The Effect of a Tilting Seat on Back, Lower Back and Legs during Sitting Work

Hiroshi UDO1*, Masahiko FUJIMURA2 and Fumitaka YOSHINAGA1

1 Department of Public Health, Hiroshima University School of Medicine, 1-2-3, Kasumi, Minami-ku, Hiroshima 734-0037, Japan
2 Department of Physical Therapy, Institute of Health Sciences, Hiroshima University School of Medicine, 1-2-3, Kasumi, Minami-ku, Hiroshima 734-0037, Japan

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Abstract: The purpose of this study was to examine the possible effects of a tilting seat on the back, lower back and legs. Ten healthy male subjects aged 22–28 performed word-processing operations while sitting on a chair for one hour under two different seating conditions: the rocking condition and the fixed condition. While the subjects were performing the task, measurements of lower leg swelling were taken using bioelectrical impedance plethysmography, and pain scores were recorded every five min for the neck, shoulders, back, lower back, hips and legs. Electromyograms (EMGs) of the back and lower back (at Th5-6, Th8-9, L1-2 and L3-4) were recorded every sec. In addition, the subjects were videotaped while using the rocking seat, in order to analyze the angle and frequency of seat tilting. At the end of the experiment, the subjects were asked to evaluate the two conditions with respect to localized fatigue and operational efficiency. There was no significant difference in lower leg swelling between the two conditions. EMGs were significantly different at Th5-6, Th8-9 and L1-2 between the two conditions. The rocking condition generated greater EMGs at Th5-6 and L1-2, whereas the fixed condition produced greater EMGs at Th8-9. The pain scores for the neck, shoulders, back and lower back were higher under the fixed condition, while those for the buttocks were higher under the rocking condition. The average tilting frequency was as low as 25.2 times per hour, with 15.6 times per hour for tilting angles ranging from 1 to 2 degrees, and 9.6 times per hour for tilting angles exceeding 2 degrees. As for the subjective evaluations of localized fatigue, seven of the ten subjects preferred the rocking condition, while two preferred the fixed condition and one subject had no preference. Thus, there was a significant difference in the subjective evaluations of the two chairs. These findings suggest that the rocking condition, in contrast to the fixed seating condition, reduced back and lower back pain as a result of its tilting capability. The results of EMGs suggest that the rocking condition reduced back and lower back pain by increasing the overall muscle activity of the back and lower back. The leg impedance measurements showed no effect of the rocking condition on the leg swelling, as compared with the fixed condition.

Key words: Sitting work, Lower back pain, Leg swelling, Rocking chair, Tilting seat

*To whom correspondence should be addressed.
Introduction

Sitting is one of the most common postures used in various settings in the workplace and daily life. Current research shows that sitting positions induce lower back pain more often than a standing posture does because it causes pelvic posterior circumflex with lordosis reduction. As well, sitting postures cause leg swelling as often as standing positions, especially when changing the position of the legs is difficult. Since office automation, industrial robotics and microelectronics technologies have been introduced into offices and manufacturing plants, there has been an increasing amount of office work and machine monitoring and operating work that is performed in a sitting position, often continuously, for many hours at a stretch. These changes in the work environment seem to have led to an increase in lower back pain and other health problems in the lower legs, which are related to long periods of sitting work.

Although various recommendations have been made for increasing the ease of alternating between various postures while sitting. This is because there is probably no single ideal posture, and because it is impossible to maintain a single posture for long periods of time. Also, it has been reported that a fixed posture adversely affects nutrition distribution and results in alimentary deficiency, which causes intervertebral disc disorders. To solve the problems associated with fixed sitting postures, the following approaches have been investigated: 1) The first is using seats with tilting capability rather than fixed ones; 2) another is enabling the occupant to alternate between standing and sitting positions by using a seat that inclines forward to keep the occupant in a half-seated position at all times; and 3) the final one is incorporating break periods to facilitate posture changes. Among these, the use of tilting seats has received much attention as a potentially effective solution because these seats allow users to change positions more easily than the other approaches.

