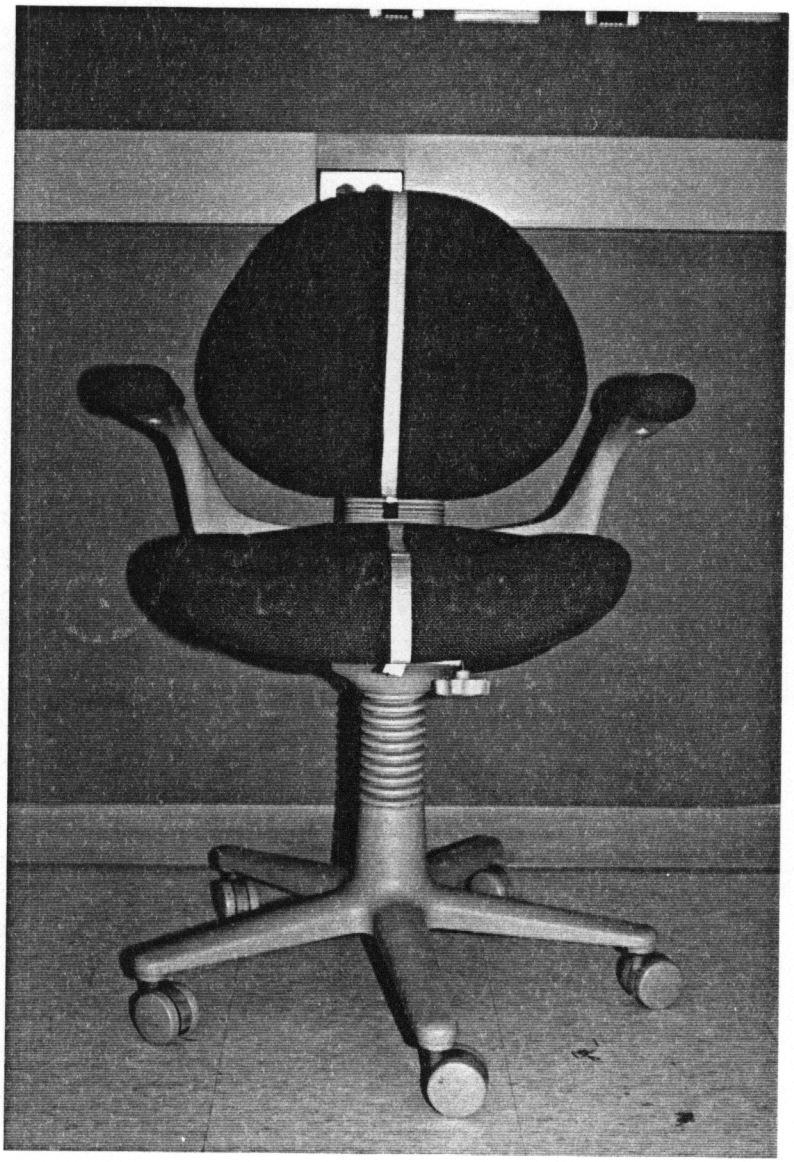

Figure 8. Chair 2 (Haworth Inc., Model S 151-224).

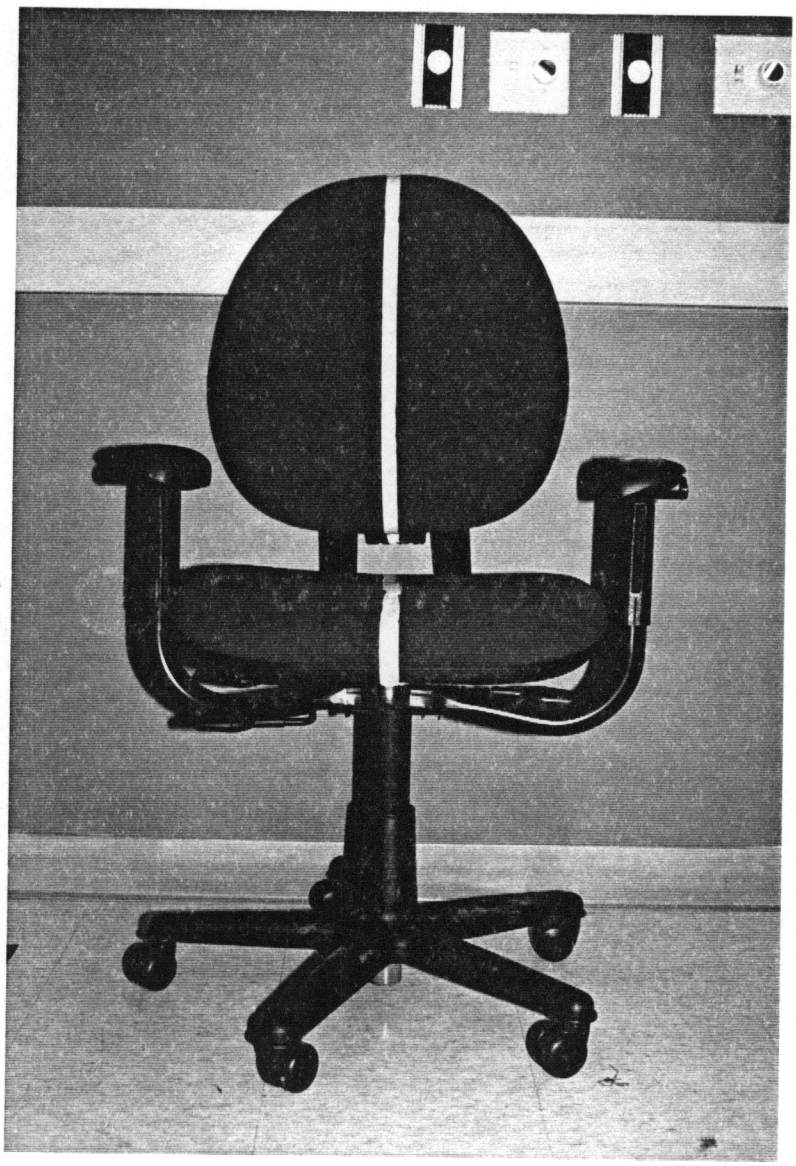

Figure 9. Chair 3 (Steel Case Inc., Model S 2670).

