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THE EVALUATION OF THE EFFECT OF STOOL HEIGHT ALTERATION ON WORKLOAD OF SQUATTING POSTURES PERFORMED BY INDONESIANS WITH DIFFERENT BODY MASS INDEX (BMI)

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Indonesians commonly perform activities on the floor that require squatting postures. It has been identified that adopting squatting postures without any proper support would gradually cause postural stress. This study examines the influence of different squatting heights to the body kinematics and subjective discomfort rating. The subjects were divided into two different body types: overweight subjects with BMI > 24.9 and normal weight subjects with BMI 18-24.9. The subjects adopted a squatting posture at no-stool condition and at the stool height of 10, 15, and 20 cm. The task was to simulate the work close to the ground level with the hip joint deeply flexed. Body segmental angular flexion (SAF) and the visual analog scale (VAS) method were selected for parameter analyses. Significant differences were found in both parameters SAF (trunk, hip, knee, and ankle) and VAS. The interaction effect was found by squatting height and the body type for SAF of the trunk ($p<0.05$). However, the increasing BMI index was also found significantly affected associated with the anthropometrical characteristics for buttock height and lower limbs depth. It is suggested that normal weight subjects sit comfortably at 15 cm stool height, whereas overweight subjects preferred 20 cm stool height as a better acceptability condition in terms of overall parameter analyses.
Key words: squatting posture; Body Mass Index; body angular flexion; stool height.

INTRODUCTION

Squatting is one of the posture patterns under the influence of the traditional lifestyle in Asian countries. Indonesian workers typically adopt their jobs in prolonged squatting postures in various fields to handle objects on the ground in furniture assembling, agriculture, metal welding and trimming, shoe making, homemade-food industries and other areas of small-scale industries.

Workers reported complaints about musculoskeletal problems after adopting the squatting posture since they were supported with non-suitable facilities (Manuaba, 1997; Tirtayasa et al., 2003). Although this phenomenon is common in discussions about occupational safety and health, there have been a few in-depth studies about squatting postures from the viewpoint of physical human behaviour (Bridger, 1995). Chung et al. (2000) indicated that the stool height of 10 cm contributed to a low level of discomfort for those who often performed their job above the ground level. The discomfort feeling rating of the squatting posture was found to increase rapidly after 6 min of work. Despite the variability of typical seat-heights, little has been known about how a sitting posture changes in the population in terms of different body types and seat height alteration. Working on the ground level in a squatting posture is suspected to gradually cause the health risk of musculoskeletal injuries and to contribute to a higher rate of discomfort (Keyserling, 1988). During performing a dynamic motion task in lower level seating, the strategy of body angular movement can be quite dif-

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ferent for those with functional limitations (Hughes et al., 1994).

It has been known that the overweight population has unique ergonomic problems during performing the job. The total population of Indonesian based on demographics data in 2004 showed that, among 214.6 million people, 15% of the adult population is overweight with an increasing incidence of chronic diseases such as heart diseases, osteoporosis and musculoskeletal complaints (Atmarita, 2005). In this study, Body Mass Index (BMI) was selected to reflect the presence of an excess of adipose tissue mass and the ability of task performing. Other than some specific occupational populations, there have been a few studies of how body weight conditions affect the design of a seat support (Bridger, 1991). Normal weight (NW) is defined when BMI lies around 18.5–24.9. Overweight (OW), including obesity in this investigation, is defined as a person who has a BMI over 24.9. Posture adaptations and subjective discomfort feelings at various heights of squatting by comparing OW and NW subjects are of particular interest. The aim of the study was to analyze the relationship between working postures and the incidence of postural stress as stool height increased during squatting. Body kinematics and feeling judgments were examined in the parameter analysis.

