Effects of the Height of Ball-Backrest on Head and Shoulder Posture and Trunk Muscle Activity in VDT Workers

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Abstract: This study was designed to elucidate the effects of a ball-backrest at different heights on the head and shoulder posture and neck and trunk muscles of visual display terminal (VDT) workers who adopted a forward head posture when working at a VDT. Twenty-three VDT workers with forward head posture performed the keyboard typing work at a VDT without and with a ball-backrest at the L3, T10, and T4 levels. Surface electromyograms were recorded from the neck, shoulder, and trunk muscles, and the forward head angle and forward shoulder angle were analyzed using a 3-D motion analysis system. The significance of differences for the ball-backrest at different heights was tested by repeated one-way ANOVA, with the significance cutoff set at \(p=0.05\). The mean forward head angle and forward shoulder angle decreased in the order of no backrest, T10-level ball-backrest, T4-level ball-backrest. Compared with not using a backrest, the activity of midcervical muscles was significantly lower and that of the lower trapezius was significantly higher when using a T4-level ball-backrest, and the activity of the internal oblique abdominal muscle was significantly higher when using a T10-level ball-backrest. We suggested that using T4 and T10-level ball-backrests would produce similar effects to active exercise, such as ball exercise for trunk stabilization, and that a ball-backrest would prevent kinematics changes. Therefore, the height of the backrest must be determined on the basis of the characteristics of work-related musculoskeletal disorders when applying a ball-backrest to VDT workers with such disorders.

Key words: Backrest height, Ball-backrest chair, Forward head posture, Work-related musculoskeletal disorders

Introduction

Work-related musculoskeletal disorders (WRMDs), also called overuse injuries, account for a significant proportion of work injuries\(^1\). Several risk factors are associated with the development or exacerbation of WRMDs in the workplace, including physical and biomechanical factors, and the inherent predisposition of the individual\(^2\,\,3\). A static sitting posture increases muscle tension, resulting in pain, numbness, loss of function, and a variety of neuromuscular symptoms, most often in the upper body\(^2\,\,4\,\,5\). Work-related neck and upper-limb disorders (WRNULDs) are the most common form of occupational disease\(^6\). WRNULDs have been associated with prolonged periods of computer work and holding a static pos-
tured. There is mounting evidence of the adverse effects of a static neck and shoulder posture, such as that frequently assumed by visual display terminal (VDT) workers.

Proper posture is considered to be a state of musculoskeletal balance that involves minimizing the stresses and strains acting on the body. A flexed spine results in higher activity in the cervical erector spinae and upper trapezius muscles, with a posture in which the trunk is slightly inclined backward. Forward head and trunk flexion may have gradually developed into a fixed postural habit whenever the workers worked at VDTs, and different muscle control strategies may have also developed concurrently.

The forward head posture (FHP) that is commonly adopted by VDT workers involves a combination of lower cervical flexion and upper cervical extension and has been linked to musculoskeletal dysfunctions such as upper crossed syndrome. A FHP reduces the average length of the muscle fibers, which contributes to extensor torque about the atlanto-occipital joint, and it is possible that this shortening reduces the tension-generating capabilities of the muscles. In clinical practice it is widely believed that a FHP contributes to the development of chronic neck and shoulder pain. Chiu found that approximately 60% of individuals with neck pain had FHP.

If FHP is evident, it has been proposed that the clinician may assume that the thoracic kyphosis angle will have increased and that the position of the scapula will have altered, with the potential for pathology. FHP and trunk flexion have been linked to musculoskeletal dysfunction of the neck and trunk such as upper crossed syndrome. Many studies have attempted to determine the seating postures that reduce the risk of developing musculoskeletal pain of the neck and trunk. Different chair designs have emerged aimed at allowing the individual to assume a correct seating posture while maintaining comfort and functionality. Numerous studies have investigated the impact of chair design parameters and the position of VDTs on neck, shoulder, and back pain, including the backrest type, and the associated physiological responses, subjective discomfort ratings, and user perceptions. Among the various factors in seating and chair design, the backrest has become a focal point.

Leivseth and Drerup reported that sitting in an office chair with a backrest reduces the compressive loading on the spine compared to adopting an upright sitting posture without a backrest. However, the VDT workers appeared to be using the backrest to unload the spine during their habitual posture and when they were reclined in the backrest during their VDT works, the cervicobrachial muscles had a longer lever arm over which to stabilize the distal movement when compared to an upright or slouched forward posture.

