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Original Article

Relationship between using tables, chairs, and computers and improper postures when doing VDT work in work from home

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Abstract: This study focused on everyday furniture and computers used in work from home and aimed to investigate how improper postures increase the risk of musculoskeletal disorders using different combinations of tables, chairs, and computers. Twenty-one healthy participants were asked to perform a visual display terminal task for 30 minutes in a laboratory modeled on the work from home concept. Seven experimental conditions were set up according to the different combinations of desks, chairs, and computers. Three-dimensional body posture was measured using a magnetic tracking device. The results showed that when using a low table, floor chair, and laptop computer, the body posture above the hip was similar to that when using a dining table, chair, and desktop computer. When using a sofa, and tablet computers, or laptop computer, severe neck flexion, which is stressful to the neck, was observed. Moreover, excessive low back flexion was observed when using a floor cushion and laptop computer. We suggest that computer work while sitting on a sofa or floor cushion without a backrest is harmful to the neck and low back.

Key words: Biomechanics, Neck, Low back, Telework, Occupational health

Introduction

Owing to the COVID-19 pandemic and lockdown in many cities and countries, work from home (WFH) has become an important work style worldwide. WFH, as a type of remote work, is an effective way to avoid the risk of viral exposure. Other benefits of WFH include reducing traffic congestion and improving work-life balance[1, 2]. Before the COVID-19 pandemic, teleworkers addressed work in both a prepared work environment as well as an office. However, an abrupt situational change was experienced during the COVID-19 pandemic. In the spring of 2020, the government of Japan declared a state of emergency and set a target of over 70% of the employees to work remotely. Consequently, many employees were forced to WFH. A scientific report on WFH during the COVID-19 pandemic in Japan showed that over 60% of enterprises introduced WFH[2]. According to data from the Tokyo Metropolitan Government of Japan, 56.6% of employees in Tokyo had been

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WFH in April 2021[3)]. This situation forced people to make use of their daily life furniture for work purposes, for example, the dining table and chair, sofa, or Japanese traditional low table (kotatsu) and floor chair.

The main task of WFH is visual display terminal (VDT) work, such as typing and reading documents on a laptop computer, tablet computer, or desktop computer. Musculoskeletal disorders (MSDs), especially neck/shoulder pain and low back pain, are the most common complaints among VDT workers, with a prevalence of over 40%[4–6)]. Improper postures, which generate significant load on joints, have been suggested as the main cause of MSDs among VDT workers[7, 8)]. The sitting postures were reported to be affected by the design of the furniture and computers used in VDT work, such as the height of the display monitor, arm support of the chair, and angle of the backrest[9)]. There is a guideline for VDT work published by the Ministry of Health, Labour and Welfare, Japan[10, 11)]. The height of the desk and chair, brightness in the room, distance from the display to the eyes, and other environmental details are described in the guidelines for preventing occupational health degradation related to VDT work. These guidelines contribute to staying healthy in the office but is not suitable for WFH using daily life furniture, such as a low table, floor chair, sofa, or floor cushion. However, no study has examined body postures during VDT work using daily life furniture. Whether the daily life furniture used in WFH leads to an improper posture, which joints are at risk of MSDs, and how to prevent these risks are still unknown. Therefore, a biomechanical study that investigates the problem of body posture and discusses the risk of MSDs in VDT work using daily life furniture is required.

Recently, as information technology is growing rapidly, various types of electronic devices have been developed. In addition to desktop computers, laptop computers, tablet computers, and even smartphones are widely used in VDT work, as well as in daily life. Computer design can also be a risk factor for improper postures. Text neck syndrome, which has become a prevalent problem, is an example. Text neck syndrome is a series of problems associated with excessive use of personal computers, smartphones, or tablet computers. Symptoms include neck pain, alteration of cervical spine alignment, headache, and reduced mobility of the head and shoulder[12)]. With such a large load on the neck lasting for a long time during the use of personal computers, tablet computers, and smartphones, MSDs have consequently been prevalent. In regard to WFH, laptops and tablet computers are commonly utilized devices, and it is possible that improper postures occur with the use of these devices, and the risk of neck problems, as well as other MSDs, can develop.

No study has evaluated the risk of MSDs in teleworker postures when using daily life furniture and various types of computers. Therefore, the present study focused on the daily life furniture and computers used in WFH scenarios and aimed to investigate improper postures that increase the risk of MSDs using different combinations of tables, chairs, and computers. As WFH is increasing, investigating the problem of work postures when using daily life furniture and various types of computers has become important in occupational health.

Sample and Methods

Sample

This study included 21 healthy participants, 10 men and 11 women (height: 166.4 ± 7.5 cm, body mass: 59.8 ± 9.0 kg, age: 26.0 ± 4.9 yrs., presented in mean value ± standard deviation). The inclusion criterion was healthy people aged 20–39 years who were familiar with VDT work. Patients with MSDs were excluded from this study, and all participants were right-handed. This study was approved by the Ethics Committee of the National Institute of Occupational Safety and Health in Japan (approval number: 2020N11). All participants provided written informed consent prior to participating.