METHODS

Data were obtained from 14 healthy Indonesian adult males consisting of seven overweight and seven normal weight subjects (Table 1). In order to determine the appropriate stool height, buttock height (BH) was measured from the minimum level of the gluteus maximus muscle with respect to the floor when the subject was adopting a fully squatting posture (Figure 2A). Beforehand, the subjects gave written informed consent about the experiment. All the participants selected reported to have no history of back pain complaints or pathological disease that would influence their ability to perform the task during squatting.

Four conditions of squatting posture were examined randomly at different levels of buttock height (squatting height): no stool, 10, 15 and 20 cm. In these conditions, subjects were asked to adopt a squatting posture as they simulated the job on the ground level. Typical jobs done in a squatting posture are shown in Figure.1. Subjects were instructed to keep their trunk joint flexed with the ankles flexed, the knees deeply flexed, and the torso close to the thigh, sometimes with the upper limbs held on the knees as much as possible (Figure 2). During squatting, the subjects were instructed ‘to cut the paper’ along the pathway that required posteriorly movement. No instructions about movement speed and time duration were given. Each subject had ten practice trials prior to the data collection in each task condition. The trials confirmed free from technical problems were analyzed.

Between the trials at each task condition, the subjects were required to have 3 min rest by sitting

Table 1. The subjects’ demographics shown by the means, SD (parentheses) and their statistical analysis (unpaired-sample *t*-test)

Physical measurements	OW subjects (n=7)	NW subjects (n=7)	Difference (*p*)
Age (year)	32.7(3.5)	30.0(4.7)	NS
Stature (cm)	169.0(3.4)	165.7(3)	NS
Weight (kg)	82.3(9.1)	64.2 (5.1)	<0.001
BMI (kg/m2)	27.5 (2.9)	24.0(1.7)	<0.01
Minimum thigh depth/MTD (cm)	16.5(1.0)	14.7(0.9)	<0.05
Maximum shank depth/MSD (cm)	12.9(1.2)	11.6(1.2)	<0.05
Abdominal depth/AD (cm)	24.8 (2.7)	20.3 (2.6)	<0.05
Buttock height/BH (cm)	13.0(2.5)	8.5(1.6.)	<0.01

NS, not significant.

Fig. 1. The examples of squatting postures in small-scale industries: squatting posture in the agriculture sector (left) and squatting posture in die casting industry (right).

on a chair while reporting the discomfort feeling rating on the visual analog scale (VAS). This questionnaire was given to the subjects to investigate the intensity of muscular tension, comfort feeling, and squatting height expectation after each condition was completed. In this method, the subjects were asked to express their perception of the tested condition by producing a line on the perceived intensity line indicating the level of acceptance feeling rating from the low to high rate of pain feeling on the back, pain feeling on the lower limb, pain feeling on the abdominal region, comfort feeling, and squatting high preference. By means of the chair feature checklist developed by Shackel (1969), the modified subjective discomfort rating on a 10 cm VAS with 0–100 scoring was recorded at the end of each tested condition. The criteria set to determine the acceptable condition are shown in Table 2.

An adjustable stool dummy was used as the experimental stool that could be seat at three kinds of height. Eight light reflective markers were attached over the right side of the body on the fourth thoracic vertebra, the seventh thoracic vertebra, the fourth lumbar vertebra, and the shoulder (gleno humeral joint), hip joint (greater trochanter), knee (middle of lateral knee joint line), ankle (lateral malleolus) and foot (head of fifth metatarsal) using LED (Light Emitting Diode) in green color in order to analyze body kinematics. All of the markers had a black base to maximize the contrast between the markers and the subject's clothes (Figure 2A–D). The working postures during each trial were videotaped with a fixed sampling rate at 29.9 Hz by a digital video camera. The camera was mounted on a tripod of 45 cm in height at a distance of 4 m at the right angles to the subject's sagittal plane as they performed the task with their right hand. With the aid of a motion analysis system (WinAnalyze1.3), the video data were analyzed and the two-dimensional coordinates of the markers were obtained.

Table 2. A list of VAS questions and the criteria of scoring. Subjects just needed to tick (/) in the horizontal bar base on what they felt in relation to the questions.