Procedure

Participants who were selected after screening, were contacted and scheduled for a particular time and date to complete the data collection sessions. On the scheduled time and date, each participant came to the laboratory, and was instructed to complete one trial measurement before they began the experiment. Participants completed three sessions, one per day, and three or four repetition of all measurements per session.

All participants made the chair measurements in the same sequence. The measurement sequence involved setting up the chair to be measured, setting up the CMD on the chair, and then taking measurements of lumbar support height, seat height, seat depth, backrest height, seat pan angle, and seat to back included angle of the chair. Following these measurements, the CMD was removed from the chair. Further details of the measurement procedures are presented in the Appendix D.

Experimental Design.

This study used a two-factor, within-subjects design. The factors were: chairs and measurements.

1. Chairs. Three levels of chairs were measured: Chair 1, Chair 2, and Chair 3.

2. Measurements. Six levels of measurements were taken for chair 1: lumbar support height, seat height, seat depth, backrest height, seat pan angle, and seat to back included angle. Nine levels of measurements were taken for chair 2: maximum lumbar support height, minimum lumbar support height, maximum seat height, minimum seat height, seat depth, maximum backrest height, minimum backrest height, seat pan angle, and seat to back included angle. Twelve levels of measurements were taken for chair 3: maximum lumbar support height, minimum lumbar support height, maximum seat height, minimum seat height, maximum seat depth, minimum seat depth, maximum backrest height,

minimum backrest height, seat pan angle-forward, seat pan angle-reclined, maximum seat to back included angle, and minimum seat to back included angle.

This experiment produced 6 measurements x 8 evaluators x 10 replications = 480 data points for chair 1, 9 measurements x 8 evaluators x 10 replications = 720 data points for chair 2, and 12 measurements x 8 evaluators x 10 replications = 960 data points for chair 3. Therefore, the total number of data points or observations was 2,160.

RESULTS

The purpose of this study was to examine the reliability of the CMD across people, as well as within persons. Therefore, the data were analyzed from two separate points of view.

Inter-evaluator reliability (consistency across people). The purpose of this analysis was to examine the variability of the measurements across evaluators. Basically, this is to determine the degree of similarity in the measurements made by different people. Standard deviation and 99% confidence interval analysis approach was used to analyze the data.

First, mean values (Table 2), standard deviation of the measurement (Table 3), and the 99% confidence interval (Table 4) across the 10 replications of each measurement made by each evaluator were computed from the measurements data of Chair 1.

TABLE 2

Mean Value across Replications of Each Measurement by Each Evaluator for Chair 1
(Unit: M1 ~ M4: cm, M5 ~ M6: rad)

	S1	S2	S3	S4	S5	S6	S7	S8	Mean
M1	16.22	16.00	15.92	15.88	16.35	15.87	15.75	15.30	15.91
M2	42.13	42.06	42.12	42.11	41.97	42.12	42.04	42.04	42.07
M3	43.47	43.38	43.34	43.42	43.33	43.50	43.44	43.41	43.41
M4	38.84	39.00	38.92	39.07	38.96	39.01	38.72	38.80	38.92
M5	0.035	0.034	0.040	0.036	0.032	0.036	0.025	0.034	0.034
M6	1.710	1.690	1.690	1.670	1.680	1.680	1.680	1.690	1.690

Abbreviation: S1 - subject 1, S2 - subject 2, and so on.
M1 - lumbar support height, M2 - seat height, M3 - seat depth, M4 - backrest height, M5 - seat pan angle, M6 - seat to back include angle.

TABLE 3

Standard Deviation of Each Measurement by Each Evaluator for Chair 1
(Unit: M1 ~ M4: cm, M5 ~ M6: rad)

	S1	S2	S3	S4	S5	S6	S7	S8	Mean
M1	0.250	0.330	0.200	0.270	0.260	0.300	0.050	0.230	0.240
M2	0.067	0.097	0.079	0.057	0.125	0.063	0.126	0.107	0.090
M3	0.164	0.103	0.117	0.079	0.095	0.094	0.171	0.129	0.119
M4	0.143	0.133	0.092	0.116	0.207	0.145	0.114	0.105	0.132
M5	0.006	0.003	0.008	0.003	0.008	0.006	0.007	0.003	0.006
M6	0.007	0.015	0.007	0.010	0.012	0.011	0.015	0.017	0.012

Abbreviation: S1 - subject 1, S2 - subject 2, and so on.
M1 - lumbar support height, M2 - seat height, M3 - seat depth, M4 - backrest height, M5 - seat pan angle, M6 - seat to back include angle.

TABLE 4

99% Confidence Interval of the Measurements of Chair 1 (Unit: M1 ~ M4: cm, M5 ~ M6: rad)

	Mean	Mean Standard Deviation	Range (Note 1)	99% Confidence Interval	% Error (Note 2)
M1	15.91	0.240	± 0.72	$15.19 < \mu < 16.63$	± 4.5
M2	42.07	0.090	± 0.27	$41.80 < \mu < 42.34$	± 0.6
M3	43.41	0.119	± 0.36	$43.05 < \mu < 43.77$	± 0.8
M4	38.92	0.132	± 0.40	$38.52 < \mu < 39.32$	± 1.0
M5	0.34	0.006	± 0.02	$0.32 < \mu < 0.36$	± 5.9
M6	1.69	0.012	± 0.03	$1.66 < \mu < 1.72$	± 1.8

Abbreviation: M1 - lumbar support height, M2 - seat height, M3 - seat depth, M4 - backrest height, M5 - seat pan angle, M6 - seat to back include angle.
μ - population mean.

Note 1. Range: ± 3 x mean standard deviation
2. % Error = Range / Mean

From Table 2 and 3, the range of mean values across evaluators is small for all measurements. For the linear measurements of Chair 1, standard deviation was the smallest for M2 (seat height), then M3 (seat depth), followed by M4 (backrest height), and was the largest for M1 (lumbar support height). For the angular measurements of Chair 1, the standard deviation of seat pan angle was less than that of seat to back included angle.

