An increasing number of employees spend most of their working hours using computers. Work-related musculoskeletal disorders (WRMSDs) occur not only because of the dynamic loaded tasks such as lifting but also because of long-term use of computers\(^1\). Epidemiological studies have been published investigating computer operation as the cause of low back pain (LBP) and neck and shoulder pain (NSP)\(^2, 3\). Although it has been suggested that a number of factors cause these symptoms including ergonomic configuration, lack of breaks from computer operation and chair design, it is agreed that the main cause of WRMSDs is sustained poor posture during computer operation\(^4–6\).

Within the sagittal plane, habitual poor postures include forward head and flexed-relaxed postures\(^4, 6\). Both of these positions are easily adopted by computer users due to their low muscular effort, and they result in increased load on passive paraspinal structures\(^6, 7\). Increased forward head, specifically, which combines lower cervical flexion and upper cervical extension with rounded shoulders, might result in weakness of the cervical extensors as well as increased compressive forces in the articulations of the cervical spine\(^8, 9\). Previous research has presented data on the positive relationship between activation of the upper trapezius muscle and flexion of the cervical spine muscles during computer operation\(^8, 10, 11\). It has been documented that the disadvantages of flexed-relaxed sitting are that it leads to increased disc pressure, tension in passive structures and flexion relaxation within the pain-free population\(^7\).

Therefore, the definition of an ideal sitting posture to avoid poor posture has been discussed in biomechanical and ergonomic arenas. An “ideal” sitting posture was classically suggested as a neutral spine position involving slight lumbar lordosis and a relaxed thorax, with a neutral cervical spine\(^13–15\). Although such an ideal posture might be difficult to adopt...
and maintain and there are questions relating to its practical application in daily life, recent findings by O’Sullivan et al. (2011) suggested that there were no major differences in the clinically perceived ideal posture and the subjectively perceived ideal posture\(^\text{15}\).

In several ergonomic studies, it has been reported in several ergonomic studies that the use not only of devices but also of assessment tools and interventions can reeducate the posture\(^\text{16-18}\). The majority of ergonomic research pertaining to sitting focuses upon chair type and seat back alignment and their effects on kinematics and muscle activity. These devices are thought to provide support for postural alignment, reducing static muscle activity. However, they may also reduce spinal motion and thereby compromise disc nutrition\(^\text{10}\). Additionally, a recent review article reported that ergonomic configuration was usually not effective for instances of long-term low back and neck pain\(^\text{16}\).

Biofeedback has been reported to be an effective intervention for re-educating posture and reducing altered activation of the upper trapezius muscles\(^\text{19-21}\). Vedsted et al. (2011) suggested that EMG-based biofeedback could specifically reduce the activation of the targeted muscle in the upper extremities during computer operation\(^\text{19}\). Park and Yoo (2011) also added that visual feedback based on pressure signals could reduce flexed posture during computer operation\(^\text{22}\). Although several studies investigated the effect of feedback systems on posture correction, there remains a lack of evidence on the kinematics of the lumbar and cervical regions. Also, a limited number of studies have assessed feedback using both the lumbar para-spinal muscles and the upper trapezius muscle. Therefore, we designed an EMG-based feedback device to detect alterations in the activation of the upper trapezius muscle and the electrical silence of the lumbar erector spinae. The purpose of the present study was to investigate the effects of EMG-based feedback on the human musculoskeletal system by assessing the kinematics of the lumbar and cervical regions during computer operation.

**Methods**

**Subjects**

In total, 14 sedentary computer operators were recruited from the university. The subjects had no history of musculoskeletal or neuromuscular disorders within the last 6 months and were excluded if their daily seated working hours did not exceed 6 h based on a questionnaire. The subjects were 14 males aged between 27 and 35 (32 ± 2.6; mean ± SD). Their mean height and weight were 178 ± 5.9 cm and 76 ± 8.4 kg, respectively. Subjects gave informed consent prior to execution of the study, as required by the Inje University Faculty of Health Science Human Ethics Committee.