No	Questions	Abbreviation	Score (0-100)
			Too low Too high
1	Pain feeling in the back	PFB	
2	Pain feeling in the leg and foot	PFL	
3	Pressure in the abdominal region	PAR	
4	Over all comfortable of condition tested	OC	
5	Squatting height acceptance	SH	

The position of (/) is set as criteria of the most acceptable condition. For item 5, acceptable condition is set at 50 (not too low and not too high of the stool height).

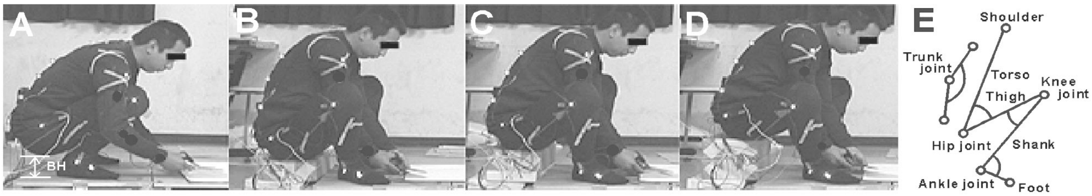

Fig. 2. The location of markers on the subject's body. Four squatting height conditions (no-stool (A), 10 cm (B), 15 cm (C) and 20 cm (D) stool height) were tested in the random order. Body SAF is defined by linking the markers (E).

The preparation including the installation of markers and laboratory set up took 30 min. The subjects were required to adjust the position of the paper until the most comfortable handling was determined. In the starting position, the subject was asked to squat and watch the lamp on the front edge of the squatting platform that indicated the time to start. The subject put their feet position so that the toes were behind the line as shown in the protocol of experiment developed by Chung et al. (2000). In any situation while holding the task, subject's feet was not allowed to move beyond the marked line. Through the motion analysis system, the line was connected between the markers to represent the body segmentation. These markers defined a segmental model of the body made up of the trunk, torso, thigh, shank and foot (Figure 2E). As the body segments were connected, segmental angular flexion (SAF) and joint displacement could be determined. The relative postural joint angles were defined with reference to the ankle joint, knee joint, hip joint and trunk joint, and the average SAF were analyzed. An ANOVA (Analysis of Variance) was used to examine the data of subjective discomfort rating and SAF for all the parameters tested to analyze the effects of squatting height and the body type.

RESULTS

As the period of task performance differed between the subjects, subjects carried out each trial task for approximately 2 min for all of the ten trials. As shown in Table 3, the squatting height significantly affected the subjective discomfort feeling except the pain feeling in the back (PFB). In contrast, no differences in the effects were found between OW and NW subjects except the pain feeling in the abdominal region (PAR) ($p<0.05$). However, the no-stool condition was clearly not acceptable (close to 0 score) for both groups. The interaction effect was not found between squatting height and body the type.

In Table 4, the ANOVA analysis data of body kinematics indicated that OW and NW subjects showed significantly different SAF of the trunk, hip, knee and ankle joint at the four tested conditions with respect to squatting height and the body type during performing the task. Although both groups tended to perform the job with a similar trend of SAF, the trunk angular flexion of OW subjects showed slight differences in which the no-stool condition had the greatest flexion (150 ± 5.6 degrees), whereas the flexion of NW subjects was the largest at 15 cm (144 ± 4.7 degrees). In this condition, although squatting height did not affect SAF much, differences were seen in both OW and NW subjects ($p<0.05$). In addition, the interaction effect of squatting height and the body type for trunk angular flexion was found ($p<0.05$). The squatting height alteration was found to affect the hip, knee and ankle joints with the greatest increases occurring for knee and ankle angular flexions ($p<0.001$). Both OW and NW subjects showed significantly larger differences in all the tested conditions ($p<0.05$).