To date, several authors have reported on the effects of tilting seats on the back and on leg swelling. Mandal has produced a chair with a tilting seat designed to prevent lower back pain. Based on his observations, Mandal has claimed that the tilting seat (1) induces more leg movement and thus, reduces leg swelling more than a fixed seat, and (2) that it provides the occupant with more opportunities to alter their posture, thereby reducing lower back pain during sitting work more effectively than a fixed seat. However, he has yet to produce data that directly proves these claims. Bendix et al. first studied to focus on the effects of a tilting seat (Bendix's chair was designed after Mandal's) versus a fixed seat, in terms of leg swelling and the load on the back. To investigate these effects, the following methodology was employed: the volume of the left foot was measured using a water plethysmograph to attain an index of leg swelling; EMGs of the lower back at the third lumbar vertebra (L3) were used as an index of the load on the back; and finally, subjective evaluations, on a digital scale ranging from one (very bad) to five (very good), were used to rate the subjects' level of satisfaction with the two seats. In this study, the authors observed no obvious differences between the two seats in terms of the amount of leg swelling or the level of the EMGs; however, office operators reportedly preferred the tilting seat to the fixed one.

There are several important limitations or problems in the Bendix et al. Firstly, because the seat on this chair moves freely (within a set range of mobility), it can be somewhat unstable, making it difficult for some people to keep their balance. Secondly, the measurements of leg swelling may not be reliable because the subjects had to walk from their offices to the site where the measurements were taken, which may have reduced the level of swelling. The fact that the distance of this walk varied from 50–200 m further calls into question these results. Thirdly, because EMGs were obtained only for L3, this study does not adequately investigate the effects of a tilting seat on the muscle load of the entire back. Lastly, because the subjective evaluation is focused only on the level of general satisfaction with the seats, it does not distinguish between evaluations of the physical effects of the chairs (i.e. back fatigue/pain or the load on the back), and evaluations of their effect on operational efficiency.

In order to avoid similar problems, the following methodology was used in the present study to investigate the effects of a tilting seat. Firstly, the chair used in this study has a rocking seat that may be more stable than the seat on Bendix's chair. Secondly, the bioelectrical impedance method was used to measure leg swelling because it enables the researcher to take these measurements as the subject performs the assigned task. Thirdly, in order to get a more comprehensive picture of the effect of the seat on the back load, EMGs of the back and lower back muscles were recorded. Fourthly, detailed subjective complaints about localized symptoms were used to rank the level of pain experienced in the neck, shoulders, back, lower back, hips.
and legs. Finally, the comprehensive subjective evaluation was divided into two parts in order to distinguish between the effects of the seat in terms of local fatigue and operational efficiency.

**Subjects and Methods**

**Research subjects**

The subjects were ten healthy male university students with no history of cardiac or renal disease, leg varices or other diseases of the back or legs. Prior to participating in the experiment, the conditions and procedures of the experiment were explained to all subjects, and all signed an informed consent form. Anonymity of the subjects was secured by assigning each a random identification number. Their average age, stature, sitting height and weight were (mean ± SD) 23.5 ± 1.7 years, 171.9 ± 3.4 cm, 93.2 ± 1.8 cm and 61.9 ± 7.3 kg, respectively.

**Chair, desk, personal computer and room conditions**

For the tilting seat, we used a commercially available rocking chair with armrests (as shown in Figure 1). The seat is made of wood and is slightly concave to accommodate the buttocks. There are three main types of tilting seats available: the rocking seat used in the present experiment; the Bendix’s chair, in which the seat tilts freely on a rotational axis that is fixed at the base of the chair; and an experimental air ball chair. As indicated above, it is difficult for some people to keep their balance on Bendix’s chair due to the freely moving seat, so they may become tired. This feature also makes the Bendix’s chair inappropriate for precise deskwork. The air ball chair has the same problems as the Bendix’s chair, because it can incline and move freely all directions. For this reason, both the Bendix’s chair and the air ball chair were rejected as possibilities for this study. On the other hand, the rocking chair is the most widely used among the three main types, not only for resting but also for office work. In addition, it is considered more stable than the other two chairs because it has a much smaller range of inclination, and a tendency to return to the middle position of inclination. Based on this information, the rocking chair was chosen for this study. The dimensions of the chair and desk are shown in Table 1. The chair was first set to the rocking seating condition (rocking condition) and second to the fixed seating condition (fixed condition). For the fixed condition, each subject was asked to initially determine the position and the angle of inclination of the seat (in the rocking chair), which would be most favorable to working on a personal computer. The seat was then fixed by engaging a board between the legs of the chair and the floor. Table 2 shows the angle of seat inclination selected under the fixed condition. The mean and standard deviation of the seat angle were −8.8 degrees and 1.1 degrees respectively. The height of commercial rocking seats is usually not adjustable; therefore, the seat height was not adjusted for each subject in this study. To prevent the chair’s armrest from touching the front of the desk and disturbing the rocking movement, the distance between the front edge of the desk and the center of the seat was set at 22 cm. To facilitate the word processing operation, a desk that was slightly lower than conventional ones was used. As with the chair, the height of the desk was not adjusted. A notebook-type (laptop) personal computer was placed on the desk. The dimensions of the chair and desk are shown in Table 1.