Experimental conditions

Seven experimental conditions were set up according to different combinations of desks, chairs, and computers, which were grouped into three categories (Fig. 1). Three of the seven conditions were replicated in each category. The first category (Category 1) included three conditions that are common in WFH in Japan: (A1) a dining table, chair, and desktop computer; (A2) a low table, floor chair, and laptop computer; and (A3) a sofa and tablet computer. Among these three conditions, condition A1 was deemed to be similar to an office environment and consequently defined as the control condition. The second category (Category 2) included the same furniture of the dining table and chair, but different types of computers, such as (B1) desktop computers, (B2) laptop computers, and (B3) tablet computers. The third category (Category 3) included the same laptop computers, but different furniture frequently used in WFH instances: (C1) dining table and chair, (C2) low table and floor chair, (C3) sofa without a table, and (C4) floor cushion without a table. A1 and B1, B2 and C1, and A2 and C2 were subjected to the same conditions.

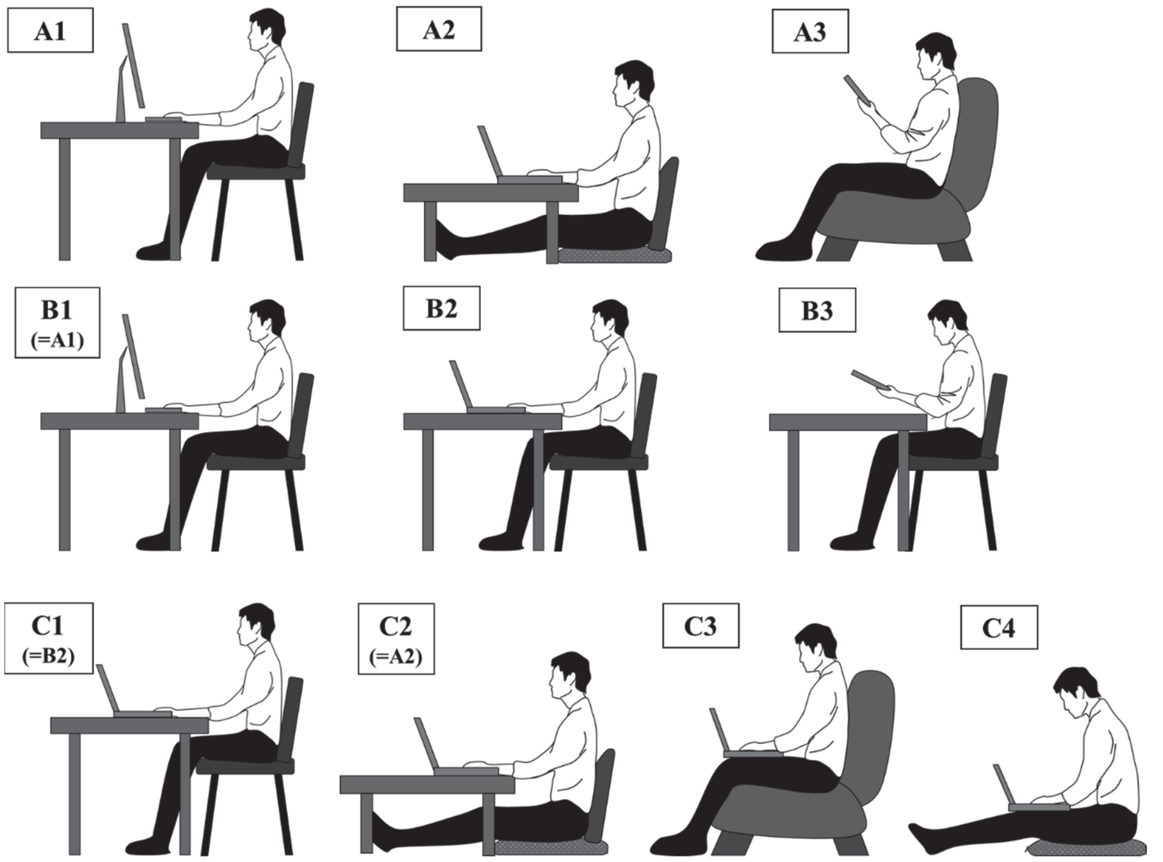

Fig. 1. Images of experimental conditions.
(A1) a dining table, chair, and desktop computer; (A2) a low table, floor chair, and laptop computer; and (A3) a sofa and tablet computer; (B1) a dining table, chair, and desktop computer, (B2) a dining table, chair, and laptop computer, (B3) a dining table, chair, and tablet computers; (C1) a dining table, chair, and laptop computer (C2) a low table, floor chair, and laptop computer (C3) a sofa and laptop computer, (C4) a floor cushion and laptop computer. A1 and B1, B2 and C1, and A2 and C2 had the same conditions.