In this study, we also found that the subjects' anthropometric features related closely to the body type (see Table 1). The correlation analysis was therefore conducted to identify the effect of BMI on the different anthropometric dimensions. Although there is a close relationship between stature and

Table 3. The results of ANOVA for discomfort feeling ratings shown as means and SD (parentheses). Abbreviations as explained in Table 2 .

Parameters	No stool	10 cm	15 cm	20 cm	Difference (*p*)		
					Squatting height (Sh)	Body type (Bt)	Sh × Bt
PFB							
OW	45.7(24.5)	50.5(21.1)	53.1(15.3)	40.6(19.3)	NS	NS	NS
NW	52.2(27.6)	56.8(18.9)	37.8(17.8)	44.5(26.4)			
PFL							
OW	62.2(18.1)	67.1(18.1)	51.7(11.7)	39.0(18.2)	<0.05	NS	NS
NW	59.1(18.1)	60.4(19.1)	41.0(15.1)	38.1(27.6)			
PAR							
OW	58.5(16.9)	73.7(20.7)	62.8(18.8)	41.2(15.6)	<0.05	<0.05	NS
NW	50.4(27.6)	60.7(16.2)	38.2(22.4)	41.0(26.2)			
OC							
OW	42.8(20.2)	43.7(24.5)	58.4(17.3)	61.4(18.8)	<0.05	NS	NS
NW	28.8(16.4)	47.7(9.7)	63.5(24.3)	50.8(30.8)			
SH							
OW	3.4(3)	22.2(15.5)	45.5(8.6)	50.5(6.8)	<0.001	NS	NS
NW	3.0(2.5)	38.1(20.4)	45.3(9.9)	59.0(24.5)			

NS, not significant.

Table 4. The result of ANOVA for body segmental limbs angular flexion (SAF) achieved during holding the task. Means and SD (parentheses) presented in degrees.

Parameters	No stool	10 cm	15 cm	20 cm	Difference (*p*)		
					Squatting height (Sh)	Body type (Bt)	Sh × Bt
Trunk							
OW	150.4 (5.6)	144.7 (4.8)	143.6 (6.7)	145.5 (3.5)	NS	<0.05	<0.05
NW	142.8 (5.7)	142.8 (4.3)	144.1(4.7)	140.6 (3.8)			
Hip							
OW	27.6(11.5)	14.9 (8.6)	18.5(7.7)	23.2 (4.3)	<0.05	<0.05	NS
NW	19.9(4.1)	12.4 (5.3)	16.0(6.6)	14.8 (3.4)			
Knee							
OW	40.4 (11.2)	71.6 (22.1)	79.1 (20.5)	80.9 (20.5)	<0.00 1	<0.05	NS
NW	29.3 (5.7)	55.7 (18.1)	53.6 (15.9)	64.4 (15.9)			
Ankle							
OW	82.5 (12.3)	120 .0(14.7)	113.8 (16.7)	100.8 (17)	<0.001	<0.05	NS
NW	72.4 (4.3)	98.9 (11.3)	94.7 (13.2)	92.4 (10.1)			

NS, not significant.

seat height based on the position of ischial tuberosities (Bridger, 1995), in the present study the lower limb depth contributed more to the change of buttock height. The total lower limb depth was calculated as a summation of thigh and shank depths that were measured when the knee was fully flexed. As plotted in Figure 3, a positive correlation appeared as BMI increased, followed by the increase of BH and that of the total lower limbs depth ($p<0.001$), with the coefficient of correlation (r) of 0.79 and 0.78, respectively. The increase of BMI was associated with BH, and thus OW subjects tended to position their buttock over the 10 cm stool height. In addition, the video data showed that the buttock clearly hung over at the end part of the trials.