Considering these variances, the CMD measurements of Chair 1 are consistent across evaluators. The ratio for M2 (seat height), M3 (seat depth), M4 (backrest height), and M6 (seat to back included angle) were equal or less than ± 2.0 %. This finding shows that the CMD allows consistent and reliable measurements.

In the same way, mean values (Table 5), standard deviation of the measurement (Table 6), and the 99% confidence interval (Table 7) across the 10 replications of each measurement by each evaluator were obtained from the measurements data of Chair 2.

The standard deviation shown in Table 6 are small. The list of the measurements in order of measuring standard deviation was: M4 (minimum seat height), M5 (seat depth), M6 (maximum backrest height), M7 (minimum backrest height), M3 (maximum seat height), M2 (minimum lumbar support height), and M1 (maximum lumbar support height). The standard deviation of seat pan angle was less than that of seat to back included angle.

Considering the % error values, measurements of Chair 2 using the CMD were determined to be consistent across evaluators, and the CMD was reliable in the measurements by the different evaluators. Though the range of the measurement of lumbar support height was relatively larger than others, it could be regarded to be consistent and reliable.

TABLE 5

Mean Value across Replications of Each Measurement by Each Evaluator for Chair 2
(Unit: M1 ~ M7: cm, M8 ~ M9: rad)

	S1	S2	S3	S4	S5	S6	S7	S8	Mean
M1	20.99	20.57	21.60	20.62	21.07	20.78	20.32	19.58	20.69
M2	16.67	16.48	17.37	16.54	16.69	16.51	15.73	15.39	16.42
M3	50.09	49.91	49.95	50.21	49.84	50.11	49.78	49.86	49.97
M4	42.50	42.47	42.66	42.59	42.55	42.58	42.42	42.46	42.53
M5	43.39	43.28	42.92	43.40	43.09	43.31	43.53	43.51	43.30
M6	52.16	52.11	52.59	52.04	52.18	52.18	51.82	51.75	52.10
M7	47.96	48.08	48.39	47.86	48.13	48.10	47.59	47.63	47.97
M8	0.095	0.087	0.100	0.090	0.099	0.086	0.082	0.084	0.090
M9	1.710	1.700	1.700	1.680	1.690	1.700	1.710	1.720	1.700

Abbreviation: S1 - subject 1, S2 - subject 2, and so on.
M1 - maximum lumbar support height, M2 - minimum lumbar support height
M3 - maximum seat height, M4 - minimum seat height, M5 - seat depth,
M6 - maximum backrest height, M7 - minimum backrest height,
M8 - seat pan angle, M9 - seat to back include angle.

TABLE 6

Standard Deviation of Each Measurement by Each Evaluator for Chair 2
(Unit: M1 ~ M7: cm, M8 ~ M9: rad)

	S1	S2	S3	S4	S5	S6	S7	S8	Mean
M1	0.341	0.400	0.316	0.959	0.766	0.725	0.616	0.555	0.585
M2	0.245	0.374	0.460	0.458	0.348	0.321	0.298	0.479	0.373
M3	0.321	0.617	0.288	0.160	0.246	0.202	0.545	0.207	0.323
M4	0.094	0.067	0.097	0.110	0.053	0.103	0.123	0.135	0.098
M5	0.438	0.155	0.181	0.094	0.412	0.197	0.517	0.137	0.266
M6	0.184	0.228	0.137	0.310	0.637	0.249	0.352	0.178	0.284
M7	0.126	0.424	0.375	0.255	0.177	0.371	0.360	0.195	0.285
M8	0.008	0.004	0.005	0.009	0.008	0.008	0.006	0.011	0.007
M9	0.007	0.011	0.007	0.005	0.006	0.014	0.007	0.014	0.009

Abbreviation: S1 - subject 1, S2 - subject 2, and so on.
M1 - maximum lumbar support height, M2 - minimum lumbar support height
M3 - maximum seat height, M4 - minimum seat height, M5 - seat depth,
M6 - maximum backrest height, M7 - minimum backrest height,
M8 - seat pan angle, M9 - seat to back include angle.

TABLE 7

99% Confidence Interval of the Measurements for Chair 2 (Unit: M1 ~ M7: cm, M8 ~ M9: rad)

	Mean	Mean Standard Deviation	Range (Note 1)	99% Confidence Interval	% Error (Note 2)
M1	20.69	0.585	± 1.76	18.93 < μ < 22.45	± 8.5
M2	16.42	0.373	± 1.12	15.30 < μ < 17.54	± 6.8
M3	49.97	0.323	± 0.96	49.01 < μ < 50.93	± 1.9
M4	42.53	0.098	± 0.29	42.24 < μ < 42.82	± 0.7
M5	43.30	0.266	± 0.80	42.50 < μ < 44.10	± 1.8
M6	52.10	0.284	± 0.85	51.25 < μ < 52.95	± 1.6
M7	47.97	0.285	± 0.86	47.11 < μ < 48.83	± 1.8
M8	0.090	0.007	± 0.02	0.07 < μ < 0.11	±22.2
M9	1.700	0.009	± 0.03	1.67 < μ < 1.73	± 1.8

Abbreviation: M1 - maximum lumbar support height, M2 - minimum lumbar support height
M3 - maximum seat height, M4 - minimum seat height, M5 - seat depth,
M6 - maximum backrest height, M7 - minimum backrest height,
M8 - seat pan angle, M9 - seat to back include angle.
μ - population mean.

Note 1. Range: ± 3 x mean standard deviation
2. % Error = Range / Mean

From the measurements data of Chair 3, mean values (Table 8), standard deviation of the measurement (Table 9), and the 99% confidence interval (Table 10) across the 10 replications of each measurement made by each evaluator were computed.