Body posture measurement

The three-dimensional body posture of each participant was measured using a magnetic tracking device (LIBERTY, Polhemus, VT, USA). The device can track the sensor's location and orientation in six degrees of freedom within the magnetic field generated by a source at 240 Hz. This device is widely used in the medical and sports fields[13–15]. Given that it is easily operated and can be used without visual information, when the participant leans on the backrest of a chair or sofa, sensors hidden on the backside of the body can be tracked efficiently. Seven sensors were attached to the backside of the head, mid-sternum, left and right acromion, distal side of the left and right upper arms, and central sacrum, to record the three-dimensional segment movements of the head, thorax, left and right scapulae, left and right humeri, and pelvis. Sensors were fixed using double-sided kinesiology tape on the body sites where there was a lack of muscle and fat between the skin and bone. For the head and the left and right upper arms, a handmade elastic headband and plastic plates were used to attach the sensors (Fig. 2).

Subsequently, a pen-shaped stylus sensor was used to pinpoint and record the coordinates of the body landmarks relative to the sensors for each segment. Body landmarks for the thorax, scapulae, humeri, and joint coordinate systems for the shoulder were defined according to ISB recommendations[16]. Body landmarks for the pelvis and joint coordinate systems for the low back were defined according to a previous study[17]. Body landmarks for the head were chosen as the vertex of the head and the left and right tragions. For the head reference system, the transverse axis was defined as a unit vector pointing from the left to right tragion. The sagittal axis was defined as a unit vector perpendicular to the plane defined by the vertex of the head

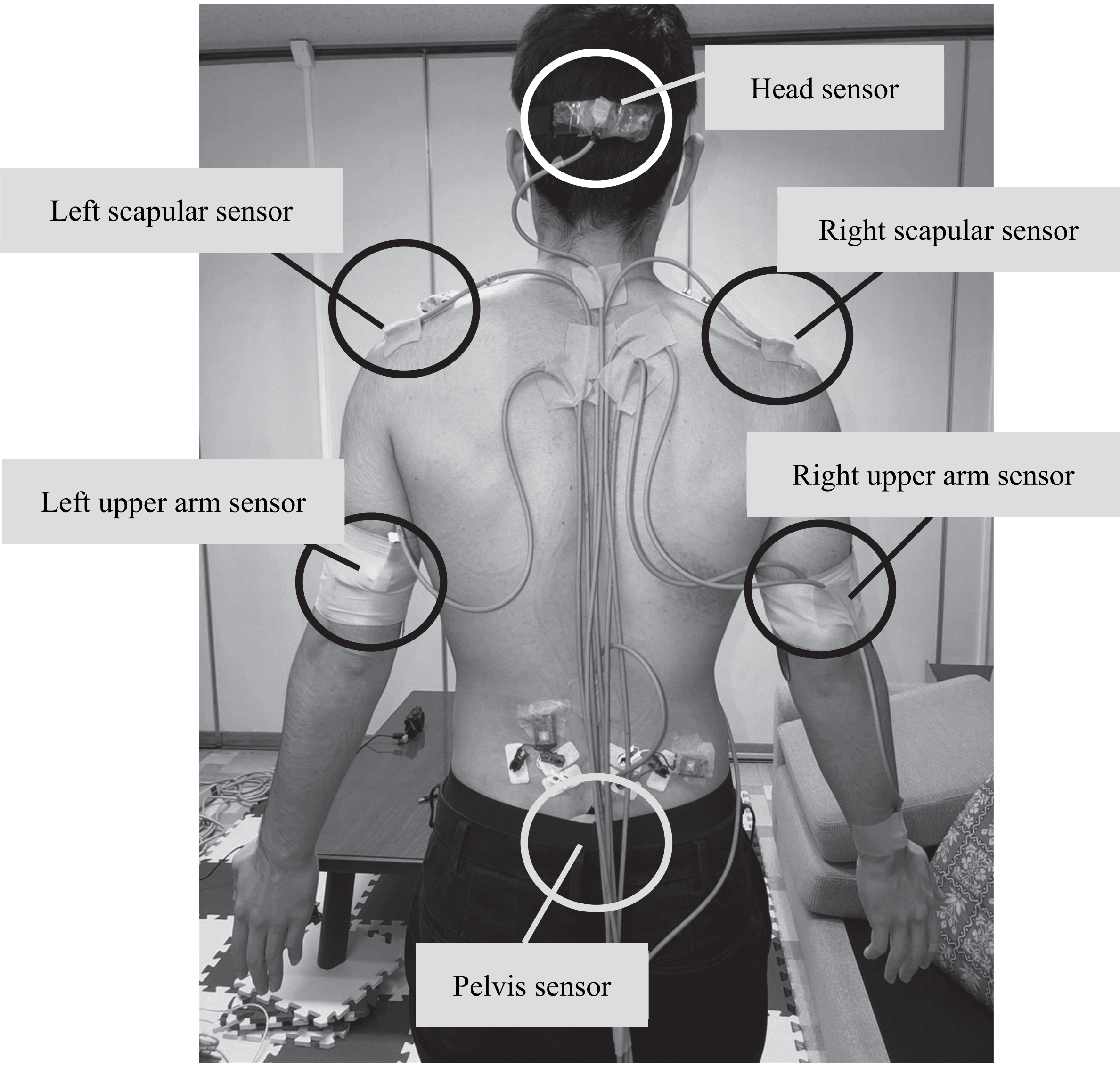

Fig. 2. Image of sensor attachment.

and the left and right tragions pointing in the anterior direction. The long axis was defined as the cross product of the transverse and sagittal axes. The orientation of the head reference system relative to the thorax was determined by the joint motion of the neck. Anatomical posture was defined as the "zero position," which is 0° of each joint angle.