![Fig. 1. Rocking seat and desk.](image-url)
The room conditions were controlled as follows: the temperature was kept within the range of 21 to 23°C; the relative humidity ranged from 54 to 65%; the background noise level ranged from 42 to 45 dB; the lighting condition was 488 lx on the keyboard, and 232 lx on the display. The room where the experiment was conducted has a tile floor.

**Task**

The subjects were asked to perform text entry of a document written in Japanese characters (Kanji and Kana), and printed on A4 size paper. The subjects performed this task on the personal computer for a one-hour period, under each of the two seating conditions.

**Measurements**

1) Lower leg swelling: lower leg swelling was utilized as an objective indicator of the load on the legs. The bioelectrical impedance method\(^{20, 21}\) was chosen for evaluating the extent of lower leg swelling in this study, over other methods that use measurements of leg volume\(^{22}\) or leg circumference\(^{23}\). The impedance method is more useful than the other two because it measures leg volume electrically and can therefore take measurements automatically, without disturbing the work. This method is designed to indirectly evaluate the swelling of the lower leg by measuring the change in the rate of impedance in the lower leg. A block diagram of the apparatus\(^{24}\) for measuring impedance is shown in Figure 2. This apparatus measures leg impedance using four-electrodes. The impedance measurement is displayed on the LCD (liquid crystal display) in ohms. The displayed value is the cumulative average of 1/3 of a sec interval, and is updated automatically. The measuring frequency and current were fixed at 5 kHz and 200 \(\mu\)Arms (root mean squared)\(^{24-27}\), respectively. Leg swelling can be detected by a reduction in impedance that is brought about by an increase in the volume of the leg as a result of the pooling of bodily fluids. Impedance is in precisely inverse proportion to the leg volume\(^ {25}\). When measuring impedance using the four-electrode method, two current electrodes supply a constant alternating current and two detecting electrodes detect the voltage difference corresponding to the impedance. The electrodes were fixed on the medial side of the right leg\(^ {24}\) as shown in Figure 2. The two detecting electrodes were fixed at proximal and distal points about 7.5 cm from the thickest part of the calf. The current electrodes were fixed at positions proximally and distally spaced 15 cm away from the upper and lower detecting electrodes, respectively\(^ {24}\). The electrodes used in this study were 1.1 cm in diameter, and made from Ag/AgCl (Nihon Kohden Corporation).

2) EMGS\(^ {28}\) were used as an index of back and lower back muscle activity during sitting work. The EMGs were measured using Ag/AgCl electrodes under bipolar guidance, as in the procedure for measuring impedance. The electrodes were applied at the levels of Th5-6, Th8-9, L1-2 and L3-4, at points 3 cm to the right of the medial line, while the two electrodes for bipolar guidance were applied at points parallel to the muscle tissue, with center-to-center spacing of 2.5

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**Table 2. Angle of seat inclination under the fixed condition**

<table>
<thead>
<tr>
<th>Subject’s No.</th>
<th>Angle of seat (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.1</td>
</tr>
<tr>
<td>2</td>
<td>9.8</td>
</tr>
<tr>
<td>3</td>
<td>8.9</td>
</tr>
<tr>
<td>4</td>
<td>7.0</td>
</tr>
<tr>
<td>5</td>
<td>9.5</td>
</tr>
<tr>
<td>6</td>
<td>8.9</td>
</tr>
<tr>
<td>7</td>
<td>7.3</td>
</tr>
<tr>
<td>8</td>
<td>9.9</td>
</tr>
<tr>
<td>9</td>
<td>8.6</td>
</tr>
<tr>
<td>10</td>
<td>7.5</td>
</tr>
</tbody>
</table>

a) The minus sign indicates a backward inclination.