**Measurements**

A 3-D motion analysis system, CMS-HS (Zebris Medizintechnik, Isny, Germany), was used to measure the angles of the head and trunk during computer operation. In total, five markers were used to analyze the kinematic data, which were obtained at a sampling rate of 50 Hz. Markers for the forward head and trunk flexion angles were placed on the right lateral tip of the acromion and the tragus of the ear, the midpoint of the greater trochanter, the 7th cervical spinous process (C7) and the level of the first lumbar spinous processes (L1) by the same investigator. The forward head angle was defined as the angle between the line from the tragus to the C7 line and the horizontal axis at C7. The trunk flexion angle was defined as the angle between the line from the tragus to the C7 line and the horizontal axis at C7. The trunk flexion angle was defined as the angle between the line from the acromion to the C7 line and the horizontal axis at C7. The trunk flexion angle was defined as the angle between the line from the acromion to the C7 line and the horizontal axis at C7.

**Features of the feedback device**

A muscle signal feedback system based on an EMG system was developed. The developed system made use of an electric circuit designed by an internal research team. By using two electrodes, the muscular signals were measured by applying a band-pass filter of 100–1,000 Hz. Using 1,000 Hz, the speed of change in angle between the line from the tragus to the 7th cervical (C7) spinous process and the horizontal axis at C7. Trunk flexion angle (TFA): the changes in angle between the line from L1 to the acromion and the line from L1 to the greater trochanter.

**Fig. 1.** Marker placements and definitions of the movement measurements. Forward head angle (FHA): the changes in angle between the line from the tragus to the 7th cervical (C7) spinous process and the horizontal axis at C7. Trunk flexion angle (TFA): the changes in angle between the line from L1 to the acromion and the line from L1 to the greater trochanter.
of a muscle signal could be measured. The analogue signal was converted to a digital signal with an A/D converter (NI USB-6009, National Instruments, Austin, Texas, USA). For the purpose of detecting the threshold and providing visual feedback, graphic software was developed as a user-friendly interface using LabVIEW (National Instruments, Austin, Texas, USA). With the measured signals, the designated thresholds of the lower and upper boundaries were displayed together. A function provided a changing color bar on the screen (from green to red) if muscular activation increased or decreased over the threshold.

Procedure

The two channels of the EMG device were used to detect the muscle activation from the right side of the upper trapezius muscle and the fourth level of the lumbar erector spinae muscle. For the upper trapezius muscle, the electrodes were placed approximately 2 cm laterally from the mid-distance between the C7 spine and the acromion. For the L4 erector spine muscle, the electrodes were placed 2 cm laterally to the midline in the L4 to L5 interspinous spaces. The ground electrode was positioned at the C7 process. Before attaching the electrodes, the skin was cleaned with sand paper and alcohol. All of the procedures for the electrode and kinematic marker placement were performed by the same investigator to reduce variability.

The kinematic data were collected with the subject in the sitting position using the EMG-based visual-feedback device. To investigate each function of the feedback device, four conditions were set: (1) absence of visual feedback (AVF), turning off the device for detecting the EMG signal; (2) providing visual feedback from the upper trapezius (VFU), turning on the function to detect excessive activation of the upper trapezius; (3) providing visual feedback for L4 erector spinae (VFL), turning on the function to detect the electrical silence of the erector spinae; and (4) providing visual feedback for both the upper trapezius muscle and the L4 erector spinae (VFUL) muscle, turning on the function of detecting excessive activation of the upper trapezius muscle and electrical silence of the erector spinae muscle. Prior to computer operation, the thresholds of the upper trapezius muscle and L4 erector spinae muscle of each participant were measured in a position of forward head posture and flexed-relaxed sitting, respectively. Three sets of threshold measurements were performed during 30 s, and average values were determined as the thresholds of the upper trapezius and L4 erector spine for typing work in each participant.

In this study, the workstation for typing work included a desktop computer and 17-inch LCD monitor. The monitor was inclined backwards by 20°, and the distance from the eyes to the top of the monitor was set at 0.8 m. By using height-adjustable chairs and plastic plates, the top of the display was positioned 20° below eye level, and the height of the chair was adjusted to each subjects’ popliteal level so that their hips and knees were flexed at 90°. Our study included an office chair with arm rests, but we eliminated the back rest for measuring kinematic changes. Each subject had 5 min to adjust the working environment to their comfort preference, and all performed copy-typing work using a generalized typing program produced by Haansoft (Hangul and Computer, Korea), which displayed a famous novel on the screen. The test order was selected by random drawing of numbers which representing AVF, VFU, VFL, and VFUL. Subjects operated the same computer workstation for 15 min in each of the four conditions, so the total duration of typing work was 60 min; 5 min of rest time was given between conditions. We explained the meaning of the changing color bar on screen, which represented the need for postural correction as a result of excessive activation of the upper trapezius or decreased activation of the L4 erector spine. Calibration of each subject’s marker placement was performed by locating the line from the tragus to the acromion parallel to the vertical line with the chin retracted and a neutral anterior pelvic tilt prior to the start of computer operation. During the 15 min duration for each test, the obtained kinematic data were analyzed with Windata (Zebris Medizintechnik, Isny, Germany) software, and these measured forward head and trunk flexion angles were differentiated from the initial calibrated angle (0°) in the erect sitting posture. Obtained values were averaged for 15 min, and used for statistical analysis. Figure 2 shows the procedure of this study as schematic form.