Ball exercises are effective in rehabilitating the musculoskeletal disorders and poor spinal balance because they help to strengthen and develop the core body muscles that help to stabilize the spine. van Dieen et al. showed that dynamic office chairs potentially offer advantages over fixed chairs. This has lead to suggestions that dynamic changes in the sitting position with frequent posture changes are beneficial such as sitting on ball. Yoo et al. reported that the muscle activities of the serratus anterior and middle trapezius muscles (which are known to be weakened in upper crossed syndrome) were significantly higher, and that of the upper trapezius muscle (which is known to be tightened in this syndrome) was significantly lower when sitting in a ball-backrest chair than when sitting in a general-purpose-backrest chair. Based on this background, the present study assessed the electromyography (EMG) activities of the neck, shoulder, and trunk muscles, and the forward head and forward shoulder angles while VDT workers exhibiting pronounced FHP performed computer work sitting in a chair with a ball-backrest at different heights.

### Subjects and Methods

Twenty-three VDT workers (12 males, 11 females) with pronounced FHP and aged 26–32 yr were recruited from laboratories and offices in Wonju city (Table 1). To select VDT workers who had pronounced FHP, each subject was videotaped with a single video camera to capture the sagittal profile of the upper body when sitting comfortably. All subjects were able to complete three trials. The measured value of FHP was recorded by a digital camera, and video motion analysis software (SIMI Twinner Pro, SIMI Reality Motion Systems, Unterschleissheim, Germany) was used to analyze the kinematics data. This system operated at a sampling rate of 30 Hz. The video camera was placed with its lens 3 m from the subject and pointing directly at the subject so as to reduce lens error, and with the camera perpendicular to the ground, parallel to the facing plane of the subject, and approximately level with the subject’s shoulder to minimize parallax error.

### Table 1. General characteristics of the subjects (N=23)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>29.5 ± 3.2</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.66 ± 0.19</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>60.8 ± 5.2</td>
</tr>
<tr>
<td>Forward head angle (˚)</td>
<td>38.2 ± 2.8</td>
</tr>
</tbody>
</table>
The selected subjects had a sagittal-plane head posture angle of 42.5˚ or less and were right-dominant, free of neck and back pain for a minimum of 1 yr prior to the study, and did not have upper-limb or cervical spine pathologies, or rheumatological or neurological conditions.

Ethical approval was obtained from the Yonsei University Faculty of Health Sciences Human Ethics Committee, and the subjects provided written informed consent prior to their participation.

The EMG signals were amplified by a preamplifier placed close to the electrodes and then sent to the data acquisition unit of an MP100 system (Biopack System, Santa Barbara, CA, USA) that amplified and sampled the EMG inputs at 1,000 Hz. The root-mean-square values were calculated for 250 samples, and the amplitude was normalized to submaximal reference voluntary contractions rather than to maximal voluntary contractions so as to reduce the risk of injury or residual muscle soreness, especially in the neck, and because there was no assurance that a maximum contraction could be obtained. Surface EMG signals from the following five muscles were measured whilst the subjects worked at a VDT: mid-cervical, and L5 paraspinal muscles (which is known to be tightened in poor sitting posture) and lower trapezius, serratus anterior, and internal abdominal oblique muscles (which are known to be weakened in poor sitting posture). These muscles are superficial and gross muscles, and were not in contact with the ball-backrest of the chair when the subject was working at the VDT. The activities of muscles on the subject’s right side were detected by surface electrodes (DE-3.1 EMG, Delsys, Boston, MA, USA) that were attached to skin that had been shaved and then cleaned using alcohol. The electrode locations were as follows: (1) midcervical muscles — approximately 2 cm from the midline over the muscle belly at approximately C4; (2) lower trapezius muscles — next to the medial edge of the scapula at an oblique angle of 55˚; (3) serratus anterior muscles — just below the axillary area, at the level of the inferior tip of the scapular, and just medial to the latissimus dorsi; (4) L5 paraspinal muscles — approximately 2 cm from the spine over the muscle mass; and (5) internal abdominal oblique muscles — just medial to the midway point between the anterior superior iliac spine and the pubic tubercle. The neck reference contractions were obtained by attaching a 0.3-kg weight to the face mask of a helmet and having the participant look straight ahead and keep the neck in line with the spine (thereby resisting neck flexion). Shoulder reference contractions were obtained by holding a 0.3-kg sandbag in each hand with arms abducted 90˚ in the frontal plane and parallel to the floor. Trunk reference contractions were obtained by holding a three-point stance with the right leg raised, following an initial four-point stance with knees and hands on the floor. Participants completed three 5-s submaximal exertions with a 1-min rest period between contractions. All EMG data were calculated from the last 30 s of 300 s of data recorded and analyzed using program created with Acqknowledge software (version 3.7.3) (Biopack System, Santa Barbara, CA, USA), and expressed as mean percentages relative to reference voluntary contractions (%RVC).