TABLE 8

Mean Value across Replications of Each Measurement by Each evaluator for Chair 3
(Unit: M1 ~ M8: cm, M9 ~ M12: rad)

	S1	S2	S3	S4	S5	S6	S7	S8	Mean
M1	22.98	23.11	23.20	22.69	23.39	23.28	23.23	22.32	23.03
M2	18.48	18.65	18.56	18.18	18.89	18.36	18.34	17.64	18.39
M3	51.41	51.36	51.46	51.28	51.17	51.51	51.54	51.37	51.39
M4	39.36	39.51	39.49	39.38	39.52	39.70	39.57	39.50	39.50
M5	44.91	44.84	44.61	44.81	44.66	44.89	44.82	44.97	44.81
M6	38.53	38.60	38.31	38.50	38.39	38.62	38.47	38.69	38.51
M7	61.73	61.83	61.73	61.99	61.81	61.91	61.59	61.60	61.77
M8	56.39	56.51	56.55	56.68	56.49	56.69	56.28	56.30	56.49
M9	0.104	0.108	0.106	0.105	0.101	0.112	0.104	0.103	0.105
M10	0.095	0.083	0.093	0.086	0.092	0.080	0.092	0.079	0.088
M11	1.740	1.730	1.740	1.720	1.730	1.720	1.720	1.740	1.730
M12	1.690	1.670	1.670	1.650	1.660	1.660	1.670	1.680	1.670

Abbreviation: S1 - subject 1, S2 - subject 2, and so on.
M1 - maximum lumbar support height, M2 - minimum lumbar support height
M3 - maximum seat height, M4 - minimum seat height,
M5 - maximum seat depth, M6 - minimum seat depth,
M7 - maximum backrest height, M8 - minimum backrest height,
M9 - forward seat pan angle, M10 - reclined seat pan angle,
M11 - maximum seat to back included angle, M12 - minimum seat to back included angle.

TABLE 9

Standard Deviation of Each Measurement by Each evaluator for Chair 3
(Unit: M1 ~ M8: cm, M9 ~ M12: rad)

	S1	S2	S3	S4	S5	S6	S7	S8	Mean
M1	0.262	0.129	0.397	0.370	0.260	0.286	0.589	0.675	0.371
M2	0.239	0.314	0.255	0.379	0.927	0.433	0.357	0.347	0.406
M3	0.238	0.299	0.196	0.193	0.306	0.238	0.523	0.359	0.294
M4	0.165	0.300	0.120	0.235	0.575	0.156	0.403	0.309	0.283
M5	0.110	0.143	0.110	0.110	0.135	0.129	0.278	0.164	0.147
M6	0.206	0.156	0.166	0.156	0.208	0.181	0.170	0.166	0.176
M7	0.183	0.183	0.226	0.074	0.137	0.120	0.681	0.141	0.218
M8	0.160	0.296	0.178	0.210	0.191	0.191	0.294	0.149	0.209
M9	0.008	0.011	0.006	0.007	0.006	0.011	0.003	0.006	0.007
M10	0.008	0.005	0.007	0.007	0.007	0.006	0.006	0.009	0.007
M11	0.013	0.010	0.014	0.016	0.004	0.013	0.016	0.021	0.013
M12	0.012	0.009	0.003	0.010	0.012	0.007	0.015	0.007	0.009

Abbreviation: S1 - subject 1, S2 - subject 2, and so on.
M1 - maximum lumbar support height, M2 - minimum lumbar support height
M3 - maximum seat height, M4 - minimum seat height,
M5 - maximum seat depth, M6 - minimum seat depth,
M7 - maximum backrest height, M8 - minimum backrest height,
M9 - forward seat pan angle, M10 - reclined seat pan angle,
M11 - maximum seat to back included angle, M12 - minimum seat to back included angle.

TABLE 10

99% Confidence Interval of the Measurements for Chair 3 (Unit: M1 ~ M8: cm, M9 ~ M12: rad)

	Mean	Mean Standard Deviation	Range (Note 1)	99% Confidence Interval	% Error (Note 2)
M1	23.03	0.371	± 1.11	21.92 < μ < 24.14	± 4.8
M2	18.39	0.406	± 1.22	17.17 < μ < 19.61	± 6.6
M3	51.39	0.294	± 0.88	50.51 < μ < 52.27	± 1.7
M4	39.50	0.283	± 0.85	38.65 < μ < 40.35	± 2.2
M5	44.81	0.147	± 0.44	44.37 < μ < 45.25	± 1.0
M6	38.51	0.176	± 0.53	37.98 < μ < 39.04	± 1.4
M7	61.77	0.218	± 0.65	61.12 < μ < 62.42	± 1.1
M8	56.49	0.209	± 0.63	55.86 < μ < 57.12	± 1.1
M9	0.110	0.007	± 0.02	0.09 < μ < 0.13	±18.2
M10	0.090	0.007	± 0.02	0.07 < μ < 0.11	±22.2
M11	1.730	0.013	± 0.04	1.69 < μ < 1.77	± 2.3
M12	1.670	0.009	± 0.03	1.64 < μ < 1.70	± 1.8

Abbreviation: M1 - maximum lumbar support height, M2 - minimum lumbar support height
M3 - maximum seat height, M4 - minimum seat height,
M5 - maximum seat depth, M6 - minimum seat depth,
M7 - maximum backrest height, M8 - minimum backrest height,
M9 - forward seat pan angle, M10 - reclined seat pan angle,
M11 - maximum seat to back included angle, M12 - minimum seat to back included angle.
μ - population mean.

Note 1. Range: $\pm$ 3 x mean standard deviation
2. % Error = Range / Mean

The standard deviation of the measurements of Chair 3, by eight different evaluators are shown in Table 9, and these values were very small like those of the other two chairs. The list of the measurements in the order of small standard deviation for chair 3 was: M5 (maximum seat depth), M6 (minimum seat depth), M8 (minimum backrest height), M7 (maximum backrest height), M4 (minimum seat height), M3 (maximum seat height), M1 (maximum lumbar support height), and M2 (minimum lumbar support height). Standard deviation of seat pan angle was less than that of seat to back included angle.

Considering the ranges, confidence interval, and the ratio of mean to the range, measurements of Chair 3 using the CMD, were determined to be consistent across evaluators, and the CMD was reliable in the measurements by the different evaluators. Though the range of the measurement of lumbar support height was relatively larger than others, it could be regarded to be consistent and reliable.

