THE INFLUENCE OF DIFFERENT LOWER SEAT HEIGHT ON THE MUSCULAR STRESS DURING SQUATTING FOR A GROUND LEVEL JOB

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Work requiring extremely body flexion is strongly associated with a high incidence of musculoskeletal injuries often reported during adopting squatting. In this study, the influence of different lower seat heights on the muscular stress in squatting on a stool (SS) were examined in comparison with fully squatting (FS). Fourteen healthy Indonesian males were recruited in the experiment. Two-dimensional body kinematics, ground reaction force (GRF) and electromyography (EMG) data were collected as subjects performed forward movement under four squatting height conditions which were FS and SS at 10 cm, 15 cm and 20 cm seat height. The results demonstrated that the change from FS to SS primarily affected the segmental angular flexions and muscular activities in the upper and lower limbs. GRF data showed that the SS conditions delivered 24% body weight onto the seat. The change of FS to SS showed significantly decrease in muscular load of the rectus femoris and tibialis anterior. In contrast, the soleus and gastrocnemius increased the activities as the seat height increased. The type of task that required the hand to handle the object on the ground level affected the trunk to be more flexed as the seat height increased. The findings of this study suggest that the use of a lower seat stool of a proper height seems to be a sub-optimal solution considering the change of muscular load associated with the discomfort in a squatting posture.
Key words: squatting posture; seat height; body flexion; muscular load

INTRODUCTION

Working at the ground level with a high degree of flexed posture clearly constitutes a health risk for the musculoskeletal system (Dieen et al., 1997). In modern work life, it may appear that squatting postures are confined to work in developing countries or less mechanized workplaces. Indonesian workers engaged in horticulture, die casting industries or handicraft areas, frequently perform tasks at the ground level and usually do so in a squatting posture (Figure 1A). In this kind of work, the squatting posture is shown as forward bending of the upper body made up of two attitudes, flexion of the hip and flexion of the trunk.

Nonetheless, the term "squatting posture" is not commonly found in ergonomics studies or literature and has been little studied as a primary risk factor for muscular disorder (Bridger, 1991). Sriwarno et al. (2006) have defined a squatting posture as the bending of the knees so that the buttocks "rest" on near the heels. In other studies, the term "awkward posture" is used broadly in ergonomics to include squatting and trunk bending in various directions (Chung et al., 2003). There are generally few studies of knee injuries associated with awkward postures, however causal studies are still lacking (Kivimaki et al., 1992). Further, work requiring an extreme body flexion is strongly associated with a high incidence of muscular disorders as workers often reported discomfort in their body during squatting (Kivimaki et al., 1992; Sriwarno et al., 2006; Tirtayasa et al., 2003).

Unfortunately, the problem of a squatting posture is not well reflected in occupational safety and health data because there were only a few efforts devoted to the study of a squatting posture from the aspect of the worker's safety and health.

Recently, Tirtayasa et al. (2003) have proposed a chair, which is meant to lower the mechanical load on the knees and back during the process of *manggur* which literally means to plane down or sharpen the gamelan blades (a traditional music instrument part). In *manggur*, craft-men sit on the floor with the folded legs and hunchbacked body while their arms hold the blades on the ground. In this condition, task-induced stress to require squatting may also suspected as the contributor of occupational musculoskeletal injuries. Since the strategies to control the squatting posture are applying a stool, handling of the object on the ground remains as other muscular problems (Housheer and Dieen, 1994). When the stool was applied, the working posture tends to be changed to have the bowed trunk with the hip overflexed. This working posture is suspected to increase the load mechanically on the spine. A previous study concerning the influence of a squatting posture related to muscular tension applied the descriptive analysis as reported by Nag et al. (1986). In order to prevent relevant musculoskeletal injuries, it is necessary to develop strategies be applied to reducing the physical load among workers having to perform in a squatting posture for a prolonged period. The presence of a proper lower seat might be a useful option with respect to ground-level jobs. In fact, it is common among workers to change their working behavior through the improper support in a squatting posture. It should be noted that the lack of empirical knowledge about appropriate seat design affects the effort to accomplish the task and may harm the musculoskeletal system.