The forward head and forward shoulder angles were recorded by a 3-D motion analysis system (CMS-HS, Zebris Medizintechnik, Isny, Germany) and calculated from the last 30 s of 300 s of data recorded. The kinetics data were obtained at a sampling rate of 30 Hz from three body markers that were placed on the tragus of the ear, C7 spinous process, and the right lateral tip of the acromion by the same investigator. The forward head angle was defined as that between the line from the tragus to the C7 line and the X-axis at C7, and the forward shoulder angle was between the line from the acromion to the C7 line and the X-axis at C7 (Lewis, Green, and Wright 2005) (Fig. 1).

The ball-backrest was a backrest with adjustable-height 25 cm ball (Fig. 2). We designed the ball-backrest to exert a continuous external load via the tension of the ball against the trunk (Fig. 3).

A digital pressure sensor (AP-series pressure sensor, Keyence, Japan) directly connected to the ball-backrest was used to ensure that either (1) the subject did not lean or (2) any leaning that was already present was not exacerbated. The digital display of the sensor was placed alongside the VDT so that the subject could monitor and self-adjust the applied pressure (Fig. 4).

This study measured the activities of the neck, shoulder, and trunk muscles, and the forward head and shoul-

![Fig. 1. Forward head (A) and forward shoulder (B) angles identified by three markers.](image)
der angles of VDT workers performing computer work while sitting on a chair without and with the ball-backrest at different heights (T4, T10, and L3 levels) (Fig. 5). We used T4, T10, and L3 levels because these are the processes at which the thoracic and lumbar segments are most flexed\textsuperscript{4, 31}.

The initial calibration posture was obtained by holding the line from the tragus to the acromion parallel to the vertical line with the chin retracted, and with a plumb line suspended from the ceiling to provide a vertical and magnification reference. The kinematics data were the average forward head and shoulder angles, with all of these angles differing between the initial calibration posture and the end posture during VDT work.

The subjects adopted a working posture that they considered to be comfortable and natural, and performed the selected keyboard typing work in Hangeul typing program. All of the experimental procedures were performed by the same investigator in order to reduce variability in marker and electrode placement. Out-of-plane artifacts were minimized by asking the subjects not to swivel on the chair. During data collection, the study participants were barefoot with arms relaxed and their feet separated by the shoulder width. An adjustable-height table and
chair were used to set the initial sitting posture so as to ensure that the hips and knees were flexed by 90°. A 5 min adjustment period was provided during which subjects were instructed to select a workstation configuration (such as keyboard position) in a manner which felt most comfortable to them. The configuration maintained for the duration of the 10 min work periods.

The SPSS statistical package (SPSS, Chicago, IL, USA) was used to analyze differences in the muscle activities and head and shoulder angles. The significance of differences for the ball-backrest at different heights was tested by repeated one-way ANOVA, with significance defined as being present when \( p < 0.05 \). For the significant main effect, Bonferroni’s correction was performed to identify the specific mean differences.

### Results

The normalized EMG data of the midcervical, lower trapezius, L5 paraspinal, and internal abdominal oblique muscles differed significantly with the height of the ball-backrest (Table 2). Compared with not using a backrest, the midcervical muscle activity was significantly lower and the lower trapezius and L5 paraspinal muscle activities were significantly higher with a T4-level ball-backrest, the internal abdominal oblique muscle activity was significantly higher with a T10-level ball-backrest, L5 paraspinal muscle activity was significantly lower with a L3-level ball-backrest, and the serratus anterior muscle activity was not significantly affected by the presence of a ball-backrest (Figs. 6, 7).

The forward head angle and forward shoulder angle also differed significantly with the height of the ball-back-