Intra-evaluator reliability (consistency within a person). The purpose of this evaluation was to examine the variability of the measurements made within the evaluators. Basically, it is to determine the degree of similarity in the measurements made by the same person. The fundamental source of information is the data obtained by the same evaluator, across the replications for the measurements.

The 99% confidence interval ranges of each measurement made by each evaluator were obtained for Chair 1(Table 11), for Chair 2 (Table 12), and for Chair 3 (table 13). It is shown in these tables that the 99% confidence interval ranges are small. The bold font figures are ranges that seem relatively large (larger than 1cm, or 0.02 radian:1 degree).

Comparing these Tables 11-13, it is found that the 99% confidence interval ranges for Chair 1 are smaller than those of other two chairs. All the ranges are within 1

centimeter, but some ranges of seat to back included angle measurement are beyond 0.02 radian (1 degree), for Chair 1.

The 99% confidence interval ranges for Chair 2 are shown on Table 12. Many range values for lumbar support height and seat to back included angle measurements are beyond 1 centimeter and 0.02 radian (1 degree). And, this is true for the ranges for Chair 3.

From the 99% confidence interval ranges in Table 11, 12, and 13, it is found that the measurements made by the same evaluator are reliable and consistent, except for lumbar support height and seat to back included angle measurements. The reliability of the CMD measurements depends upon the type of chair evaluated.

TABLE 11

99% Confidence Interval Ranges (±) of the Measurements by Each Evaluator for Chair 1
(Unit: M1 ~ M4: cm, M5 ~ M6: rad)

	S1	S2	S3	S4	S5	S6	S7	S8
M1	0.75	0.99	0.60	0.81	0.78	0.90	0.15	0.69
M2	0.20	0.29	0.24	0.17	0.38	0.19	0.38	0.32
M3	0.49	0.31	0.35	0.24	0.29	0.28	0.51	0.39
M4	0.43	0.40	0.28	0.35	0.62	0.44	0.34	0.32
M5	0.02	0.01	0.02	0.01	0.02	0.02	0.02	0.01
M6	0.02	**0.05**	0.02	**0.03**	**0.04**	**0.03**	**0.05**	**0.05**

Abbreviation: S1 - 99% confidence interval range of measurements by evaluator 1,
S2 - 99% confidence interval range of measurements by evaluator 2, and so on.
M1 - lumbar support height, M2 - seat height, M3 - seat depth, M4 - backrest height,
M5 - seat pan angle, M6 - seat to back include angle.

TABLE 12

99% Confidence Interval Ranges (±) of the Measurements by Each Evaluator for Chair 2
(Unit: M1 ~ M7: cm, M8 ~ M9: rad)

	S1	S2	S3	S4	S5	S6	S7	S8
M1	**1.02**	**1.20**	0.95	**2.88**	**2.30**	**2.18**	**1.85**	**1.67**
M2	0.74	**1.12**	**1.38**	**1.37**	**1.04**	0.96	0.89	**1.44**
M3	0.96	**1.85**	0.86	0.48	0.74	0.61	**1.64**	0.62
M4	0.28	0.20	0.29	0.33	0.16	0.31	0.37	0.41
M5	**1.31**	0.47	0.54	0.28	**1.24**	0.59	**1.55**	0.41
M6	0.55	0.68	0.41	0.93	**1.91**	0.75	**1.06**	0.53
M7	0.38	**1.27**	**1.13**	0.77	0.53	**1.11**	**1.08**	0.59
M8	0.02	0.01	0.02	**0.03**	0.02	0.02	0.02	**0.03**
M9	0.02	**0.03**	0.02	0.02	0.02	**0.04**	0.02	**0.04**

Abbreviation: S1 - 99% confidence interval range of measurements by evaluator 1,
S2 - 99% confidence interval range of measurements by evaluator 2, and so on.
M1 - maximum lumbar support height, M2 - minimum lumbar support height
M3 - maximum seat height, M4 - minimum seat height, M5 - seat depth,
M6 - maximum backrest height, M7 - minimum backrest height,
M8 - seat pan angle, M9 - seat to back include angle.

TABLE 13

99% Confidence Interval Ranges (±) of the Measurements by Each Evaluator for Chair 3
(Unit: M1 ~ M8: cm, M9 ~ M12: rad)

	S1	S2	S3	S4	S5	S6	S7	S8
M1	0.79	0.39	**1.19**	**1.11**	0.78	0.86	**1.77**	**2.03**
M2	0.72	0.94	0.77	**1.14**	**2.78**	**1.30**	**1.07**	**1.04**
M3	0.71	0.90	0.59	0.58	0.92	0.71	**1.57**	**1.08**
M4	0.50	0.90	0.36	0.71	**1.73**	0.47	**1.21**	0.93
M5	0.33	0.43	0.33	0.33	0.41	0.39	0.83	0.49
M6	0.62	0.47	0.50	0.47	0.62	0.54	0.51	0.50
M7	0.55	0.55	0.68	0.22	0.41	0.36	**2.04**	0.42
M8	0.48	0.89	0.53	0.63	0.57	0.57	0.88	0.45
M9	0.02	**0.03**	0.02	0.02	0.02	**0.03**	0.01	0.02
M10	0.02	0.02	0.02	0.02	0.02	0.02	0.02	**0.03**
M11	**0.04**	**0.03**	**0.04**	**0.05**	0.01	**0.04**	**0.05**	0.02
M12	**0.04**	**0.03**	0.01	**0.03**	**0.04**	**0.03**	**0.05**	0.02

Abbreviation: S1 - 99% confidence interval range of measurements by evaluator 1,
S2 - 99% confidence interval range of measurements by evaluator 2, and so on.
M1 - maximum lumbar support height, M2 - minimum lumbar support height
M3 - maximum seat height, M4 - minimum seat height,
M5 - maximum seat depth, M6 - minimum seat depth,
M7 - maximum backrest height, M8 - minimum backrest height,
M9 - forward seat pan angle, M10 - reclined seat pan angle,
M11 - maximum seat to back included angle, M12 - minimum seat to back included angle.