Since BH of each subject differed in the initiation squatting at the no-stool condition, it was demonstrated that the hip joint gradually moved vertically at the stool height to a level lower than the subject's BH as plotted in Figure 4. When the subjects moved posteriorly, hip joint movement rapidly

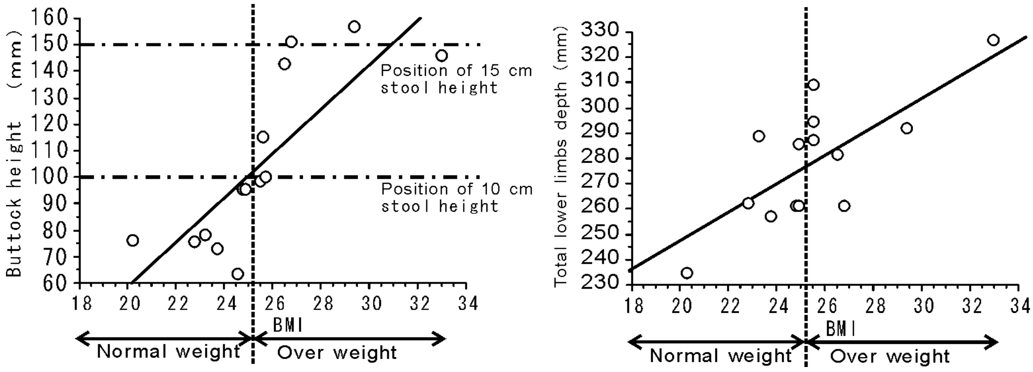

Fig. 3. The relationships between predicted buttock height and BMI in relation to the body type (r=0.79, $p<0.001$) and between total lower limbs depth and BMI (r=0.78, $p<0.001$).

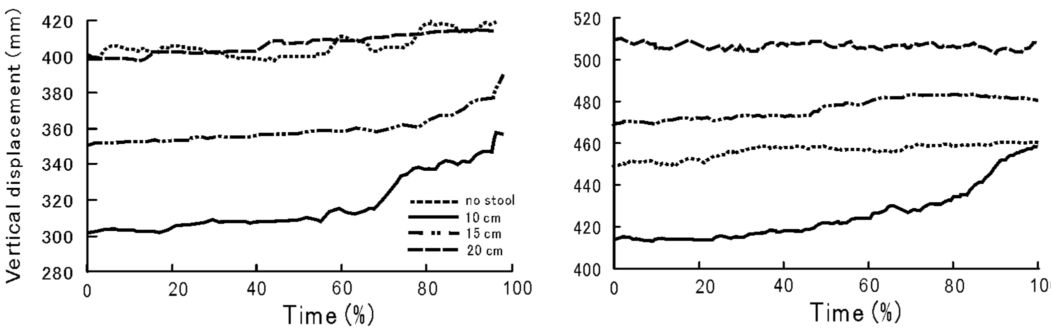

Fig. 4. Changes in vertical displacements of the hip joint performed by a representative subject of OW (left) and NW (right). Hip joint height lower than the no-stool condition test gradually increased when the subject moved posteriorly (10 cm and 15 cm for OW subjects and 10 cm for NW subjects).

increased vertically in 60% of the trials. In addition, the buttock was found to slightly slide posteriorly on the seat of 10 cm height in both OW and NW subjects though relevant data is not presented. Other evidences also supported that, in a fully squatting posture, OW subjects showed the mean knee angular flexion wider than that for NW subjects (Table 4).

DISCUSSION

The obtained data showed differences in anthropometric features between the two groups (Table 1). Other than the differences due apparently to overweight (18.1 kg heavier in weight, 2.5 point higher in BMI, 1.8 cm larger in minimum thigh depth, 1.3 cm larger in maximum shank depth, 4.5 cm larger in abdominal depth, and 4.5 cm higher in buttock height), significant difference was not found in terms of age and stature between OW and NW groups. This implies that the division of the subjects by body type (OW and NW groups) reflects the significant differences in physical measurements. In general, the seat height alteration showed the effect on the discomfort feeling in all the subjects but this did not mean any differences between OW and NW groups. According to body kinematics analysis, any squatting posture involved the complex co-ordination of the whole body in achieving this extremely angular flexion. As compensation, each body joint adapted to maintain the balance and keep the body's center of mass correctly on the feet through the ankle and hip joints that shifted as a pivot of angular rotation. In addition, deep squatting showed a high degree of motion in comparison with squatting on the stool in which only the hip joint was allowed to be a center of rotation. On the other hands, Bridger (1995) considers that this postural adaptation can be regarded as fundamental in an anatomical sense and shows an advantage in flexibility of a deep squatting posture.