In accordance with the evidence that chair seat height affected the burden of the body limbs during dynamic movements (Yamada and Demura, 2004; Chung et al., 2002), this study examined various seat heights usually applied in actual workplaces. In the experiments, the changes of the associated muscular load on the upper and lower limbs were compared to understand the coordination of the body limbs during squatting between fully squatting (FS) and squatting on a stool (SS). Therefore, the relationship between the squatting height and the degree of postural stress based on the assessment of muscular activities could be determined.

METHODS

The data obtained from fourteen healthy Indonesian males who mostly use their right hands at daily work are presented in Table 1. The buttock height was measured from the minimum level of the gluteus maximus muscle with respect to the floor when the subjects adopted fully squatting (Sriwarno et al., 2006). At the time of the experiment, all the subjects had been free of low back pain for at least one year and were briefed after returning a written informed consent form.
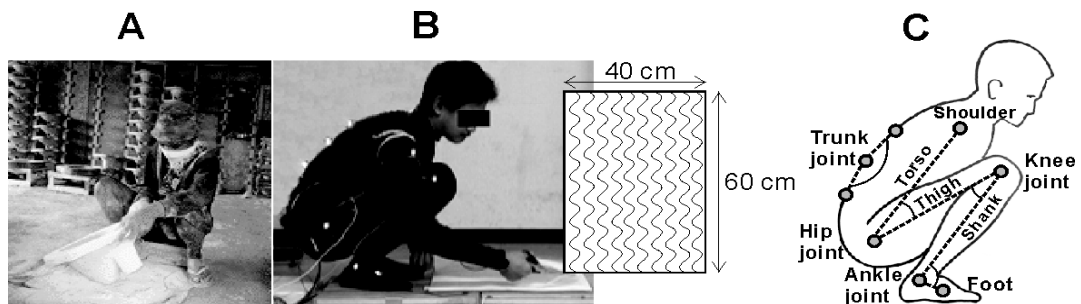

Fig. 1. An example of a squatting posture in the sanitary product home-industry (A), a standardized posture with the placement of anatomical markers and the 40x60 cm paper matt with zigzag patterns (B), and the definition of segmental joint and angular flexions (dotted lines) (C).

Table 1. Physical characteristics of the subjects.

	N	Age (years)	Height (cm)	Weight (kg)	Buttock height (cm)
Mean	14	31.5	167.6	74.1	10.7
SD	14	4.1	3.7	11.7	3.0
Range	14	27.0-37.0	160.0-173.5	54.0-95.5	7.3-12.3

SD: Standard Deviation

At first, a pretest was performed to familiarize the subjects with test conditions in order to investigate potential technical problems that might appear from the subjects' functional limitation. Four conditions of squatting height: FS, SS at 10 cm seat height (SS10), SS at 15 cm seat height (SS15), and SS at 20 cm seat height (SS20) were applied randomly. None had shown technical problems in the pretest. FS was standardized squatting with the trunk bent and the hip overflexed so that the torso was close to the thighs, the knees deeply flexed with the buttocks "resting" on near the heels and the upper limbs sometimes were held by the knee with the hands located over the feet (Chung et al., 2003). A laboratory task was designated to simulate postures and movements that occurred during cutting a paper matt of 40x60 cm in size. In each trial, the subjects were asked to cut the matt along zigzag pathways and therefore required forward movement with a constant speed until maximum reach was achieved. Subjects had to accomplish all ten trials for each condition of squatting height without definite instructions on speed of work. Vertical ground reaction force (GRF) and surface electromyograms (EMG) were recorded to analyze the relationship between the shifting of body weight and muscular stress. The recorded data from the last trial, which were free from any noises, were analyzed. In order to recover the muscular stress after finishing each condition, subjects were allowed to rest through sitting on a comfortable chair for 3 min.

As illustrated in Figure 1B, for determining the body segmental joints markers (light emitting diodes) were placed on the following eight anatomical landmarks only on the right side of the body: head of fifth metatarsal, lateral malleolus, middle of lateral knee joint line, greater trochanter, lateral aspects of gleno humeral joint, fourth thoracic process, seventh thoracic process, and fourth lumbar. These markers defined a six-segment model of the body made up of the trunk, torso, thighs, shanks, and feet. The subjects' movements were recorded by a camcorder (Sony HDV 1080i) from the right side of the subjects' sagittal view at a fixed sampling rate of 29.9 Hz so that the segmental angular flexion could be determined. Segmental angular flexion (trunk, hip, knee, and ankle joint) was calculated as relative angles in space (Figure 1C) as proposed by Dean et al. (1999).