Procedure

The measurements were performed in a 30 m^2 room. A standard dining table (height: 70 cm) and chair (height: 42 cm, backrest-seat angle: 102°), a low table (height: 38 cm) and floor chair (height: 8 cm, backrest-seat angle: 92°), three-seater sofa (height: 35 cm, backrest-seat angle: 115°), and a floor cushion (height: 8 cm) were placed in the room. Three types of computers were prepared: a desktop computer with a 23.8-inch height-adjustable monitor, standard keyboard, and mouse; a laptop computer with a 14.1-inch monitor and 1.61 kg weight; and a tablet computer with an 11-inch monitor and 0.466 kg weight (participants typed with the screen keyboard: a QWERTY keyboard or a Japanese Kana keyboard, as their preference). Seven work conditions with different combinations of furniture and computers were randomly assigned to each participant. To reduce the effect of the magnetic field distortion caused by computers, the source of the electromagnetic device was placed beside the sensors attached to the participants. According to the manual of the device, a short distance between the source and sensor helps to reduce measurement errors owing to the distortion conductor in the field. The accuracy of the electromagnetic tracking device in the measurement area was tested using two sensors fixed at certain distances and orientations. The error was found to be less than 3° in orientation and 10 mm in proximity. After the sensors were attached, the participants were asked to perform a 30 minute reading and typing task on the computer for each condition. The electronic document used in the task was part of a Japanese novel. For each page of the material, participants were asked to read the page first and subsequently type the words on the page into a blank document. During the task, the participants were instructed to relax as if at home and were allowed to change their postures as they felt comfortable, but they were not allowed to talk, drink, eat, stand, or lie down. In addition, a medical check for active range of motion (ROM) of the neck, shoulder, and low back was performed for each participant.

Three-dimensional joint angles were calculated for the neck, shoulder (glenohumeral joint), and low back during the entirety of measurements. The flexion-extension angle of the neck (forward-backward bending of the head), shoulder abduction angle (elevation of the upper arm), tilt angle of the shoulder girdle (the tilt of the left-right shoulder line), and flexion-extension and lateral tilt angles of the low back were utilized to describe the work posture. To evaluate the extent of spinal motion, the percentages of the neck and low back angles to their active ROM were calculated and represented as %ROM. The mean and standard deviation for the above variables were calculated every 10 minutes during the task and were represented as the mean ± standard deviation. In addition, to evaluate the variation in neck and low back motion within participants, an original variable, the motion-variation index, was defined. It calculated for each participant as the integration of the difference between joint angles and the mean value for each 10 minute session. If the mean joint angles were different from the control condition and fell into the ranges of "large stress," as reported within the literature, the posture in the condition was defined as an improper posture.

Statistics

A two-way ANOVA (conditions × time sessions) of repeated measures was used to compare the variables of postures among the furniture-computer conditions and time sessions in each category. Post hoc Bonferroni tests were conducted to evaluate the significant effect of the furniture-computer conditions, time sessions, and interactions. In addition, the word counts for each condition were recorded and compared using a one-way repeated measures ANOVA. Statistical significance was set at $p<0.05$. Statistical analyses were conducted using MATLAB R2016a ver. (MathWorks, USA).

Results

Category 1: comparison of common WFH conditions

Table 1 shows the comparison results of body postures and variation across time under three conditions: (A1) dining table, chair, and desktop computer; (A2) low table, floor chair, and laptop computer; and (A3) sofa and tablet computer. A significantly larger neck flexion ($p<0.001$) and %ROM of neck flexion ($p<0.001$) were observed in condition A3 than in conditions A1 and A2. Condition A2 had the largest shoulder abduction angle, while condition A3 had the smallest angle ($p<0.001$). Condition A3 showed a significantly larger right tilt angle of the shoulder girdle ($p<0.001$) than conditions A1 and A2. There were no differences in the conditions for the low back angles ($p=0.586$ for flexion and $p=0.162$ for tilt angle). The motion-variation index of the low back was different among the furniture-computer conditions ($p=0.001$) and time sessions ($p=0.024$). The index increased as work time increased. No interaction effect of the furniture-computer conditions or time sessions was observed. The word count results were 2301 ± 940 Japanese characters in condition A1, 2216 ± 837 Japanese characters in condition A2, and 1364 ± 478 Japanese characters in condition A3. The typed characters in condition A3 were significantly less than those in conditions A1 and A2 ($p<0.001$).