Statistical analysis

The SPSS statistical package (Version 18.0; SPSS, Chicago, IL, USA) was used to analyze differences in the head and trunk flexion angles. The significant differences among the four conditions were tested by repeated-measures one-way ANOVA, with significance defined as p values <0.05. Multiple post hoc comparisons were assessed using on Bonferroni correction.

Results

Forward head angle

The sagittal kinematic data for the forward head angle differed significantly among the four conditions of computer operation. The average changes in forward head angle were 25.97 ± 4.02° under the AVF conditions, 19.63 ± 4.96° under the PVFU conditions, 15.14 ± 3.56° under the PVFL conditions, and
14.52 ± 3.47° under the PVFUL conditions (Table 1; Fig. 3). The AVF conditions, which represented the control, showed significantly higher angles compared with conditions using visual feedback (p<0.05). The angle was also significantly increased under the VFU conditions compared with the VFL and VFUL conditions (p<0.05). There was no significant difference in the forward head angle between the VFL and VFUL conditions.

**Trunk flexion angle**

The trunk flexion angle was 34.00 ± 7.53° under the AVF conditions, 30.35 ± 7.72° under the VFU conditions, 20.57 ± 5.07° under the VFL conditions and 20.16 ± 5.54° under the VFUL conditions (Table 1; Fig. 3). The VFL and VFUL conditions showed significantly smaller changes in trunk flexion angle compared with the AVF and VFU conditions (p<0.05). There were no significant differences in the angles between the AVF and VFU conditions and the VFL and VFUL conditions (p>0.05).

**Threshold of visual feedback devices**

The thresholds from each participant were averaged to collect general information about the thresholds. In the forward head posture, the average threshold was 38.01 ± 12.6 mV in the upper trapezius muscle. In the flexed–relaxed posture, the average threshold was 18.02 ± 7.21 mV in the L4 lumbar erector spinae.

**Discussion**

The aim of the present study was to determine the effect of an EMG-based feedback device on kinematic changes in the forward head and trunk flexion angles during computer operation. This study was also designed to investigate which function of altering posture can efficiently reeducate the body posture by including the specific use of a feedback function. The effect of feedback assessment during computer operation

**Table 1.** Descriptive statistics of averaged kinematic data of the four conditions of computer work

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<thead>
<tr>
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<th>AVF</th>
<th>VFU</th>
<th>VFL</th>
<th>VFUL</th>
<th>p-value</th>
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<tr>
<td>Forward head angles</td>
<td>25.97 ± 4.02°</td>
<td>19.63 ± 4.96°</td>
<td>15.14 ± 3.56°</td>
<td>15.52 ± 3.47°</td>
<td>0.000*</td>
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<tr>
<td>Trunk flexion angles</td>
<td>34 ± 7.53°</td>
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<td>20.16 ± 5.54°</td>
<td>0.000*</td>
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AVF, absence of visual feedback; VFU, visual feedback from the upper trapezius; VFL, visual feedback from the L4 erector spinae; and VFUL, visual feedback from both of the upper trapezius and L4 erector spine.

*Significant difference between conditions.
operation has frequently been investigated as a form of ergonomic intervention\textsuperscript{9, 21, 22}. Ma et al. (2011) reported that the use of EMG feedback was effective in reducing the altered activation of the upper trapezius muscle and lowering subjective pain in patients with work-related neck pain\textsuperscript{20}. Additionally, several studies have suggested that assessment using feedback devices could prevent habitual poor posture during computer operation\textsuperscript{21, 22, 24}. Although the importance of ergonomic chair design, the presence of back and arm rests and well-designed workstations are understood, these settings have limitations in reflecting individual differences and producing constant attention to one’s posture. Recent findings by Epstein et al. (2012) suggested that continuous caution provided by feedback was necessary to maintain and reeducate people on a good sitting posture even within the context of a proper ergonomic environment\textsuperscript{25}. However, the present study was not designed to report whether the feedback for postural correction was superior to other devices or interventions investigated previously, but was designed to investigate the presence of postural changes by using a feedback device and determine which of body segment we should focused on for postural reeducation. Based on our findings, feedback assessment effectively reduced kinematic changes in the sagittal plane compared with the control, leading to a similar result to previous studies using feedback devices.

