2008-5435/12/42-32-38
INTERNATIONAL JOURNAL OF OCCUPATIONAL HYGIENE

IJOH 4: 32-38, 2012

ORIGINAL ARTICLE

The Effect of Wearing Different Types of Respirators on Postural Stability and Comfort

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Received May 8, 2012; Accepted June 14, 2012

ABSTRACT

Respirators are commonly used to protect workers against workplace airborne contaminants, but this equipment may become a safety hazard by creating discomfort, disorientation and postural instability. Although postural stability is critical to workers, especially those working near moving objects or on surfaces where a loss of balance may become life threatening, little attention has been given to the effect of respirators on wearers' postural stability. The purpose of this study was to examine the effects of wearing a half-mask respirator, a full-face respirator, a self-contained breathing apparatus (SCBA), and no-respirator on postural stability, using computerized dynamic posturography (CDP). The subjects' perception of comfort was also assessed. Over 60% of the subjects reported that wearing a respirator was uncomfortable and 20% felt that they had difficulty balancing while wearing the SCBA. The half-mask respirators, full-face respirators or SCBA did not produce any differences in postural stability over a baseline (no-respirator). However, the subjects expressed concerns with comfort.

Keywords: *Respirator, Postural Balance, Comfort*

INTRODUCTION

Respirators are one of the crucial members of a variety of personal protective equipment (PPE) used in work-related tasks to protect workers from exposure to hazardous conditions. A study by the U.S. Occupational Safety and Health Administration (OSHA) revealed that 37.7% of occupational injuries and illnesses could have been prevented by the proper application of PPE [1].

Workers frequently are opposed to wearing PPE, particularly respirators, due to factors such as discomfort, improper fit, added weight, out-of-fashion style and color, resistance to air movement, limited communication, restricted visual fields, reduced senses and reduced dexterity [2]. These factors may result in workers being exposed to hazards greater than those the PPE are designed to protect against. Earlier studies have also examined the issue of worker comfort and the use of PPE in industrial settings and have suggested that approximately half of the workers did not perceive their respirator as comfortable or acceptable [3-4].

Studies examining the physiological effects of respirator use have indicated that wearing a half-mask respirator or a full-face respirator results in increased blood pressure [5], increased oxygen consumption [5-8], decreased breathing frequency and tidal volume [6], increased heart rate [6, 9], and reduced mean minute ventilation [8]. Although respirator usage has not been shown to be associated with significant increases in skin or body temperatures, it has been suggested that PPE may impose thermoregulatory and cardiovascular stresses on the wearer [7].

Psychomotor tasks, such as steadiness of work performance and accurate control for positioning objects may be significantly reduced while wearing a full-face

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respirator, relative to a no-mask condition [5]. However, tests of cognitive function show that choice reaction times and response accuracy do not seem to be adversely affected by respirator usage [5, 10].

Overall, using respirators has an adverse effect on physiological function and some psychomotor tasks and they are perceived to be less than comfortable. All of these variables may affect a wearer's desire to use PPE in hazardous situations.

Little attention has been given to the effects of respirator usage on the biomechanical aspects of postural control or balance. Balance is a prerequisite of upright standing and is necessary for the performance of many of the activities of daily living. To maintain postural control, the position of the body's center of gravity relative to the base of support must be determined and remedial actions executed to correct the center of gravity displacement. These functions depend on the interaction of the sensory organization and motor coordination components of the neurological system and the biomechanics of the musculoskeletal system [11-12]. Postural orientation obtained from the visual, vestibular and somatosensory systems depends on the accuracy of the input from each system, their interaction, and the selection of the most appropriate sense for the task [11-13]. The motor components of postural control depend on the movement strategies that occur in the trunk and lower extremities [14].

Individuals' ability to safely function within their environment may be jeopardized if anything (1) interferes with fully utilizing the visual, vestibular and somatosensory inputs required for postural orientation or motor coordination, and (2) affects maintaining the center of gravity within the base of support provided by foot and surface contact.

A study quantitatively examined the effect of full-face respirator usage on balance performance and observed increased sway following varied workloads performed on a bicycle ergometer test [9]. These authors found that subjects' postural sway increased, particularly at higher workloads, suggesting that wearing a respirator may have an adverse effect on balance. There was, however, no difference in the sway patterns obtained from a pre-exercise condition in which the subjects stood with and without wearing a respirator. Balance was assessed following the exercise situation, and not during the performance of the actual exercise task. In addition, the automatic postural responses to changes in support surface orientation were not assessed.