GRF data recording was obtained simultaneously from four load cells which were positioned under the platform. Miniature load cells LMA-A-P, with a capacity up to 1kN (Kyowa Electronic Instrument Co. Ltd), were set up at four edges of the platform to determine the upright force distribution to the feet during movement. Data from the platform were sampled through a 4-channel force amplifier (TEAC SA-30A, sampling rate 1750 Hz) and plotted over time during adopting squatting while performing the task on the ground. Data of force distribution at SS conditions were averaged with respect to the force in FS as the maximum value of GRF and expressed as percentages of body weight (BW).

The EMG active electrodes (Biopac Narrow TSD150, electrode placement 20 mm apart, bandwidth 12 Hz-500Hz) were placed and held with surgical tapes over seven muscles on the lateral body: the deltoideus (D), rectus femoris (RF), tibialis anterior (TA), soleus (SOL), gastrocnemius (G), iliocostalis lumborum (IL) and trapezius (T) after cleaning the skin with alcohol. EMG signals were recorded using the data acquisition interface Biopac MP 150 System. Muscle activities data were stored in the computer using signal acquisition software (*AcqKnowledge* 3.8.1) at a sampling rate of 1000 Hz. A light emitting diode was placed in front of the subjects as a cycle control of each trial that dimmed by a switch. Signal from the switch was synchronized both on the videotape and the interface to mark the waveform of measurement in the computer, which indicated the duration of each trial. In order to analyze the data, EMG data were converted to the root mean square (RMS) val-

ues from each trial test, which were free of noises. The values were transformed to relative values based on mean values of all tested condition for each muscle.

Analysis of variance (ANOVA) was employed to analyze the effect of squatting height conditions on parameters of segmental angular flexion, GRF, and EMG. Benferroni post-hoc tests were conducted to examine the difference in mean values for each condition. The results of post-hoc tests were presented as to the significance level set as 0.05 (*) and 0.01 (**).

RESULTS

In general, segmental angular flexion was variably affected by the squatting height. As shown in Figure 2, significant differences were found between FS and SS conditions on the lower limbs flexion but not found between those on the upper limbs. The change of trunk joint angle shown from the trunk flexion did not reveal significant differences. Although the results were unexpected, it is important to note that the trend of trunk angular flexion decreased as the condition changed from FS to SS conditions with the difference angle about 3 degrees wider.
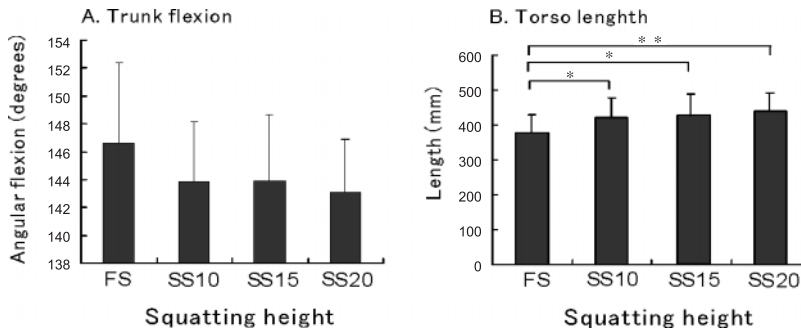