Category 2: comparison of types of computers

Table 2 shows body postures and variation across time by using the same furniture of a dining table and chair in all conditions, while using different computers: (B1) desktop computer, (B2) laptop computer, and (B3) tablet computer. Condition B3 showed a significantly larger neck flexion (11.5° ± 15.4°, $p<0.001$) and %ROM of neck flexion (25.4 ± 20.3%, $p<0.001$) than conditions B1 and B2. The shoulder abduction angle was different between the furniture-computer conditions ($p=0.002$), and a significantly larger value was observed in condition B2 compared to condition B3 ($p=0.001$). No difference was found among conditions for the shoulder gilder tilt angle ($p=0.767$) and low back angles ($p=0.894$ for flexion and $p=0.887$ for tilt angle). The motion-variation index of the neck was significantly higher in condition B3 than in condition B2 ($p=0.007$), and the motion-variation index of the low back was significantly higher in condition B3 than in condition B1 ($p=0.003$). The motion-variation index of the low back increased as work time increased ($p=0.033$). No interaction

Table 1. Work postures and variation across time in typical WFH conditions

		(A1) dining table, chair, desktop computer			(A2) low table, floor chair, laptop computer			(A3) sofa, tablet computer					
		0–10min	10–20min	20–30min	0–10min	10–20min	20–30min	0–10min	10–20min	20–30min	ANOVA	Post hoc (condition)	Post hoc (time)
neck	flexion (°)	−5.4±11.5	−4.6±11.9	−5.3±11.8	−2.5±16.5	−1.0±15.2	−1.1±15.8	23.3±16.1	24.8±12.6	22.5±17.2	p_c<0.001 p_t=0.867	(A1)(A3), (A2)(A3)	
	%ROM of flexion	15%	15%	14%	22%	20%	21%	43%	42%	43%	p_c<0.001 p_t=0.849	(A1)(A3), (A2)(A3)	
	motion-variation index	1,908	2,235	2,376	1,334	2,214	1,528	2,042	2,912	2,623	p_c=0.042 p_t=0.107	(A2)(A3)	
shoulder	abduction (°)	32.2±14.7	32.6±13.4	32.4±12.3	49.2±17.4	49.0±16.1	49.5±16.5	11.3±9.2	11.5±8.3	14.3±11.7	p_c<0.001 p_t=0.864	(A1)(A2), (A1)(A3), (A2)(A3)	
	right tilt (°)	2.0±2.5	2.0±2.7	2.0±2.7	2.9±2.3	2.9±2.3	3.0±2.4	6.1±1.8	6.0±2.0	5.8±2.1	p_c<0.001 p_t=0.983	(A1)(A3), (A2)(A3)	
low back	flexion (°)	43.4±15.5	43.5±14.3	32.4±12.3	46.6±15.0	46.8±14.9	47.2±14.1	43.8±9.2	45.6±10.0	45.8±12.4	p_c=0.586 p_t=0.927		
	%ROM of flexion	78%	79%	78%	84%	84%	85%	79%	82%	81%	p_c=0.604 p_t=0.947		
	right tilt (°)	0.9±3.8	0.9±4.0	0.5±4.5	2.0±4.5	2.0±4.2	1.2±4.8	2.5±4.3	2.4±4.9	2.2±5.0	p_c=0.162 p_t=0.825		
	%ROM of tilt	8%	8%	9%	11%	10%	10%	9%	9%	8%	p_c=0.102 p_t=0.994		
	motion-variation index	1,132	1,971	2,200	984	1,239	1,063	1,077	1,236	1,734	p_c=0.001 p_t=0.024	(A1)(A2), (A1)(A3)	(A1)(A3)

Note: p_c: *p*-value of the main effect in work conditions; p_t: *p*-value of the main effect of time sessions

%ROM: percentages of joint angles to their active range of motion

Motion-variation index: integration of the difference between joint angles and the mean value

Table 2. Work postures and variation across time using the same furniture but different computers