DISCUSSION

The purpose of this research was to evaluate the reliability of the CMD and to establish a procedure for the measurement of chairs using the CMD. It was shown that the CMD produced reliable measurements, across different evaluators, as well as within the same evaluator. Additionally, the measurement procedure used in this experiment seems viable for compliance evaluation purpose.

During the experiment, however, some defects in the CMD were noticed. First, it was difficult to locate the exact contact point between the CMD elastic member and the surface of the backrest during the CMD set-up. Second, it was difficult to measure the seat to back included angle using a separate protractor. These difficulties may have contributed to the standard deviations obtained for these two measurements. Also many subsidiary measurement devices were required (i.e., T-square, yard stick, ruler, and seat pan angle measuring device), but none was specified for use with the CMD. The reliability of the CMD and the consistency of the measurements might be affected by the accuracy of these subsidiary devices.

Many evaluators made constructive suggestions and recommendations concerning the CMD after completing the experiment:

- the width of the elastic member of the CMD should be narrower in order to locate the exact contact point of the elastic member and the surface of backrest,
- the CMD should be fitted with integral protractors for the measurement of seat pan angle and seat to back included angle, to eliminate the need for a subsidiary angle measuring device such as a protractor that might produce significant errors in measuring and reading the scale,

- the integral protractor, if installed on the CMD, should have a fine scale such as one tenth of a degree at least, to decrease the error in measuring,
- the CMD could be provided with several measurement bars fitted with an arrow pointer installed on the CMD, for the measurement of lumbar support height, seat depth, and backrest height, and this would eliminate the need for T-squares used in measuring heights and width, and would allow for the reduction in error when reading measurement scales,
- the CMD weights interfaced with the measurements of lumbar support height and seat to back included angle. The CMD should be redesigned to keep rear weights away from these measurements areas,
- one front weight and two rear weights of the CMD are manufactured to be different in size and weight, but those three weights should be made to be identical to reduce the error caused from the incorrect placement of those weights, and this can be done by increasing the height of the steel plate on the CMD base.

CONCLUSION

This research was the first evaluation of the CMD. It was found that the measurements made by using the CMD were reliable and consistent across the different evaluators and within the same evaluator.

Comparing the data measured by the different evaluators, it was found that the standard deviations of the measurements of Chair 1 were relatively less than those of Chair 2 and Chair 3. From this fact, it could be concluded that the CMD was more reliable for the measurement of the simple chair rather than complicated ones.

As for the measurements, the standard deviation of seat depth was the smallest, seat height was the second, backrest height is the third, and lumbar support height was the last.

It was shown that the CMD was reliable for the measurements made by a same evaluator, but there were small differences in standard deviations of measurements between the evaluators.

Considering that the CMD was proved to be reliable and consistent, the procedures established for the measurements of chairs using the CMD could be regarded to be proper and adequate.

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APPENDIX A : Pre-Screening Explanation

Pre-Screening Explanation

The purpose of this research is to evaluate the reliability and validity of Chair Measurement Device (CMD). Your contribution to this research will be to make specific measurements of 3 chairs, using one CMD. The specific measurements include seat height, seat depth, backrest height, seat to back included angle, seat pan angle, and lumbar support height.

To make accurate measurements, your understanding of the instructions and procedures of the measurements is essential. Before participating in this experiment, you will be asked to answer the questionnaire about the instructions and procedures of the measurements, to make sure you understand those clearly. If you have any questions regarding the experiment, please ask them at this time.

APPENDIX B : Questionnaire

Questionnaire

Name :

This questionnaire is provided to verify that you understand the instructions and procedure of the research.

A. Please fill in the parenthesis with proper words, among maximum, minimum, highest, lowest, horizontal, vertical, rear, front.

1. When you set up chairs before you set up CMD;
   1) If seat depth is adjustable, adjust seat to its ( ) depth.
   2) Adjust the seat pan to its ( ) position.
   3) If seat pan angle is adjustable, adjust it to its most ( ) position.
   4) If the backrest is adjustable, adjust it to its ( ) position.
   5) If the backrest angle is adjustable, adjust it to the most ( ) position.
2. When you load the weights on CMD, you should load ( ) weight first, and then ( ) weight later. And when you remove the weights from CMD, you should remove ( ) weight first, and then ( ) weight later.

B. The followings are the definitions of the 6 measurements. Please name the each definition

1. The angle between the horizontal plane and the upper surface of the seat cushion.
2. The height of the point on the backrest that is closest to the upright of CMD, as measured perpendicularly from the front of CMD upright.
3. The horizontal distance, as measured at the seat depth scale slot on CMD, from the back of CMD to the front of the seat cushion.

4. The vertical distance from the top of the backrest to the bottom of CMD, as measured on the backrest height scale on the front of CMD upright.
5. The vertical distance , as measured at the seat depth scale slot on CMD, from the floor to the underside of CMD nearest the front of the seat cushion.
6. The angle between the backrest and the seat cushion, measured at the center of the chair.

C. Please name, as many as you can, 6 measurements which will be taken in this research.

APPENDIX C : Informed Consent

PARTICIPANTS INFORMED CONSENT

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigating Projects

Title of Project: The Validity and Reliability Evaluation of the Chair Measurement Device

Principal Investigator: Hyun Lee

I. THE PURPOSE OF THIS RESEARCH / PROJECT

You are invited to participate in a study investigating the reliability and validity of the Chair Measurement Device (CMD). Further detail about the project will be explained in the separate instructions of the experiment.

II. PROCEDURES

You will be asked to take part in a briefing session before the experiment begin, where all the instructions and demonstration will be given, and after that, questionnaire will also be given to verify your understanding of the instructions.

You will be asked to work during your assigned period of time, following all instructions and training provided by investigator.

Your task is to take specific measurements of 3 different chairs, using one CMD. The specific measurements include seat height, seat depth, backrest height, lumbar support height, seat to back included angle, and seat pan angle.

This experiment does not intrinsically contain hazards nor danger, but the possible risk or hard work may be moving a heavy CMD (weighs about 100 pound), between chairs.

The accuracy of the measurements is the most important thing in this experiment and you will be asked to take those measurements very carefully and attentively.