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**Fig. 2. Block diagram of the bioelectrical impedance apparatus and the electrode location.**
The EMG apparatus consists of an EMG amplifier and a computer, as shown in Figure 3. The EMG signal was rectified, and then it was smoothed by passing it through a low-pass filter at 6.4 Hz. The y-axis of the signal (in micro-volts) was divided into 4096 sections for quantifying the amplitude of the signal. The EMG was recorded at an interval of one sec during the 1-hour sitting task.

3) Subjective complaints: subjective complaints of pain in the neck, shoulders, back, lower back, hips and legs, were ranked using a body pain rating chart. The rating scale used was Borg’s category ratio scale (CR-10), which uses 10 to indicate “extremely strong” pain and 0.5 for “extremely weak” pain, as shown in Table 3. This table was shown to the subjects, who then used it to assess the level of their pain and answered to the examiner. The subjects were asked about their subjective symptoms once every 5 min.

4) Comprehensive subjective evaluations: The subjects were asked the following questions and answered to the examiner immediately after the two trials were completed: (1) “Which seating condition is better for you in terms of local pain in the neck, shoulders, back, lower back, hips and legs?” and (2) “Which seating condition is better for you in terms of the operational effectiveness of the word processing task?”.

5) Video recording: A continuous video recording was taken using an 8mm-video camera to identify seat tilting and postural changes during the task. The camera was set at an 80cm elevation, at a distance of 180 cm from the seat center in the orthogonal direction against the sagittal plane.

Experiment procedures

The 10 subjects were randomly divided into two groups, each of which included 5 subjects. The groups were tested first under one seating condition, and then under the other, with one group starting with the fixed condition and the other group starting with the rocking condition. The experiments were carried out over two days, with one seating condition for one day. Before the experiments, the subjects were asked to practice word-processing operations. They were advised to avoid hard exercise and heavy drinking, and to get a normal night’s sleep in the 24 hours prior to the experiment. On the day of the experiment, they were asked to enter the laboratory one-hour before the scheduled starting time of the experiment. Then, after the electrodes for measuring EMG and lower leg impedance were applied to the back and lower back and to the right leg, respectively, the subjects were asked to sit on the seat. They did text-entry continuously for one hour under each of the two seating conditions. They were instructed to perform the operation at a usual speed, and they were permitted to place their legs wherever they preferred. The leg impedance measurements and subjective complaints were taken once every five min.

Statistical analysis

The impedance of the lower leg is denoted by Z. The level of swelling in the leg was derived from the rate of
change in impedance according to the following formula:

$$\Delta Z\%_t = \left( \frac{Z_0 - Z_t}{Z_0} \right) \times 100$$

(1)

where $\Delta Z\%_t$ is the rate of change in impedance at time $t$, and $Z_0$ and $Z_t$ is the impedance level measured at time 0 and $t$, respectively. According to the results of a previous study\(^2\), the $\Delta Z\%_t$ is theoretically about four times larger than the rate of change of the leg volume.

The average EMG was calculated once every five min from the start of the experiment. For example, the average value of the EMGs in the first 5-min interval is calculated using the EMG values between 0 min to 4 min, 59 sec (300 pieces of data). The average EMG was standardized by the mean and the standard deviation (SD) of the subject’s total average EMG at specific sites, according to the following formula:

$$sEMG = \frac{(\text{average EMG} - \text{mean of the subject’s total average EMG of 1 h}) \, \mu V}{(\text{SD of the subject’s total average EMG of 1 h}) \, \mu V}$$

(2)

where sEMG indicates the standardized EMG. sEMG is a coefficient value, and has no unit, as shown in formula (2).

The tilting frequency and maximum tilting angle of the rocking seat were analyzed using the recorded videotapes. Tilting events with an angle of 1 degree or more were included in the analysis. The tilting events were further classified into two categories; tilting events ranging from 1 to 2 degrees in angle, and tilting events surpassing 2 degrees in angle. The tilting events were totaled and analyzed every 5 min. For example, a 3-degree forward tilting and a subsequent 4-degree backward tilting were counted as two events.