Since many jobs require workers to be involved in activities in which balance is essential and a loss of balance may potentially be life threatening, insight into the effects of PPE on postural stability is important. Therefore, the purpose of this study was to examine the effects of wearing different types of respirators on the (1) biomechanics of postural stability, and (2) perception of comfort.

MATERIALS AND METHODS

Subjects

Fifteen subjects, 13 males and 2 females participated in the study. The study was performed in Toledo, Ohio during 2002. The subjects' age, height and weight had a mean (standard deviation) of 32.3 years (10.3 years), 174 cm (6 cm) and 60.4 kg (9.2 kg), respectively. Subjects would be excluded from participation if they exhibited known neuromuscular or musculoskeletal disorders, blindness, amputations, current fractures, dizziness or vestibular problems that affected their ability to stand; no subject was excluded from the study.

The research was approved by the authors' Institutional Review Board and accordingly written informed consent was obtained from each subject prior to participation in the study. Subjects were asked to wear loose-fitting clothing during the testing sessions and were asked to refrain from alcohol and recreational drug use for at least 48 hours prior to testing.

Respirators

The respirators consisted of (1) half-mask respirators (MSA Company, Pittsburgh, Pennsylvania, USA) in three sizes (small, medium, large), each equipped with a combination of chemical cartridge and mechanical filter; weighing a total of approximately 0.5 kg; (2) full-face respirators (MSA Company, Pittsburgh, Pennsylvania, USA) in three sizes (small, medium, large), each equipped with a combination of chemical cartridge and mechanical filter, weighing a total of approximately 0.9 kg, and; (3) positive demand self-contained breathing apparatus (SCBA) (Racal Company, Dayton, Ohio, USA) which supplies breathing air for about 60 minutes and weighs approximately 9.8 kg.

Climatic Factors

The ambient temperature in the laboratory was maintained between 20 and 22 °C and the relative humidity was approximately 50%. The ventilation system was operational and running during the testing sessions.

Testing Procedures

Each subject was asked to complete a series of tests of postural stability, under conditions of wearing no respirator, wearing a half-mask respirator, wearing a full-face respirator and wearing SCBA. The baseline trial with no-respirator was performed first. The order of wearing the three types of respirators was randomized for each subject, as was the order of presentation of the postural stability tests. The respirators were fitted to each subject by one of the investigators to ensure appropriate respirator size and donning or doffing. Each subject performed several training trials while wearing the respirator prior to actual data collection. The comfort surveys were administered at the completion of the sensory organization, motor control latency and adaptation tests for each of the baseline and the three respirator testing conditions. All testing for each subject was performed in one session.

Fig 1. A subject is standing on the floor of the Equitest during postural stability assessment

Biomechanical Assessment of Postural Stability

Postural stability or balance was assessed by computerized dynamic posturography (CDP) using the Equitest (NeuroCom International, Inc., Clackamas, Oregon, USA; Fig.1.). The assessment consisted of the sensory organization, motor control latency and the adaptation tests. The following outlines the procedures for each of these assessments.

Sensory Organization Test (SOT)

During the SOT, the subject was asked to complete the standard protocol for the Equitest, consisting of three 20-second trials for each of six sensory conditions. A harness was placed on the subject to prevent falls (Fig. 1). The subject was instructed to stand as still as possible, with the head erect and eyes facing forward, the feet approximately shoulder width apart on the two force platforms which formed the floor of the Equitest, and the hands clasped comfortably in front of the body.

The specific visual, floor surface and visual surround manipulations for each of the six sensory conditions are presented in Table 1. The subject initially completed three conditions in which visual information was altered, while the support surface was fixed. These visual conditions included eyes open (SOT1), eyes closed (SOT2), and the visual surround sway-referenced (SOT3). During conditions four through six, the support surface was sway-referenced and the visual conditions included eyes open (SOT4), eyes closed (SOT5), and the visual surround sway-referenced (SOT6). An equilibrium score based on the magnitude of the center of gravity movements, expressed as a percentage of the limits of stability, was calculated for each trial. A score of 100% indicates perfect stability and 0% indicates sway that exceeds the limits of stability or a fall [15]. A composite equilibrium score, which is a weighted average of the scores for the six sensory conditions, was also calculated and used in the statistical analyses.