It has been previously reported that 60\% of seated workers suffering neck pain had a forward head posture, which is defined as hyperextension of the upper cervical spine\textsuperscript{6}. It has also been reported that having a habitual forward head posture could contribute to altering the soft tissue in the cervical region by reducing the muscular requirement of the paracervical and suboccipital muscles and increasing stress on the ligaments\textsuperscript{8}. McLean (2005) suggested that a sustained forward head posture decreased the muscular efficiency and increased the muscular activity of the upper trapezius and the masseter muscles\textsuperscript{10}. Our result showed that feedback from the upper trapezius muscle had an effect in decreasing the forward head angles. However, the conditions for using feedback for the upper trapezius muscle represented significantly higher contributions from forward head angles than from the lumbar erector spinae. There were two possible factors influencing this result. First, posture correction of the trunk during computer operation was an effective means of re-educating cervical spinal alignment as well as the lumbar segments. It has been reported that the flexed-relaxed sitting posture increases anterior translation of the cervical spine and that thoracolumbar posture influences head and neck posture\textsuperscript{26}. Kuo et al. (2009) suggested that the kinematic chain of the spine may coexist in a static posture, referred to as a “bottom-up” postural adjustment\textsuperscript{27}. Second, adoption of a flexed-relaxed posture resulted in earlier electrical silence in the lumbar erector spinae muscles compared with excessive activation of the upper trapezius muscle. Although excessive activity of the upper trapezius muscle was one factor contributing to neck pain associated with forward head posture, the relationship between altered activation of the upper trapezius muscle and forward head posture in a healthy population has not been identified clearly\textsuperscript{8}.

There was no difference between VFL and VFUL. This means additional usage of feedback from the upper trapezius was unnecessary if the postural correction of lumbar segments has been done. It also suggested the postural correction as “top-down” have not effectively applied rather than “bottom up” postural adjustment. The results of our study indicated that the use of feedback based on electrical decreases of the L4 erector spine resulted in less change in trunk flexion than was seen in the control or with the use of feedback from the upper trapezius muscle. This is a similar result to a previous study that developed an ergonomic device for correcting trunk posture during computer operation\textsuperscript{17, 18, 22, 24}. In the present study, the feedback for correcting lumbar posture was based on electrical silence in the lumbar erector spinae in a flexed-relaxed posture. This is referred to as the flexion-relaxation phenomenon, which was originally suggested by the electrical silence in the erector spinae in a full-trunk bending posture\textsuperscript{28}, but it was also reported that it could be used as a sensitive marker for response to posture changes\textsuperscript{7, 12}. When the sitting posture changes from erect to slumped, postural muscle activity decreases, as the trunk posture supported by the passive paraspinal structure is responding to gravity\textsuperscript{12}. Although the flexion-relaxation phenomenon is an appropriate response of musculature in the asymptomatic population, sustained sitting with a slumped posture might be risk factor for those with lumbar pain because the load on the lumbar discs and ligaments is increased by positioning the head and lumbar region away from the line of gravity. Mork and Westgaard (2010) also considered that constitutive exposure to a relaxed sitting posture might exacerbate low back pain in sedentary workers\textsuperscript{41}.

It might be a natural result that usage of feedback is effective for postural correction. However, the present study suggested two things. First, feedback from the lumbar erector spinae based on electrical decreases of musculature, which implied the lower bound of muscular activation, also could be a criteria for assessing posture with electromyography. Second,
the results of our post hoc analysis, present study showed that reeducating the proximal part of the spine was more effective than reeducating the distal part for postural correction.

There were some limitations to the present study that must be considered for future studies. First, it might be difficult to standardize the effect of the feedback device due to the short duration of measurement and the small sample size. Second, this study did not contain a factor of subjective discomfort associated with using the feedback device. Third, all procedures were performed with asymptomatic participants, so the device might be inappropriate for a patient with low back pain.

Conclusion

We showed that the use of an EMG-based feedback device was effective in reducing habitual forward head and flexed-relaxed postures during computer operation. Clinically, adjusting feedback for the lumbar region is a more effective way of reducing forward head posture as well as flexed-relaxed posture than are other feedback conditions.

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References