III. BENEFITS OF THIS PROJECT

Your participation in this project will provide information regarding chairs, chair design, chair dimensions, and CMD. This type of information can provide general knowledge of chair and the importance of proper sitting.

CMD and its use in this experiment may provide basis of ANSI (American National Standard Institute) / HFES (Human Factors and Ergonomic Society)100-199x standard, and you will obtain the information of the part of ANSI / HFES standard.

However, no guarantee of benefit has been made to encourage you to participate.

You may receive a result or summary of this research when it is completed. If you want to, please bring a self-addressed envelop.

IV. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The results of this study will be kept strictly confidential. At no time the researcher release the results of this study to anyone other than individuals working on the project without your written consent. The information you provide will have your name removed and only a participant number will identify you during analyses and on any written reports of this research.

V. COMPENSATION

You will be compensated by researcher at your hourly rate ($ 5.00 / hour), for all time spent during this experiment.

VI. FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time without any penalty. If you chose to withdraw, you will be compensated for the portion of the time of the study in which you participated.

There may be circumstances under which the researcher may determine that you could not continue as a participant of this project. In this case, you will be compensated for the portion of the time of study in which you participated.

VII. APPROVAL OF RESEARCH

This research project has been approved, as required, by the Institutional Review Board for the projects involving human participants at Virginia Polytechnic Institute and State University, by the Department of Industrial and Systems Engineering.

VIII. PARTICIPANT'S RESPONSIBILITY

I know of no reason I can not participate in this study. I have no any known physical defects which will make me unable to participate in this experiment.

_____ _____

Participant's Name Signature and Date

IX. PARTICIPANT'S PERMISSION

I have read and understand the informed consent and conditions of this project. I have had all my question answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

Should I have any question about this research or its conduct, I will contact:

	Phone
Hyun Lee - Investigator	540-951-0612
Robert J. Beaton - Faculty Advisor	540-231-5936
Ernest R. Stout - Chair, IRB Research Division	540-231-9359

APPENDIX D : Participants Instructions

Instructions of Experiment

Virginia Polytechnic Institute and State University

Instructions of experiment for the thesis of M.S degree

of Hyun Lee

1. The purpose of this experiment

It was in the 19th century that physiologists and orthopedists began publishing theories about proper sitting postures, and studies were performed for seat and office furniture design. From that time, many efforts were made to design, build, and test chairs which are not only good enough to sit in comfortably and properly, but are functionally adapted to the task of the occupant.

One organization involved in the design of chairs is the HFES (Human Factors and Ergonomics Society) and its ANSI / HFES 100 committee. This committee has designed a Chair Measurement Device (CMD) for specific assessment of seat height, seat depth, seat width, backrest height, backrest width, lumbar support , seat to back included angle, seat pan angle, armrest height, armrest clearance and so on, for the purpose of developing chairs in connection with other related furniture, such as computer desks.

The validity and reliability evaluation of this CMD will determine the future use of this device for the study of chair design, as well as will provide the basis of the part of ANSI/HFES 100-199 standard.

The purpose of this study is to evaluate the accuracy, validity and reliability of the CMD. Repeated measurements by different participants, on different chairs, using CMD will be employed.

2. Experiment Method

A. Participants.

Eight participants will be recruited for this experiment after proper screening. Participants will be screened for their understanding of the instructions and procedure of the experiment. Participants will be given the instructions and procedure of the experiment at the first meeting, and brief questionnaires also will be given to participants to determine if all participants understand the contents of the instructions and procedure. There will be discussion period after the evaluation of the questionnaires, and a demonstration of measurements required by researcher.

B. Apparatus

One CMD, manufactured by BIFMA(the Business and Institutional Furniture Manufacturer's Association-the subcommittee of ANSI/HFES) will be used in this experiment. Three different chairs also will be measured. The chairs will represent a variety of contemporary "ergonomically designed" chairs used for office applications.

C. Definition of Measurements

1. Lumbar support height.

   The height of the point on the backrest that is closest to the upright of CMD, as measured perpendicularly from the front of CMD upright.

2. Seat height.

   The vertical distance , as measured at the seat depth scale slot on CMD, from the floor to the underside of CMD nearest the front of the seat cushion.

3. Seat depth.

   The horizontal distance, as measured at the seat depth scale slot on CMD, from the back of CMD to the front of the seat cushion.

4. Backrest height.

   The vertical distance from the top of the backrest to the bottom of CMD, as measured on the backrest height scale on the front of CMD upright.

5. Seat pan angle.

   The angle between the horizontal plane and the upper surface of the seat cushion.

6. Seat to back included angle.

   The angle between the backrest and the seat cushion, measured at the center of the chair.

D. Procedure

Participants who are selected after screening will be contacted and scheduled for a particular time and date. On the scheduled time and date, participant is supposed to come to the laboratory of this experiment, and will be given the instructions again, with the forms which he or she is supposed to fill the measurements of chairs in.

Participants will take those six specific measurement of chairs (seat height, seat depth, backrest height, lumbar support height , seat to back included angle, seat pan angle), following the procedure as below :

Procedure of the chair measurements using CMD.

Chair set-up

A. Place the chair on a hard, flat and level horizontal surface, and secure it.

B. Marking a center line on the seat, (using chalk or masking tape), running from front to back of the seat, and another center line on the backrest, running from top to bottom.

C. If seat depth is adjustable, adjust seat to its maximum depth.

D. Adjust the seat pan to its highest position.

E. If seat pan angle is adjustable, adjust it to its most horizontal position.

F. If the lumbar support is adjustable independently of the backrest, adjust it to its lowest position.

G. If the backrest is adjustable, adjust it to its lowest position.

H. If the backrest is adjustable backward and forward, position it farthest from the seat.

I. If the backrest angle is adjustable, adjust it to the most vertical position.

Note: When proceeding from one measurement to the other, make sure that chair is set-up in accordance with the above procedure.

CMD set-up

A. Lock the upright of CMD.

B. Center CMD without weights on the seat over the seat center line without touching the backrest but using the vertical center line on the backrest as a positioning guide.

C. Load the rear weights first and then the front weight.

D. Push CMD back along the seat center line until either:

1. the base of CMD contacts the backrest or;
2. the elastic member of the upright of CMD minimally contacts the backrest.