		(B1) desktop computer			(B2) laptop computer			(B3) tablet computer					
		0–10min	10–20min	20–30min	0–10min	10–20min	20–30min	0–10min	10–20min	20–30min	ANOVA	Post hoc (condition)	Post hoc (time)
neck	flexion (°)	−5.4±11.5	−4.6±11.9	−5.3±11.8	−1.1±14.0	−0.2±13.2	−1.4±11.9	10.0±16.1	12±15.4	12.5±15.2	$p_c<0.001$ $p_t=0.879$	(B1)(B3), (B2)(B3)	
	%ROM of flexion	15%	15%	14%	15%	14%	13%	24%	25%	27%	$p_c<0.001$ $p_t=0.981$	(B1)(B3), (B2)(B3)	
	motion-variation index	1,908	2,235	2,376	1,442	1,700	1,978	2,098	2,591	2,694	$p_c=0.009$ $p_t=0.103$	(B2)(B3)	
shoulder	abduction (°)	32.2±14.7	32.6±13.4	32.4±12.3	38.4±14.9	37.4±14.6	37.4±13.5	28.4±14.9	27.7±19.5	27.5±18.1	$p_c=0.002$ $p_t=0.975$	(B2)(B3)	
	right tilt (°)	2.0±2.5	2.0±2.7	2.0±2.7	2.2±3.0	2.2±2.7	2.6±2.7	2.3±2.8	1.8±2.6	1.9±2.4	$p_c=0.767$ $p_t=0.899$		
low back	flexion (°)	43.4±15.5	43.5±14.3	32.4±12.3	42.6±16.5	41.4±17.6	42.3±15.0	44.6±17.7	40.4±19.7	44.2±17.8	$p_c=0.894$ $p_t=0.810$		
	%ROM of flexion	78%	79%	78%	77%	76%	76%	82%	74%	81%	$p_c=0.889$ $p_t=0.876$		
	right tilt (°)	0.9±3.8	0.9±4.0	0.5±4.5	0.4±4.5	0.9±3.9	0.2±3.9	1.4±5.0	0.5±4.9	0.8±4.9	$p_c=0.887$ $p_t=0.882$		
	%ROM of tilt	8%	8%	9%	8%	7%	8%	8%	8%	9%	$p_c=0.831$ $p_t=0.878$		
	motion-variation index	1,132	1,971	2,200	1,705	2,492	3,008	2,413	3,798	4,226	$p_c=0.004$ $p_t=0.033$	(B1)(B3)	(B1)(B3)

Note: p_c: *p*-value of the main effect in work conditions; p_t: *p*-value of the main effect of time sessions

%ROM: percentages of joint angles to their active range of motion

Motion-variation index: integration of the difference between joint angles and the mean value

effect of the furniture-computer conditions and time sessions was observed. Typed characters in condition B3 (1351 ± 423) were significantly less than those in conditions B1 (2301 ± 940 Japanese characters) and B2 (2242 ± 835 Japanese characters) ($p<0.001$).

Category 3: comparison of the furniture

Table 3 shows body postures and variation across time by using the same laptop computer and different furniture: (C1) dining table and chair, (C2) low table and floor chair, (C3) sofa, and (C4) floor cushion. All variables showed a significant main effect of the furniture-computer conditions. No main effect or interaction effect of time sessions was observed. Condition C3 showed significantly larger neck flexion ($p<0.001$) and %ROM ($p<0.001$) than other conditions. In addition, condition C3 showed a smaller shoulder abduction angle ($p<0.001$) and low back flexion ($p<0.001$) than other conditions. Condition C4 had the largest low back flexion among the four conditions ($p<0.001$). Condition C1 showed a significantly higher motion-variation index of the low back than other conditions ($p<0.001$). Typed Japanese characters were 2242 ± 835 in condition C1, 2216 ± 837 in condition C2, 2265 ± 703 in condition C3, and 2103 ± 766 in condition C4. There was no statistical significance among conditions ($p=0.955$).

Discussion

The present study focused on the furniture and types of computers used in WFH context and aimed to investigate improper postures that may develop the risk of MSDs. Seven experimental conditions were selected and grouped into three categories. In Category 1, the conditions of using a low table, floor chair, and laptop computer had a similar neck and low back posture to the control condition of using a dining table, chair, and desktop computer. Significantly large neck flexion and small shoulder abduction angles were observed when using a sofa and a tablet computer without a table. In addition, when using a sofa and tablet computer, the right shoulder tilt angle was large. Postures did not change considerably throughout the 30 minute VDT work duration; however, the motion-variation index of the low back increased in the last 10 minute session. Work performance, represented by the number of typed characters, was however, much lower when using a sofa and tablet computer than in the other conditions.

These results indicate a similar above-hip posture for the condition of using a dining table, chair, and desktop computer to the condition of using a low table, floor chair, and laptop computer. The participants used an altered posture when working with a sofa and a tablet computer. Compared with condition (A1), a dining table, and condition (A2), a low table, condition (A3), a sofa, had no table to support the participant's arms and computer. Most participants conducted VDT work by holding a 466g tablet computer with one hand and typing with the other hand. Although the tablet is not heavy, holding it without any support for 30 minutes is not an easy task. A small angle of shoulder abduction was necessary to hold the computer steady and comfortably. This posture leaves the deltoid and supraspinatus muscles in a relatively relaxed position and provides steady support to the forearm and hand. However, this restricts the direction and location of the tablet computer, which may require the neck to flex more to achieve a comfortable position for looking at the display monitor. The neck flexion when using a sofa and tablet was 23°, which is within, but near the limit of the acceptable range (0°–25° of neck flexion/extension) according to ISO 11226 ergonomics evaluation of static working postures[18]. The neck flexion angle when using a sofa and tablet accounted for 43% of the active ROM. In a previous study, a range of over 39.8% flexion of the whole cervical spine was suggested to develop a large internal force, stretching the ligaments and muscles around the neck[19]. Improper neck flexion posture is suggested to generate a large load on the cervical spine and is the main reason for text neck syndrome[12, 20]. Barret *et al.*[21] calculated the shear force and compression in the cervical spine and found that the forces in the cervical spine at 45° of neck flexion were two to four times that of the neutral position. Working in such a stressful neck flexion posture for an extended period of time may lead to the development of MSDs of the neck, such as text neck syndrome[22, 23]. In addition, when using a sofa and tablet, the shoulder girdle tilted significantly to the right, indicating an imbalance in body posture as well as an asymmetric load on the spine. The reason may be that all participants were right-handed and typed on the screen keyboard of the tablet with their right hand, while in other conditions, they used both hands to type on the keyboard. Moreover, arm elevation ranging from 0° to 60° without full arm support is an unacceptable posture with health risks according to ISO 11226[18].