### Table 2. Normalized EMG data of the neck and trunk muscles

<table>
<thead>
<tr>
<th>Muscle activities (%RVC)</th>
<th>Types of backrest</th>
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<tbody>
<tr>
<td></td>
<td>No backrest</td>
<td>L3-level</td>
<td>T10-level</td>
<td>T4-level</td>
<td>( p )</td>
<td></td>
</tr>
<tr>
<td>Mid cervical</td>
<td>48.57 ± 16.75*</td>
<td>52.39 ± 15.47</td>
<td>44.91 ± 14.06</td>
<td>33.93 ± 10.40</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Lower trapezius</td>
<td>55.69 ± 15.39</td>
<td>57.93 ± 15.62</td>
<td>62.29 ± 17.98</td>
<td>70.17 ± 17.67</td>
<td>0.007</td>
<td></td>
</tr>
<tr>
<td>Serratus anterior</td>
<td>26.82 ± 10.34</td>
<td>29.45 ± 11.34</td>
<td>33.02 ± 9.53</td>
<td>33.59 ± 12.09</td>
<td>0.106</td>
<td></td>
</tr>
<tr>
<td>L5 paraspinal</td>
<td>62.92 ± 12.34</td>
<td>56.39 ± 11.46</td>
<td>65.04 ± 10.53</td>
<td>70.20 ± 9.75</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Internal abdominal oblique</td>
<td>57.90 ± 13.17</td>
<td>52.68 ± 13.82</td>
<td>62.34 ± 14.73</td>
<td>60.86 ± 18.82</td>
<td>0.013</td>
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*mean ± SD.

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**Fig. 6.** Normalized EMG data of the midcervical and lower trapezius muscles (\( * p_{adj} < 0.05/6 \)).

**Fig. 7.** Normalized EMG data of the L5 paraspinal and internal abdominal oblique muscles (\( * p_{adj} < 0.05/6 \)).
rest. The mean forward head angle and forward shoulder angle were significantly lower with T10 and T4-level ball-backrests compared with no backrest condition (Table 3) (Figs. 8, 9).

### Discussion

The purpose of this study was to determine the effects of using a ball-backrest at different heights on the head and shoulder posture and trunk muscles of VDT workers with FHP. The mean forward head angle and forward shoulder angle decreased in the order of no backrest, T10-level ball-backrest, T4-level ball-backrest, and the normalized EMG data of the midcervical, lower trapezius, L5 paraspinal, and internal abdominal oblique muscles differed significantly with the height of the ball-backrest.

FHP can alter the soft tissue in the cervical region, with a shortening of the posterior cervical and suboccipital muscles, weakening of the scapular retractor muscles, and increased stress on the ligaments. The imbalances created by this position decrease the muscular efficiency and increase the muscular activity required to hold the head and neck in a stable position.

Compared with not using a backrest, when using a T4-level ball-backrest the mean forward head and forward shoulder angles and the activity of the lower trapezius muscle (which is known to be weakened in upper crossed syndrome) were significantly higher, and the activity of the midcervical muscle (which is known to be tightened in this syndrome) was significantly lower. We hypothesized that using a T4-level ball-backrest would produce similar effects to active exercise, such as the McKenzie retraction exercise for upper crossed syndrome and FHP. However, the activity of the L5 paraspinal muscle was significantly increased when using a backrest. These changes in the activities of the trunk muscles may have been responsible for the negative effects of using a backrest reported by patients with back pain.

Compared with not using a backrest, when using a T10-level ball-backrest the mean forward head and forward shoulder angles were significantly decreased and the internal abdominal oblique muscle activity was significantly increased. The co-contraction of deep abdominal muscles with the lumbar multifidus has the potential to provide a dynamic corset for the lumbar spine, enhancing its segmental stability during functional tasks and the maintenance of neutral spinal postures. Stabilization exercises are beneficial for patients with abdominal weakness, and long-term data suggest that combining specific exercise therapy with medical management and resumption of normal activity is more effective in reducing back pain recurrence. Ball exercises are effective in rehabilitating the musculoskeletal disorders because they help to strengthen and develop the core body muscles that help to stabilize the spine. It has previously been shown that specific exercises are more effective than other treatments for low back pain. We suggested that using a T10-level ball-backrest would produce similar effects to active exercise, such as ball exercise for lumbar stabilization, and that a ball-backrest would prevent kinematics changes such as slumping and kyphosis. The resulting lumbar stability could have positive effects on VDT workers with FHP and forward shoulder posture.
Compared with not using a backrest, when using a L3-level ball-backrest the L5 paraspinal muscle activity was significantly decreased and the mean forward head and forward shoulder angles did not differ significantly. In mean muscle activity, when using a L3-level ball-backrest the internal abdominal oblique muscle activity was lower than others. During upright sitting co-contraction of spinal stabilizing muscles such as the multifidus, erector spinae and abdominal wall muscles is observed, whereas poor posture such as slump sitting have been shown to result in decreased of these same muscles\(^{27}\). En-range flexion has also been associated with a decrease in back muscle activity. This response of the back muscles is referred to as the flexion-relaxation phenomenon (McGill, and Kippers 1994). We thought that a L3-level ball-backrest would elicit the flexion-relaxation phenomenon, which is the occurrence of muscle activity silence during peak forward bending.