The squatting posture is one of the natural ways of sitting. However, performing this posture in a long period of working may cause musculoskeletal injuries on the body limbs. Since the no-stool condition allowed the upper body of OW subjects to rotate angularly forward without any support, SAF of the trunk showed a wider change than in other conditions. It probably explains that in the no-stool condition OW subjects feel more comfortable when the trunk was almost in the erect position achieved and that therefore the hip joint gradually opened regarding abdominal room. It has been reported that the use of stool could reduce the muscular tension on the upper body (Chung et al., 2000), thus in this condition OW subjects revealed the biggest SAF of the trunk at 20 cm, whereas NW subjects did so at 15 cm. This relationship, however, was not shown to differ as we expected. Probably the tiptoe squatting conducted by a few subjects influenced the data concerning the trunk. Although the squatting height did not affect SAF of the trunk, this evidence agreed with the subjective discomfort rating as shown in Table 3, with OW subjects tending to accept 20 cm (40.6 ± 19.3), whereas NW subjects did so at 15 cm (37.8 ± 17.8) for PFB. An increase of 0.8 degrees for trunk flexion in OW subjects from 10 cm to 20 cm condition actually was followed by the decrease of pain feeling in the back (Table 4).

The discomfort of squatting on the stool height alteration could be determined from the kinematics data of vertical displacement performed by the hip joint. The subjects having the high degree of abdominal depth (AD) may tend to have the lack of ability to flex the hip joint especially at the low level stool. This may occur in most discomfort conditions as reported by Mandall (1981). According to the motion analysis, OW and NW subjects hardly achieved the task at 10 cm condition in terms of the stool height that was actually lower than BH. This condition probably corresponds to the muscular complaints in PAR (Table 3) that the subjects may suffer due to abdominal stress when the hip joint is deeply flexed. An increase in hip flexion angle (8.3 degrees) from 10 cm to 20 cm condition helps reduce muscular complaints in OW subjects. This kind of task required the abdominal muscles to be more mechanically demanded in order to increase the angular momentum to transport the upper body posteriorly corresponding to the effort of the hand to reach the objects further from the body (Hirao and Kajiyama, 1989). The postural adaptation occurring in this condition may be one of the main sources for the increased incidence of lower back pain in both OW and NW subjects in spite of the task-induced stress that has to be taken into account. Although there was no such data provided about BH of Indonesians in squatting positions, we consider that BH has certain relationships with stature. Table 1 shows that among the body type groups, OW and NW subjects did not show a significant difference in stature ($p>0.05$, F=4.357) and that significant differences were seen in BMI and weight. Based on these findings, it is suggested that the change of BH was influenced more by the increase of the total lower limb depth than by that of stature.

The increase of AD requires more room in front of the body for the trunk to incline rearward. Some OW subjects did not seem completely accustomed to it so that they felt uncomfortable because they could not dorsiflex the ankle joints sufficiently to attain a proper angle between the foot and lower leg, as required to maintain balance. For this reason, they tended to fall over backward when attempting to squat. In order to avoid rear back falling at the no-stool condition, those OW subjects lifted the heel up (held by the tiptoe) with the hip joint extended to require abdominal room approximately 28 degrees (wider than at 20 cm) in the middle of task performing (Table 4). But the most comfortable condition during squatting was obtained on the stool adjusted to SAF of the hip joint, OW subjects accepted 20cm as an appropriate height, whereas NW subjects preferred to sit on 15 cm stool height. This implies that the body segmental coordination of the two groups is different regarding balance maintenance. OW subjects were found to extend the hip joint more than NW subjects. This difference may relate to the difference in PAR that was higher in OW subjects. As the hip joint performed a wider angle, the pain feeling in the abdominal region decreased.