Fig. 2. Mean and SD of upper limb kinematics of trunk flexion (A) and torso length (B) for all the subjects at four squatting conditions. The results of post-hoc tests are presented with the significance level set at 0.05 (*) and 0.01 (**).
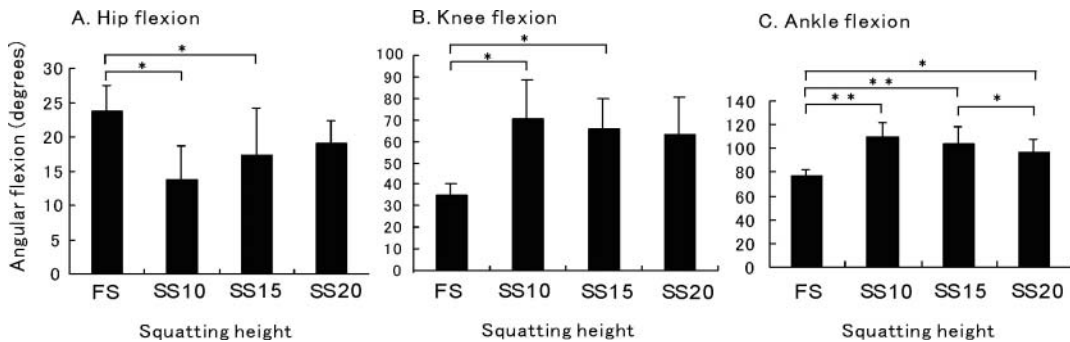

Fig. 3. Mean and SD of hip flexion (A), knee flexion (B), and ankle flexion (C) for all the subjects at four squatting heights. The results of post-hoc tests are presented with the significance level set at 0.05 (*) and 0.01 (**).

Depicted in Figure 3A, as a compensation of this seat height variation, the hip joint adapted to be more flexed when the hip angular flexion gradually increased as seat height changed from SS10 to SS15 ($p<0.05$) and SS20 in comparison with FS. No significant difference appeared in the mean values of SS conditions. Interestingly, although trunk flexion was not clearly affected by squatting

height conditions, torso length was significantly extended ($p<0.01$) when the seat height increased with respect to FS with the greatest length at SS20 (Figure 2B). Significant differences were found for knee flexion at SS10 and SS15 ($p<0.05$) as depicted in Figure 3B but there were no significant differences among different SS conditions. Furthermore, ANOVA found the interaction among SS conditions on the ankle flexion, except between SS10 and SS15. The smallest effect occurred between SS15 and SS20 (Figure 3C).
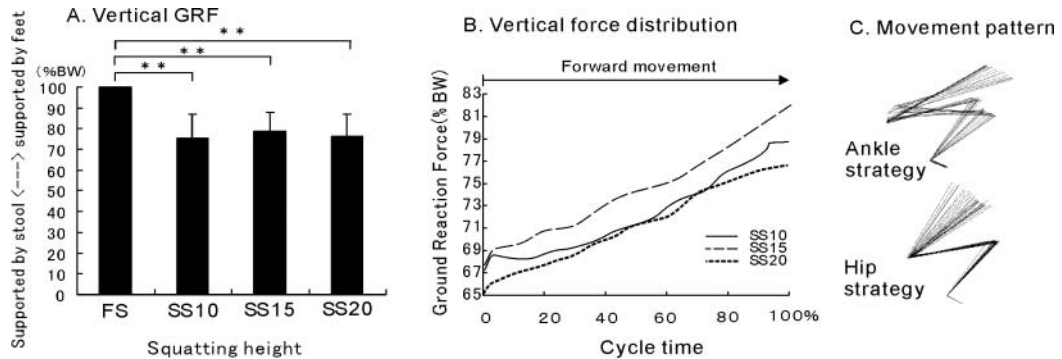

Fig. 4. Mean and SD of the GRF at four squatting heights (A), force distribution on the feet in stool use conditions plotted over the cycle of the trial (B) and trajectory movement of squatting on the stool normalized from all the subjects (C) based on the ankle strategy at FS (above) and the hip strategy at SS (below). The results of post-hoc tests are presented with the significance level set at 0.05 (*) and 0.01 (**).
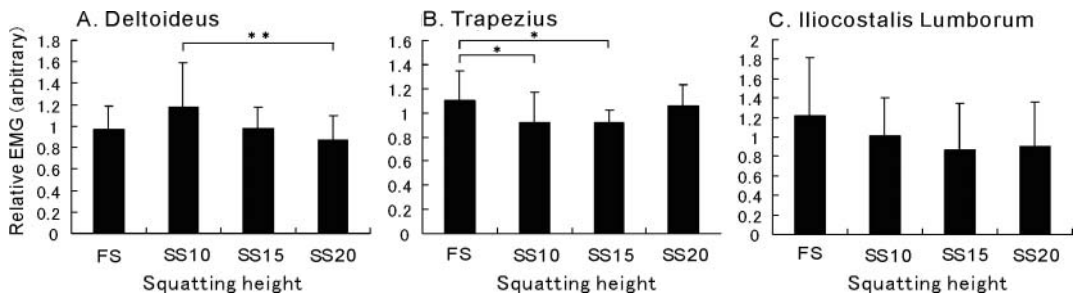