E. If the seat pan angle is adjustable, adjust it so that the top surface of CMD base can be its horizontal position, using a level between the front and rear weights.

F. Mark reference points on CMD and chair to ensure the position of CMD does not change throughout the measurement.

Lumbar support height

A. If both the backrest height and the lumbar support position are not adjustable;

1. Locate the point on the backrest that is closest to the upright of CMD, within the lumbar support zone (the zone between 15 to 25 cm from the bottom of CMD).

2. Measure the height of the point using the lumbar support height scale on CMD.
3. Record it as the "lumbar support height".

B. If the backrest height is adjustable and the lumbar support position is not adjustable;

1. Adjust the backrest to its highest position.
2. Repeat step A.1 and A.2, and record it as "maximum lumbar support height".
3. Adjust the backrest to its lowest position.
4. Repeat step A.1 and A.2, and record it as "minimum lumbar support height".

C. If the backrest height is not adjustable and the lumbar support position is adjustable;

1. Adjust the lumbar support to its highest position.
2. Repeat step A.1 and A.2, and record it as "maximum lumbar support height".
3. Adjust the lumbar support to its lowest position.
4. Repeat step A.1 and A.2, and record it as "minimum lumbar support height".

D. If the backrest height is adjustable and the lumbar support position is adjustable independently of the backrest;

1. Adjust both the backrest and the lumbar support to its highest position.
2. Repeat step A.1 and A.2, and record it as "maximum lumbar support height".
3. Adjust both the backrest and the lumbar support to its lowest position.
4. Repeat step A.1 and A.2, and record it as "minimum lumbar support height".

Seat height

A. If the seat pan height is not adjustable;

1. Using a rigid straight ruler perpendicular to the floor, move it into the seat depth scale slot of CMD, until it touches seat cushion.
2. Measure the distance from the underside of CMD to the floor.
3. Record it as "seat height".

B. If the seat pan height is adjustable;

1. Adjust the seat pan to its highest position.
2. Repeat step A.1 and A.2, and record it as "maximum seat height".
3. Adjust the seat pan to its lowest position.
4. Repeat step A.1 and A.2, and record it as "minimum seat height".

Seat depth

A. If the seat depth is not adjustable;

1. Insert a square into the seat depth scale slot on CMD.
2. Keep it at 90 degrees to the top of CMD, and move it until the blade of the square touches the seat cushion.
3. Read the seat depth from the seat depth scale on CMD.
4. Record it as "seat depth".

B. If the seat depth is adjustable by moving the seat pan and/or the backrest;

1. Adjust the seat pan and/or the backrest to produce the maximum seat depth position.
2. Repeat step A.1, A.2 and A.3, and record it as "maximum seat depth".
3. Adjust the seat pan and/or the backrest to produce the minimum seat depth position.
4. Reposition CMD, following step D of CMD set-up
5. Repeat step A.1, A.2 and A.3, and record it as "minimum seat depth".

Backrest height

A. If the backrest is not adjustable;

1. Using a square and keeping it perpendicular to the front of CMD upright, slide it down until it touch the top of the backrest.
2. Measure the distance from the top of the backrest to the bottom of CMD by using

the backrest height measurement scale on CMD upright.

3. Record it as "backrest height".

B. If the backrest is adjustable;

1. Adjust the backrest to its highest position.
2. Repeat step A.1 and A.2, and record it as "maximum backrest height".
3. Adjust the backrest to its lowest position.
4. Repeat step A.1 and A.2, and record it as "minimum backrest height".

Seat pan angle

A. If seat pan is fixed;

1. Place an angle measuring device on the base of CMD between the front and rear weights.
2. Adjust the level of the angle measuring device until the level is balanced.
3. Record the angle as "seat pan angle".

B. If seat pan is adjustable;

1. Tilt the seat to its most forward position, and repeat step A.1 and A.2.
2. Record the angle as "seat pan angle - forward".
3. Recline the seat to its fullest position, and repeat step A.1 and A.2.
4. Record the angle as "seat pan angle - reclined".

Note: 1. Tilting the seat forward may dislodge CMD and cause personal injury or damage to CMD. Use caution while making this adjustment.

2. Reclining the seat may require manually reclining the seat and/or the back to achieve the maximum reclined seat angle.

3. Make sure that chair should be placed on level floor.

Seat to back included angle

A. If the backrest is fixed;

1. Unlock the bolt that holds CMD upright at 90 degrees to CMD base, and allow CMD upright to rest naturally against the backrest.
2. Using angle measuring device, measure the angle between the top of CMD base and the front of CMD upright.
3. Record it as "seat to back included angle".

B. If the backrest is not fixed;

1. Adjust the backrest and the lumbar support position to their lowest position, and allow the backrest to move forward fully.
2. Repeat step A.1 and A.2, and record it as "minimum seat to back included angle".
3. Move the backrest rearward fully.
4. Repeat step A.1 and A.2, and record it as "maximum seat to back included angle".

Removal of CMD

A. First remove the front weight and then the rear weights from CMD.

B. Lock the upright.

C. Remove CMD from the chair.

APPENDIX E : Measurement Recording Form

Measurements Record

Name :

Measurement no. :

Date : Apr. , 1996

Unit : cm, radian

		Chair 1	Chair 2	Chair 3
Lumbar support height	fixed			
	maximum			
	minimum			
Seat height	fixed			
	maximum			
	minimum			
Seat depth	fixed			
	maximum			
	minimum			
Backrest height	fixed			
	maximum			
	minimum			
Seat pan angle (radian)	fixed			
	reclined			
	forward			
Seat to back included angle	fixed			
(radian)	maximum			
	minimum			

VITA

Hyun Lee was born in Seoul, Korea on July 20, 1959. He obtained his B. S. in Mechanical Engineering from Seoul National University of Korea in February, 1983. As an undergraduate, he was actively involved in Tennis Team of Engineering College.

After graduation, he worked with Daelim Construction Company of Korea for 6 years as a construction engineer, and he moved to Yukong Petrochemical and Refining Company of Korea in September 1988, for which he has been working until now as a safety manager.