Standard backrests have been shown to reduce the loading on the lower back, but they also can induce kyphosis because individuals push their lumbar spine backwards against the backrest to increase their stability\(^{36}\). In an examination of three chairs, one with a fixed seat and back rest and two dynamic chairs, van Dieen et al.\(^{14}\) found that the stature was improved after 3 h of sitting in the two dynamic chairs compared with sitting in the fixed chair. They attributed this to the recovery of disc height due to the better support provided by the spring-loaded backrest of the dynamic chair reducing spinal compression.

Our ball-backrest would provide more effective support and dynamic contraction of the trunk. A ball-backrest may produce a continuous co-contraction for stability against a continuous low-load via the tension of the ball. This continual low-level activation can prevent the relaxation of the Type I muscle fibers\(^{14,21}\). The general biomechanical and specific loading of some structures may contribute to the musculoskeletal resistance in the subjects, and these factors are likely to play a major role in the present situation, perhaps explaining the difference in the results between chairs with no backrest and the T4 and T10-ball-backrest. The instability when pressing against the ball increases co-contraction patterns so as to promote an upright sitting posture when compared to a stable surface. The use of a labile surface underneath subjects for stability training of the trunk muscles is increasing in popularity\(^{22,37,38}\).

Vergara, and Page\(^{39}\) suggested that large changes in sitting posture are indicative of discomfort while small movements are necessary to alleviate pain caused by static lumbar and pelvic postures. This may indicate that seating conditions that promote movement are more comfortable\(^{19}\). The use of a ball-backrest not only enhance the co-contraction of the trunk muscles for stability, but also result in a more comfortable sitting posture than when sitting on an exercise ball.

Factors of reduced trunk muscle endurance would include altered muscle patterns and prolonged passive system loading associated with reduced activity of spinal stabilizing muscles\(^{40}\). Poor muscle endurance was correlated to increased periods of habitual sitting and lower physical activity levels\(^{41}\). Combining exercises with the provision of information on the correction of poor posture represent a common treatment approach for the management of neck and shoulder pain\(^{10,21}\). Falla et al.\(^{32}\) showed the effect of neck exercise on sitting posture in the presence of chronic neck pain, and found that people with chronic neck pain demonstrate a reduced ability to maintain an upright position. Therefore, interventions should target the exercising of cervical region muscles so as to improve the ability to maintain a neutral cervical posture\(^{32}\).

Deviation from normal alignment suggests the presence of imbalance and abnormal strain on the musculoskeletal system. Yoo et al.\(^{17}\) described the effect on posture of using a proximity-sensing feedback device to provide biofeedback when slouching or FHP is present during VDT work. Poor trunk muscle endurance was correlated with increased periods of sitting and lower physical activity levels\(^{27,42}\). This is supported by recent research showing a relationship between a passive slumped sitting posture and reduced trunk muscle activity. O’Sullivan et al.\(^{42}\) showed that decreased trunk muscle endurance is associated with habitually adopting a passive sitting posture and reduced activity levels.

Balls are frequently employed in clinical practice to facilitate deep muscle activities\(^{22,43}\); however, it is not possible to measure the activities of deep muscles because we used surface EMG to investigate muscle activity and assumed that the detected signal represented each muscle in its entirety, but there are potential signal alterations caused by muscle movements below the surface electrode or cross-talk from adjacent muscles.

McGill et al.\(^{44}\) suggested that prolonged sitting on a dynamic, unstable seat surface such as a ball does not significantly affect the muscle activity, spine posture, spine loads, or overall spine stability, and that the associated spreading out of the contact area may result in uncomfortable soft tissue compression, which perhaps explains the discomfort reported by users of such balls. The role of a chair backrest is to attenuate the stresses exerted on the spine while maintaining lumbar lordosis and increasing comfort\(^{19}\), but the present study did not examine spinal moments or the comfort of subjects. Future research should assess the effects of using ball-backrests at different heights on spinal moments and the comfort of
users. Moreover, the long-term changes in contact pressure and localized muscle fatigue should also be measured.

Our data were obtained during short recording time from young healthy subjects, so we cannot explain factors associated with age and longer duration changes in the forward head and forward shoulder posture appearance and the trunk muscle activity. Such a further study will need to recruit various ages and to record the EMG and postures for longer durations.

An office chair with a backrest reduced the compressive loading on the spine compared to an upright sitting posture without a backrest. However, using a backrest at the incorrect height can produce a poor posture and fatigue. The selection of backrest height is a very important factor for preventing work-related disorders, so the backrest height must be determined on the basis of the characteristics of WRMDs when applying a ball-backrest to VDT workers with such disorders.

References

EFFECTS OF THE HEIGHT OF BALL-BACKREST ON VDT WORKERS