Fig. 5. Mean and SD of tension on the upper limb muscles for the deltoideus (A), trapezius (B), and illiocostalis lumborum (C) for all the subjects at four squatting heights. The results of post-hoc tests are presented with the significance level set at 0.05 (*) and 0.01 (**).

As depicted in Figure 4A, no significant difference was found among SS conditions in the mean of GRF. But whilst the difference was compared to FS, the decreased magnitude was marked in all SS conditions ($p<0.01$). SS conditions reduced vertical force up to 24.4% at SS10, 21.4% at SS15 and 23.9% at SS20 whilst the remaining vertical force was transferred through the feet about 75%BW. Due to the task requiring the torso to angularly bend forward, the vertical pressure moved from the seat to the feet linearly and increased as the body mass shifted forward while SS15 contributed to the highest pressure (Figure 4B). As shown in Figure 4C, the task required the forward movement, and the change of conditions into SS shifted the pivot point of forward angular movement from the ankle at FS to the hip joint at SS.

From EMG data of the seven muscles observed, we found significant effects of squatting height on the upper limb muscles (deltoideus and trapezius) and lower limb muscles (rectus femoris, tibialis anterior, gastrocnemius and soleus). In Figure 5A, D was very active at SS10 and remained to increase significantly at SS20 ($p<0.01$). As for the other upper limb muscle, T decreased into the lowest activities when a lower seat height was applied at SS15 ($p<0.05$) (Figure 5B). Although the SS

conditions demonstrated the decrease of muscle activity in IL with the greatest reduction at SS15 (Figure 5C), ANOVA did not reveal any effects (p=0.227).

In the lower limb muscles, the activity of RF and TA (Figure 6A, B) were strongly influenced by the squatting height when the condition was shifted from FS to SS ($p<0.01$). Both muscles RF and TA showed a similar trend that the muscular load decreased as seat height increased. Furthermore, TA appeared to be significantly smaller between SS10 and SS20 ($p<0.05$) as depicted in Figure 6B. In contrast, SOL and G became more active as the seat height was increased. SOL showed that the significant effects were found between FS and SS20 ($p<0.05$) and also SS15 was significantly differ- ent for SS10 and SS20 ($p<0.05$) (Figure 6C). No remarkable effects were found in G except between SS10 and SS20 ($p<0.05$) (Figure 6D).
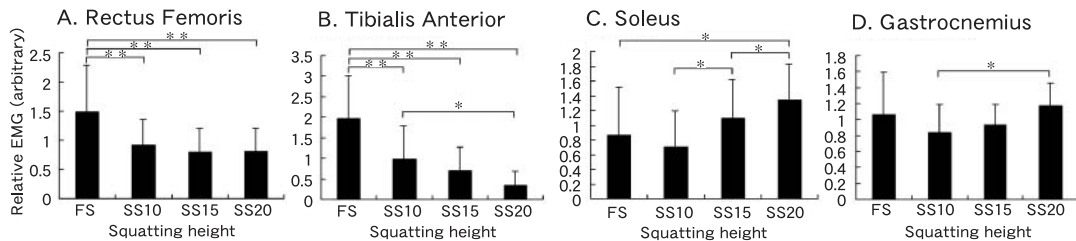

Fig. 6. Mean and SD of tension on the lower limb muscles for the rectus femoris (A), tibialis anterior (B), soleus (C) and gastrocnemius (D) for all the subjects at four squatting heights. The results of post-hoc tests are presented with the significance level set at 0.05 (*) and 0.01 (**).