The rate of change in lower leg impedance, the sEMG and the subjective complaint scores were analyzed using a two-way analysis of variance (ANOVA), and the seat type and subject as the factors. The tilting frequency was also analyzed using a one-way ANOVA with the time as a factor. The comprehensive evaluation was analyzed using a $\chi^2$ test. The number of transcribed letters was analyzed using a paired $t$-test. For these parameters, the significance level was assumed to be 5%.

Results

Lower leg impedance

Figure 4 shows the changes in lower leg impedance. The $\Delta Z\%$ increased as time elapsed for both seating conditions.

Fig. 4. Changes in the rate of lower leg impedance (Mean, SE) during one hour of sitting work.

The mean and SD of the $\Delta Z\%$ reached 9.1 ± 9.9% and 8.3 ± 5.1% for fixed condition and rocking condition, respectively. There was no significant difference in $\Delta Z\%$ between the two seating conditions.

sEMG

Figure 5 shows the changes in sEMG at Th5-6, Th8-9, L1-2 and L3-4, respectively. Significant differences between the two seating conditions were observed in the sEMGs at Th5-6 ($P<0.01$), Th8-9 ($P<0.01$) and L1-2 ($P<0.01$). No significant difference was observed in sEMG at L3-4. The sEMGs at the Th5-6 and L1-2 levels were higher in the rocking condition than in the fixed one, while the sEMG at Th8-9 was higher for the fixed condition.

Subjective complaints

Figure 6 shows the changes in the neck, shoulder, back, lower back, hip and leg pain, respectively. There were significant differences in neck ($p<0.05$), shoulder ($p<0.01$), back ($p<0.01$), lower back ($p<0.01$), and hip pain ($p<0.01$) between the two seating conditions. No significant difference was observed in leg pain between the two seating conditions. The pain scores for the neck, shoulders, back and lower back were higher for the fixed condition, while those for the hips were higher for the rocking condition.

Seat tilting frequency and angle

Figure 7 shows the changes in the seat tilting frequency under the rocking condition. No significant difference was found for tilting events of less than 2-degrees, more than 2-degrees, or for all of the tilting events between the different times. The mean tilting events per hour were 15.6 for tilting angles of less than 2 degrees, 9.6 for tilting angles of 2 degrees.
or more, with the combined mean being 25.2. For tilting events exceeding 2 degrees, the occurrences of tilting varied widely from 0 to 27.6, and showed no significant difference in relation to the elapsed time. As for the subjects, individual differences in tilting frequency were substantial, with as many as 91 and 78 tilting events observed in two subjects. The maximum tilting angle ranged from one degree to 7 degrees (Mean ± SD: 3.1 ± 2.2 degrees).

**Workload**

The mean number of transcribed letters including spaces (Mean ± SD) was 807.4 ± 361.4 letters for the fixed condition, and 821.0 ± 347.9 letters for the rocking condition. There was no significant difference in the number of letters between the two seating conditions.

**Comprehensive evaluation**

Table 4 shows the preference for seating conditions among the subjects. With regards to local pain, seven subjects indicated the rocking condition as preferable while one subject preferred the fixed condition, and two subjects could not determine their preference. The preference based on local pain shows a significant difference between the two seating conditions (p<0.05).

From the viewpoint of operational efficiency, three subjects preferred the fixed condition and one subject voted for the rocking condition, while six subjects did not indicate either as favorable.

Tables 5-1, 5-2 and 5-3 show the seat preference and the subjects’ profile, local pain, and sEMG, the rate of lower leg impedance. There was no large difference in profile between the subject who preferred the fixed condition (fixed group) and the subjects who preferred rocking condition (rocking group). Lower back pain was lower in the fixed condition than in the rocking condition for the fixed group, while it was higher in the fixed condition than in the rocking condition for the rocking group. Leg pain was higher in the fixed condition than in the rocking condition for the fixed group, while there was no remarkable difference in it between the two conditions for the rocking group. All the sEMGs at Th5-6, Th8-9 and L1-2 had higher measurements in the fixed condition than in the rocking condition for the fixed group.
Fig. 6. Changes in neck, shoulder, back, lower back, hip, and leg pain (Mean, SE) during one hour of sitting work.
- □: Rocking Condition, ●: Fixed Condition.