Knee complaints often occurred in the condition where the knee joint was deeply flexed (Kivimaki et al., 1992). OW and NW subjects demonstrated this deep flexion at the no-stool condition (40.4 ± 11.2 and 29.3 ± 5.7 degrees). Similar acceptance of the stool height was revealed from both parameters of discomfort feeling rating (PFL) and SAF, with 20 cm being the most acceptable condition for OW and NW subjects. It seems that the existence of fat deposit residing around the thighs and the shaft influence due to the progressively increasing angle width performed by the knee may cause the muscular pressure in the lower limbs especially at the tibialis anterior and rectus femoris muscles (Yamada and Demura, 2004). In addition, restricted postures can prevent blood from flowing properly and make the subjects feel leg numbness as seen in the case of those who often use the squatting-toilet type (Dengchuan and Manlai, 1998).

As mentioned in the knee angular flexion analysis, the increased BMI may correspond to the fat deposit laid in the abdominal area and the lower legs. Abdominal visceral fat obesity may influence the ability of locomotion and postural stress. BMI is suspected to influence the anthropometrical characteristics with regard to the ability of performing the job on the floor as a highly demanding task. Overweight people may need more effort than normal weight subjects in terms of motion (Spyropoulos et al., 1991). OW subjects had a lack of ability to perform the smaller segmental angular joint as seen at 10 cm. Moreover, the acceptable seat height in SAF was much higher than that shown by the studies conducted by Chung et al. (2000). This is probably caused by the fact that the normal weight types of Koreans were employed in the experiments. Changes in body type and working postures are thus found to affect the effective working envelope and increase the biomechanical loads on the musculoskeletal system, resulting in an increase of the risk of lower-back pain. The increasing lower limbs depth also revealed to influence the subject's BH. The postural adaptation to overweight has, from the biomechanical points of view, adverse and undesirable consequences, e.g. for the postural tension.

CONCLUSION

Overweight subjects make up a small but significant part of the workforce in comparison to normal weight subjects in the no-stool and stool conditions in the squatting posture assessment. Changes in the body type and working postures due to increased BMI affect the effective working envelope and increase the biomechanical loads on the musculoskeletal system resulting in the complaints of postural stress. The results of this study suggested that OW and NW groups revealed to have different responses to the seat height alteration. When handling objects in front of the subject on the ground level, OW subjects showed the appropriate seat higher than NW subjects in order to reduce postural discomfort. It is important to note that the relationship between seat height alteration and SAF influences the acceptance of squatting height and that OW subjects preferred to sit on 20 cm stool height, whereas NW subjects did so on 15 cm stool height as shown by the parameter analyses. In this investigation, all the subjects showed less acceptance to the no-stool condition, followed by 10 cm stool height.

These findings imply that the stool use is able to decrease the discomfort level in comparison to the no-stool or fully squatting condition. Although a stool can relieve postural load in squatting, a proper height of the stool has to be taken into account based on BH as one of the effects of BMI. As the discomfort level is known to be associated to the risk of musculoskeletal injuries, a stool of proper height should be considered different body types of its users especially for those who have functional limitations such as overweight or obesity with a view to reducing this workload in prolonged working, where a stool is in use, it is recommended to insert breaking time during work shifts to allow the effects of muscular stress to recover. In the case of working near the floor, the improvement in adjustable stool design in order to secure safely performing jobs should be taken into account. The postures investigated in this study were limited to Indonesian subjects. At real industrial sites, however, variations of the population and anthropometrics should be carefully observed referring to more useful guidelines for the design of workstations for jobs requiring squatting for handling the objects on the floor level.

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