DISCUSSION

Multi-segmental body linkage coordination in a squatting posture has influenced the variation of musculoskeletal activities that represented the postural stress on the upper and lower limbs. In con- junction with the previous study (Sriwarno et al., 2006), the data have been obtained to demonstrate the change of squatting height affected the role of both the upper and lower limb muscles working cooperatively. From overall EMG analysis, the effects of the muscular load on the upper and lower limb muscles when the subjects adopted a squatting posture at SS conditions were variously different compared to those in FS. During the multi-segmental movement, the FS condition dominantly involved the trunk and hip, knee, and ankle joints to fully achieve the task in forward movement, whereas the effect of a lower seat height significantly differed on the ankle joint between SS15 and SS20. As the hands had to reach forward at maximum distance, all joint angles changed contributing to differences in postural demands. Since the maximum reach of the hands was determined when the subject could not maintain his balance, he started to fall forward and the center of gravity of the sub- ject during the task performance was felt in front of the base support (contact area between the body and the supporting surface). Therefore the subject had to repeat the next trial before he started to loose balance in the end part of the previous trial. As seen from the motion at FS, the ankle joint played an important role in rotating the whole body angularly forward through the activation of TA. This condition affected differently the ankle flexion at all SS conditions when the center of rotation was shifted from the ankle to the hip joint, so that the buttock was fully supported by the seat (as described in Figure 4C). From this finding, the stool confirmed to play an important function in rela- tion to the body mass distribution on the force platform (Dean et al., 1999).

During squatting, the function of the lower limbs muscles was to support as well as to balance the body over the feet on a fixed base support and to shift the body mass from one position to anoth- er. In the case of a squatting posture adopted for the cutting task on the ground level, related muscles observed in this study became significantly more active in supporting the whole body during task performance. According to Figure 6A-B, the deactivation of the anterior lower limb muscles (RF and

TA) as squatting height increased suggested that the presence of a stool with GRF delivered approximately 24%BW (average at all SS conditions) to the seat demonstrated to decrease the muscular load of RF and TA. However, this vertical force remained smaller in distribution in the case of a normal chair able to shift the body weight up to 82% on the seat as reported by Dean et al. (1999). The fact that no significant difference was noted among SS conditions in GRF was probably influenced by the kind of task that required BW to gradually shift onto the feet in all seat heights. It means, in the end part of the trial, the maximum load of each seat height showed an almost parallel trend of data as the torso had to move forward (Figure 4B).

Although none of the significant effects were not unexpected, the decrease of trunk flexion suggested that as the condition changed from FS to SS, the trunk posture became more bowed. According to videotape data, the torso played a significant role in transporting the hand to the target, where the end of cutting pathway was located in a distance beyond the arm's reach-ability. D was involved in transporting the hand through the adduction of the upper arm to reach the object in front of the feet. Interestingly, the presence of SS10 actually increased the activity with the highest muscular load in D followed by the deactivation at SS15 and SS20. This phenomenon suggested that the adoption of a flexion posture was influenced by the "too low" seat height that affected the trunk joint to be bowed or slumped and the hip joint to be deeply flexed in order to handle the object beyond the arm's length on the ground. EMG analysis also showed that in a slumped posture, the upper limb muscles were extended in particular in the case of T and IL. When the hip flexion decreased, T exhibited a reduction in muscle activity at the lowest seat height (SS10) in comparison with FS. This decrease of muscle activation in the slumped posture at SS conditions suggested that deep hip flexion relieved the muscular load on the upper back, which was known as the flexion relaxation as Callaghan and Dunk (2002) reported. While prolonged sitting has often been identified as being associated with back pain and prolonged static muscle contractions lead rapidly to fatigue and discomfort, the observed flexion relaxation would likely lead to an increase in the moment at the lumbar spine that has been shown to cause shear stress in the lumbar spine (Snijders et al., 2004; Kuriyama and Ito, 2005). Although no statistical difference was found for IL, the decreased muscle activities observed at SS conditions with respect to FS have to be taken into consideration.