Table 4. Seat preference (n=10)

<table>
<thead>
<tr>
<th>Reduction in local pain (%)</th>
<th>10 (100)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>10 (100)*</td>
</tr>
<tr>
<td>Fixed condition</td>
<td>1 (10)</td>
</tr>
<tr>
<td>Rocking condition</td>
<td>7 (70)</td>
</tr>
<tr>
<td>Undetermined</td>
<td>2 (20)</td>
</tr>
</tbody>
</table>

*P<0.05.

Fig. 7. Changes in tilting frequency (Mean, SE) during one hour of sitting work.
- □: Below 2 degrees, ●: At/over 2 degrees.
while only the sEMG at Th8-9 had higher measurements in the fixed condition than in the rocking condition for the rocking group. In terms of the rate of lower leg impedance, there was no large difference between the two groups.

**Discussions**

**Chair with a tilting seat**

Even the ideal chair could not completely eliminate the pain associated with sitting operations, and therefore it is important to allow for operating postures to be alternated during sitting operations in order to mitigate the pain. Use of a tilting seat is one of the possible measures for achieving this purpose. Mandal\(^{14}\) has claimed that the tilting seat induces more leg movement and thus, reduces leg swelling more effectively than a fixed seat, and that it enables the occupant to alter their posture during sitting work more easily than a fixed seat does. Bendix *et al.* also reported that office operators preferred the tilting seat to the fixed seat.

Nagashima *et al.*\(^{30}\) studied an air ball chair (Sitzball) which allows the occupants to alternate their postures easily. Using an infrared oxygen monitor (NIRO), they measured hemoglobin oxidization (HbO\(_2\)) and the hemoglobin (Hb) level in the blood taken from the right superior musculus trapezius and from just right of the lumbar spine of the subjects, while they were sitting on the Sitzball and fixed
seats. The authors infer that the Sitzball seat allows for more behavioral flexibility from the finding that higher hemoglobin oxidation concentrations were observed while sitting on the Sitzball seat.

Therefore, it is evident that several advantages have been observed in tilting seats as compared with fixed seats. However, the possible effects of tilting seats have not yet been adequately examined. In this study we attempted a comparison between the tilting seat and fixed seat, with a view to determining the potential effects of tilting seats on the back, lower back and legs.

Tilting seats which have actually been introduced in offices or tentatively manufactured include 1) the rocking seat17-19, 2) Bendix's chair with a tilting seat13, 14, 16, and 3) the ball chair (Sitzball, Ledraplastic Inc)30-32. In the case of the Bendix's chair, the seat tilts on a rotating axis that is fixed at the middle of chair base, which enables the seat to tilt forward/backward at angles ranging from -8° (backward) to +19.5° (forward), according to the occupant's angle of inclining. The ball chair incorporates a circular fixture with a backrest and four legs, which sits on a vinyl chloride air ball with a diameter of 42-65 cm. The occupant sits on the ball, the elasticity of which allows the occupant to easily change his/her postures. Among these chairs, the rocking seat is the most widely used17-19. Although the rocking seat has previously been used to improve comfort during break periods, it is now being used for office operations as well19. In addition, because the rocking seat is more stable than the other two chairs as indicated above, it is considered more appropriate for precise deskwork than the others. Therefore, a rocking seat was used in this study to examine the effects of a tilting seat.

Seat tilting frequency and angle

In the Bendix et al.13 the subjects performed 48 min of deskwork followed by successive 12-min typing operations, in which the mean number of tilting events exceeding 2 degrees per hour was measured. The mean frequency of tilting events during the deskwork increased from about 41 per hour in the initial measurement to about 83 per hour in the final measurement. The frequency, however, declined significantly to about 29 per hour after the typing was undertaken. Bendix et al. concluded that typing operations constrain the trunk more and require less movement than deskwork does. In our study, the mean frequency of tilting events with an angle exceeding 2 degrees was 9.6 per hour (Minimum: 0, Maximum: 27.6). This is markedly low, compared with the mean frequency that Bendix et al. reported for deskwork, or even compared with the mean frequency for the final 12-min interval, which was 18 per hour. The comparatively low tilting frequency in our study as compared with the Bendix et al. study could be explained by the fact that the latter involved deskwork and typing operations which may have encouraged more tilting because they require a greater variety of movements than word processing operations. For example the latter may have entailed writing, reading and looking up documents during deskwork, and installing/removing paper, and adjusting the position of paper during the typing operations.