A second comparison was made between the conditions of using the same furniture of a dining table and chair, but different types of computers, such as (B1) desktop computer, (B2) laptop computer, and (B3) tablet computer . The results revealed that neck flexion was significantly greater when using a tablet computer than when using other com-

Table 3. Work postures and variation across time when using a laptop computer and different furniture

		(C1) dining table and chair			(C2) low table and floor chair			(C3) sofa			(C4) floor cushion				
		0–10min	10–20min	20–30min	0–10min	10–20min	20–30min	0–10min	10–20min	20–30min	0–10min	10–20min	20–30min	ANOVA	Post hoc (condition)
neck	flexion (°)	−1.1 ±14.0	−0.2 ±13.2	−1.4 ±11.9	−2.5 ±16.5	−1.0 ±15.2	−1.1 ±15.8	26.8 ±8.4	27.4 ±8.4	28.3 ±7.6	12.1 ±9.7	11.7 ±9.1	12.0 ±9.1	$p_c<0.001$ $p_t=0.936$	(C1)(C3), (C1)(C4), (C2)(C3), (C2)(C4), (C3)(C4)
	%ROM of flexion	15%	14%	13%	22%	20%	21%	45%	46%	47%	22%	21%	21%	$p_c<0.001$ $p_t=0.910$	(C1)(C2), (C1)(C3), (C1)(C4), (C2)(C3), (C3)(C4)
	motion-variation index	1,442	1,700	1,978	1,334	2,214	1,528	1,313	1,238	1,707	1,894	2,271	2,377	$p_c=0.024$ $p_t=0.139$	(C3)(C4)
shoulder	abduction (°)	38.4 ±14.9	37.4 ±14.6	37.4 ±13.5	49.2 ±17.4	49.0 ±16.1	49.5 ±16.5	9.3 ±4.8	9.0 ±4.0	9.4 ±4.9	21.1 ±14.5	20.4 ±12.4	20.4 ±12.7	$p_c<0.001$ $p_t=0.970$	(C1)(C2), (C1)(C3), (C1)(C4), (C2)(C3), (C2)(C4), (C3)(C4)
	right tilt (°)	2.2±3.0	2.2±2.7	2.6±2.7	2.9±2.3	2.9±2.3	3.0±2.4	4.7±6.3	5.9±3.1	6.1±3.3	1.4±2.0	1.8±2.0	1.7±2.4	$p_c<0.001$ $p_t=0.292$	(C1)(C3), (C2)(C3), (C3)(C4)
low back	flexion (°)	42.6 ±16.5	41.4 ±17.6	42.3 ±15.0	46.6 ±15.0	46.8 ±14.9	47.2 ±14.1	28.6 ±24.1	27.3 ±30.1	27.7 ±31.2	58.1 ±10.0	59.2 ±10.6	59.3 ±10.4	$p<0.001$ $p_t=0.988$	(C1)(C3), (C1)(C4), (C2)(C3), (C2)(C4), (C3)(C4)
	%ROM of flexion	77%	76%	76%	84%	84%	85%	62%	62%	64%	106%	108%	108%	$p_c<0.001$ $p_t=0.976$	(C1)(C3), (C1)(C4), (C2)(C3), (C2)(C4), (C3)(C4)
	right tilt (°)	0.4±4.5	0.9±3.9	0.2±3.9	2.0±4.5	2.0±4.2	1.2±4.8	1.6±6.4	1.7±6.0	1.6±5.8	0.5±4.3	0.6±3.7	0.5±3.9	$p_c=0.017$ $p_t=0.879$	(C2)(C4)
	%ROM of tilt	8%	7%	8%	11%	10%	10%	9%	10%	10%	7%	7%	7%	$p_c=0.028$ $p_t=0.964$	(C2)(C4)
	motion-variation index	1,705	2,492	3,008	984	1,239	1,063	704	916	1,031	1,166	1,798	1,793	$p_c<0.001$ $p_t=0.085$	(C1)(C2), (C1)(C3)

Note: p_c: p-value of the main effect in work conditions; p_t: p-value of the main effect of time sessions