The vertical GRF and EMG data from the lower limb muscles suggested that the related muscles worked cooperatively to shift more weight toward the foot or feet in the direction of the reach during a squatting task. In addition, in this study, each muscle played a different role in regard to the nature of the task, for example in the presence of an increasing seat height, TA seemed to decrease its role of ankle dorsiflexion as Dean et al. (1999) confirmed. In contrast, SOL and G indicated an increase in activation, which means that muscle activities became more important in supporting the body mass in forward movement when the seat height increased from SS10 to SS20. Probably as an antagonist, both SOL and G might function to brake the forward movement of the body mass when the body started to loose balance (Nishiwaki et al., 2006). These muscles were active through the action of plantarflexing the foot, and therefore the ankle joint angle decreased at SS20 with the greatest muscle activities among SS conditions. FS represented an ankle flexion of about 20 degrees deeper in comparison with SS conditions. This condition was suspected to contribute to the leg numbness that may correspond to the muscular load of SOL and G as reported in the fully squatting posture as in the case of squatting-type toilet usage (Dengchuan and Manlai, 1998). However, although fully squatting is suspected to contribute to the disk degeneration in particular at the fourth and fifth lumbar levels, not all squatting parameters are shown to be disadvantageous in performing the task. According to the videotape data, the ankle strategy occurring at FS allowed a segmental angular flexion of the whole body as an adaptation to task demands. This might be the reason why at FS a deep flexion in the trunk and hip did not occur as seen in Figure 2A and 3A. The absence of a stool actually allowed the trunk and the hip, and ankle joints at the FS condition to achieve the most comfortable posture that was difficult when the subject sat on a "too low" stool.

The activities of the lower limbs muscles at squatting height conditions suggest that the coordination between the anterior muscles of RF-TA and the posterior muscles of SOL-G might be impor-

tant in the coordination of postural movement and balance as the condition changed from FS to SS conditions. Interestingly, although RF and TA were not strongly influenced by the SS conditions (except the small effect on TA found between SS10 and SS20), both SOL and G showed an opposite characteristic as seat height increased as shown in Figure 6. These contrasting muscles activities might confirm the task-induced stress of bodily coordination between agonist and antagonist muscles during a dynamic task that required forward movement to handle the object on the ground level (Nishiwaki et al., 2006). Angular forward rotation driven by the ankle joint for the hand to reach the object in front of the feet affected the postural demands to lengthen the torso. However, the effort of reaching the object increased the torso length at SS20 whereas significant effects were revealed to be less at SS10 and SS20. Considering the kind of task influencing the muscular stretch on the back, postural demands reflected the effort in clockwise movement while squatting on the lowest seat height as seen from someone who performed an ascending (sit-to-stand) movement from sitting on the "too low" seat height as reported by Yamada and Demura (2004). The forward rotation of the trunk to extend the reach ability, however, increased the muscular stress through the flexor iliopsoas muscle to generate momentum because part of the body mass supported by the shanks on the seat was transported toward the forward perimeter of the base support provided by the feet. When the body moved forward, the center of gravity also delivered from the seat to the feet consecutively. This means that the main function of a seat to support the body weight decreases as shown in Figure 4B. It is considered that the differences in the seat height especially in lower stools influence the different exertion of muscle strength. According to the complex coordination of the associated muscles during performing the task, it is not easy to determine an appropriate seat height based on the change of muscular load in squatting. In the case that a minimal stool height should be determined, it is suggested from all the parameter analyses that SS10 may contribute to the high risk of low back pain regarding the extreme hip flexion generating a high pressure of the lumbar intervertebral disks. On the other hand, the level of ischial tuberosities probably could be put as a consideration when referring to the minimum seat height. According to the subject's buttock height (10.7±3.0 cm), it makes sense that SS10 is not an acceptable condition of squatting because the level is positioned under the average subject's buttock height as reported by the subjects in the previous investigation (Sriwarno et al., 2006).

CONCLUSION

Regarding ground-level jobs, a change of working posture from fully squatting to squatting on a stool has proven to reduce the muscular load greatly in the rectus femoris and tibialis anterior, contributing to the reduction of working discomfort and musculoskeletal complaints during prolonged squatting. The presence of a lower seat height was revealed to decrease the muscular load on the back, although a "too low" stool might affect the hip joint to be more flexed leading to an increase in the lumbar intervertebral disc pressure. The use of a lower seat stool of a proper height seems to be a sub-optimal solution in order to minimize undue stress, preserve health and work ability, and to improve the task performance in real work sites. Furthermore, the findings of this study would be a useful reference in developing the working environment design not only for normal workers but also for those who have functional limitations such as the obese and elderly.

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