Alternatively, it could be a result of the difference in tilting mechanisms between our rocking seat and the seat of the Bendix's chair. While the seat of the Bendix's chair facilitates trunk movement because it is placed on a rotating axis, the rocking seat requires substantial trunk movement for tilting, which may have reduced the relative number of tilting events. This discrepancy indicates that the effects of different tilting mechanisms should be further examined.

Lower leg swelling

Impedance plethysmography was used to measure lower leg swelling in this study. Impedance in the lower leg is reduced as its radius increases due to swelling. The change in lower leg impedance helps determine the change in lower leg volume, and thus swelling24-27. The rate of change in impedance at the end of 60 min of sitting work was 9.1 ± 9.9% (mean ± SD) for the fixed condition, and 8.3 ± 5.1% for the rocking condition. These values are largely consistent with those reported26 for a one-hour sitting operation involving a normal seat which does not restrict leg movement (9.7 ± 7.5%). The major factors associated with leg swelling include hydrostatic pressure33, muscle pumps33 and compression of the thighs from the seat4,34. Intermittent muscular constriction and relaxation induced by movement compress and relax the surrounding veins and lymph channel to propel blood and lymph flow. When a sitting posture is maintained, frequent leg movement triggers the muscle pump to mitigate lower leg swelling. A rocking seat is, therefore, more likely to prompt the muscle pump by facilitating weight load displacement during sitting operations as compared to a fixed seat. This was the hypothesis underlying this experiment. The results indicate that the tilting seat condition had no significant effect on lower leg swelling, consistent with Bendix et al. This is probably because the subjects were preoccupied with the operation, and thus failed to use the tilting capability of the seat, resulting in a decrease in the tilting frequency and angle to only about 3 degrees, as demonstrated by the analysis of the maximum tilting angles.
EMG

The EMG at Th8-9 showed greater activity under the fixed condition, whereas the EMG at Th5-6 and L1-2 attained greater activity in the rocking condition. The difference between the two seating conditions in the sites of greater activity is inferred to be the result of differences in the way of changing postures under the two seating conditions. The subjects mainly adjusted their postures by displacing their midmost back under the fixed condition, while under the rocking condition they changed postures by tilting the seat, leading to increased overall activity in the latter. Further studies including minor movement analysis may be required to gain insight into this difference.

Subjective complaints and comprehensive evaluation

The rocking condition produced fewer complaints about neck, shoulder, back and lower back pain as compared to the fixed seat. This may be explained by the fact that the rocking seat allowed the subjects to change their back posture more easily during sitting work, albeit not so frequently, as compared to the fixed seat. Conversely, more complaints about hips pain were reported for the rocking condition, probably because the seat was tilted coincidentally with the forward/backward inclination of the hips, tending to fix the interface between the hips and seat. Another underlying factor may be the material of the seat itself. The seat was wooden and had no cushion, so it may have produced more compression and therefore induced more pain in the hips. To determine the causes of this increase in hip pain, it may be necessary to investigate the pressure distribution over the hips. And to reduce hip pain, a cushion may be required.

In the comprehensive evaluation, the subjects preferred the rocking condition to the fixed condition based on the degree of local pain experienced. The rocking condition was preferred because the subjects perceived pain in the form of back pain rather than hip pain.

The differences were observed in lower back pain, leg pain and sEMGs at Th 5-6 and L1-2 between the fixed group and the rocking group. In this study, the factors affecting such individual difference for the rocking condition were not clear. In the future, the individual difference should be discussed.

Overall evaluations

It is widely believed that less constrained sitting postures enhance blood flow in the back and lower back area and are favorable in regard to reducing fatigue and pain. This study suggests that the rocking condition, as compared to the fixed condition, mitigates pain in the neck, shoulders, back and lower back by reducing postural constraint on the subjects.