%ROM: percentages of joint angles to their active range of motion

Motion-variation index: integration of the difference between joint angles and the mean value

puters. However, the magnitude of the flexion was approximately 11° and accounted for 25% of the active ROM of neck flexion, which was suggested to be a posture with little internal force in the cervical spine[20]. This neck posture is also an acceptable posture according to ISO 11226[18], which is suggested to be without any or with minimal external stress. A third comparison was made between the conditions of using the same laptop computer but different furniture, such as (C1) a dining table and chair, (C2) a low table and floor chair, (C3) a sofa, and (C4) a floor cushion. In condition C3, sitting on a sofa, the largest neck flexion, smallest shoulder abduction angle, and smallest low back flexion was observed. The neck flexion in condition C3 was 27° and 45% ROM, which was within the stressful range of neck flexion according to the literature[18, 19]. These results indicate that improper postures in VDT work using a sofa and tablet computer should be a combined effect of the type of computer and furniture, and furniture has the main effect. Using a tablet computer can contribute to severe neck flexion and sitting on a sofa without the support of a table can significantly affect the joint angles of the neck, shoulder, and low back. Furthermore, work performance, represented by the number of typed characters, was similar among the conditions in the third comparison. This indicates that work performance is affected by the type of computer used, rather than furniture.

The Japan Human Factor and Ergonomics Society has published instructions for teleworking using tablet/smartphone devices[24]. They recommend using a stand for a tablet and raising its height to eye level to reduce neck flexion, risk of text neck syndrome, and other MSDs of the neck. Moreover, they recommend using a separate keyboard for typing, to reduce MSDs in the upper limb and neck. According to the results of our study, the above suggestions can be helpful when working from home and utilizing a sofa and tablet computer because they can make workers more comfortable and work more efficiently. However, if there was a suitable table to support the arms during VDT work, according to the results of the comparison of Category 2, using a tablet would not result in a stressful shoulder posture and neck posture during the 30 minutes of VDT work. In addition, the Japan Human Factor and Ergonomics Society suggests taking a break every 20 minutes. Our results show that during the 20 to 30 minute session of work, the motion-variation index increased significantly compared to the 0 to 10 minute session of work. This may be an indication of fatigue. Therefore, taking a break every 20 minutes is an effective way to maintain a healthy posture.

The posture of working in condition C4 of sitting on a floor cushion showed the largest low back flexion compared to the other conditions, which was approximately 59° and approached the limit of the active ROM of the low back. However, neck flexion was not as critical to internal stress as in condition C3, in which the participants sat on a sofa. The sofa and floor cushion conditions had no tables to support the upper limbs and computer. Most participants worked with a computer on their thighs and moved their heads close to the display monitor. In the sofa condition, the backrest restrained the low back angles, and a large neck flexion was required for the head to achieve a comfortable distance from the display monitor. In the floor cushion condition, because no backrest was used, the head position seemed to be achieved by a large low back flexion and moderate neck flexion. Therefore, the stress on the neck should be low when working with a floor cushion. However, without a backrest to reduce the low back load in the sitting postures[9, 18], excessively large flexion of the low back in the floor cushion condition may increase the risk of MSDs of the low back.

The present study has some limitations. First, the body postures of VDT workers were measured in each condition for only a 30 min duration, which may not represent the full period of WFH (generally 5 to 8 hours per day). Given that no main effect of time session was observed for the joint angles in our study, having a short break every 30 min is a valuable method of maintaining good posture. Further studies are required to evaluate posture variation and the prevalence of MSDs over an extended period of WFH. Second, the amount of furniture used in this study was limited. Various pieces of furniture are used in WFH context, such as a soft or hard chair, backrest with different inclination angles, chair or sofa with arm support, and rotatable chair. The ergonomic characteristics of furniture can alter body posture to reduce or increase the risk of developing MSDs. For example, arm support on a chair is reported to alter the shoulder posture and reduce the low back load in sitting postures because the weight of the upper limbs and upper torso is carried by the arm support[9]. Further studies should be conducted to discuss the effect of various furniture used in WFH contexts on teleworkers' health. In addition, cohort studies are expected to examine the relationship between the incidence of MSDs and posture in WFH patients.

In conclusion, the body posture above the hip when using a low table, floor chair, and laptop computer is similar to that when using a dining table, chair, and desktop computer, and both postures cause minor stress on body joints. However, there is a significantly large neck flexion angle when using a sofa and tablet computer or a sofa and laptop computer, which may be harmful to the neck and develop the risk of neck pain, headache, or text neck syndrome. Improper work posture when using a sofa and tablet computer is a combined effect of the computer and furniture, but the main effect is attributed to the furniture. In addition, using a floor cushion generates excessive low back flexion, which indicate a stressful posture. Hence, VDT work using a sofa or floor cushion is not recommended. To avoid MSDs while sitting on a sofa or floor cushion, we suggest using a table or arm support for the sofa and a backrest for the floor cushion to relieve part of the load on the neck and low back. Moreover, because the postures differ slightly during the 30 minutes of VDT work, taking a break for approximately 30 minutes is effective in maintaining good work postures.

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