On the other hand, in this study, the EMG results were not consistent with the subjective pain results based on the viewpoint that if EMGs were lower, indicating a lighter load on the muscles, one would expect a reduction in pain scores. Muscle exercises are classified into two categories: static and dynamic. Static muscle exercises do not allow the muscle pump to function, and constricted blood vessels fail to supply adequate oxygen and aliments. As a result, static muscle exercises are believed to cause fatigue more quickly than dynamic ones. Bendix et al. compared localized fatigue associated with three seats using a method in which lower EMG indicates a reduced muscle load. When either dynamic or static muscle exercises are predominant, they quite reasonably conclude that exercises with lower EMGs result in a lighter muscle load. However, when both dynamic and static muscle exercises are required alternately to retain or change positions, as in this study, this evaluation method may be not applicable. Indeed, intermittent dynamic muscle exercises are effective in reducing the fatigue associated with lower level muscle activities such as sitting operations. In this sense, the above-mentioned inconsistency between EMGs and subjective complaints can be explained by the fact that the rocking condition allowed dynamic muscle exercises to be interposed between static exercises. To confirm this explanation, it would be necessary to more precisely characterize the muscle exercises in the relevant operations through the launching patterns generated in the EMG. In the light muscular load with static and dynamic exercises such as this unconstrained sitting work, it was suggested that average EMG amplitudes are not appropriate for indicator because intermittent dynamic exercises may make the evaluation of EMG results difficult. Therefore we should discuss another method of EMG, i.e. mean power frequency of EMG which may reflect muscle fatigue more directly than the average EMG amplitudes.

This study involved rather short word-processing operations. Prolonged word-processing operations could lead to different results. However, several authors recommend that a period of at least 30 min of sitting time is required for evaluating seats for comfort. In light of these guidelines, the one-hour sitting operation used in this study is adequate for seat evaluation, and the results are useful in evaluating tilting seats for their effectiveness in mitigating subjective complaints.

Earlier studies have shown that word-processing operations constrain the operator's trunk more tightly than general
deskwork\textsuperscript{41}. This finding is also supported by the experiment of Bendix \textit{et al.} on typing operations. It has been observed that word-processing operations result in constrained postures because they integrate operators into human-machine system, binding them to the monitor and keyboard. This study used a rocking seat to help change the sitting posture, and compared its effectiveness with that of a fixed seat. Once immersed in word-processing operations, however, the subjects hardly tilted the seat. Despite the increased importance of tilting the seat in more restrictive operations, manually tilting seats seem to actually decrease the frequency of tilting because operators are more closely bound to the operation. To resolve this contradictory situation, it could be fruitful to examine the effectiveness of automatically tilting seats, which will be our next subject of research.

Conclusions

In this study, we have examined the effects of a tilting seat versus a fixed seat on lower leg swelling, EMGs of the back and lower back and on subjective complaints about pain during one hour of sitting work. Ten healthy male subjects performed word-processing operations while using a chair under two different conditions; the rocking condition and the fixed condition. The main results obtained are as follows.

The rate of change in impedance of the lower leg increased as time elapsed for both seating conditions. The rate reached $9.1 \pm 9.9\%$ (mean $\pm$ SD) and $8.3 \pm 5.1\%$ for the fixed condition and rocking condition, respectively. There was no significant difference in lower leg swelling between the two conditions.

Significant differences in the sEMGs of the two seating conditions were observed at Th5-6, Th8-9, and L1-2. The sEMGs at the Th5-6 and L1-2 levels were higher in the rocking condition than in the fixed, while the sEMGs at Th8-9 was higher for the fixed condition.

There were significant differences in neck, shoulder, back, lower back and hip pain between the two seat conditions. The pain scores for the neck, shoulders, back and lower back were higher for the fixed condition, while those for the hips were higher for the rocking condition.

With regards to local pain in the comprehensive evaluation, seven subjects indicated the rocking condition as preferable while one subject preferred the fixed condition, and two subjects could not determine their preference. The preference based on local pain shows a significant difference between the two seating conditions.

From the subjective evaluation, it is suggested that the rocking condition, as compared with the fixed condition, reduced back and lower back pain as result of its tilting capability. The results of EMGs suggest that the rocking condition reduced back and lower back pain by increasing the overall muscle activity of the back and lower back. The leg impedance measurements showed no effect of the rocking condition on the leg swelling, as compared with the fixed condition.

References

EFFECT OF TILTING SEAT ON BACK, LOWER BACK AND LEGS

40) Barkla DM (1964) Chair angles, duration of sitting, and comfort ratings. Ergonomics 7, 297.