Motor Control Test (MCT)

The motor control test consisted of small, medium and large translations of the floor surface parallel to the floor in a backward and forward direction. Three trials were performed for each magnitude of translation. The specific characteristics of floor translations are presented in Table 2. The duration of the translations was the same for each person, while the amplitudes of the translations were based on the subject's height, to produce an equivalent sway angle for each subject. The timing between the translation trials was randomized between 1.5 and 2.5 seconds.

The response latency or the time between the initiation of the translation and the onset of the subject's active postural response, as designated by a sudden increase in the magnitude of the shear force was determined. The average latencies for the three trials of the small, medium and large translations in the backward and forward directions were used in the statistical analyses. The weight symmetry, which indicates the percentage of body weight on each leg during the translation, for the right and left lower extremities was also determined and included in the statistical analyses. Scores near 100 indicate nearly equal distribution of total body weight supported on each leg, while lower scores indicate that the body weight is not equally distributed on each leg.

Adaptation Test (ADT)

The adaptation test consisted of five trials in which the floor surface was tilted upward (toes up) and five trials in which the floor surface was rotated downward (toes down). Each of the five rotations lasted 400 ms

Table 1. Visual, visual surround and support surface characteristics of the Sensory Organization Test (SOT)

Sensory condition	Visual inputs	Visual surround	Support surface
SOT 1	Eyes open	Fixed	Fixed
SOT 2	Eyes closed	Fixed	Fixed
SOT 3	Eyes open	Sway-referenced	Fixed
SOT 4	Eyes open	Fixed	Sway-referenced
SOT 5	Eyes closed	Fixed	Sway-referenced
SOT 6	Eyes open	Sway-referenced	Sway-referenced

Table 2. Translation characteristics for the motor control test (MCT)

Translation magnitude	Translation time (m/s)	Translation amplitude (mm/degree)	Equivalent sway (degrees)
Small translation	250	12.50 (subject height/72)	0.7
Medium translation	300	31.25 (subject height/72)	1.8
Large translation	400	56.25 (subject height/72)	3.2

Table 3. Mean ± standard deviation of the Sensory Organization Test (SOT)

Sensory condition	Baseline	Half-mask	Full-face	SCBA*	*P***
SOT1	91 ± 4.9	91 ± 8.8	91 ± 6.9	91 ± 8.2	NS***
SOT2	89 ± 4.6	88 ± 5.8	89 ± 3.6	89 ± 3.9	NS
SOT3	90 ± 4.5	88 ± 8.9	100 ±4.6	87 ± 6.5	NS
SOT4	77 ± 12	80 ± 11	79 ± 10	76 ± 13	NS
SOT5	69 ± 10	66 ± 13	67 ± 12	67 ± 11	NS
SOT6	61 ± 7.9	62 ± 12	61 ± 13	59 ± 13	NS
Composite score	77 ± 6.3	76 ± 9.1	76 ± 6.9	75 ± 8.7	NS

*SCBA=self-contained breathing apparatus; **P=probability; ***NS=not significant ($p > 0.05$)

with an amplitude of 8°. The time between trials was randomized from three to five seconds. The ADT score quantifies the magnitude of the anterior-posterior (AP) sway following unexpected support surface rotations. The mean score of the sway energy for the toes up and toes down trials were included in the statistical analyses.

Perception of Comfort Survey

The subjects' perception of comfort was assessed by a questionnaire adapted from Akbar-Khanzadeh [4] consisting of 10 statements, with each statement evaluated on a scale of 1 (strongly disagree) to 5 (strongly agree). The questions included aspects of comfort, ease of balancing, moving, breathing, disorientation, and vision, the effect of weight, ability to wear the apparatus and sensation of pressure and heat on the skin.

Statistical Analyses

A repeated-measures analysis of variance was used to determine differences in the individual equilibrium scores across the six sensory conditions, the composite equilibrium scores, the motor control latency scores, the strength symmetry and the toes up and toes down sway energy scores across the baseline and three respirator conditions. The subject's perception of comfort was analyzed using the Fisher's Exact Test across each of the experimental conditions. Statistical significance was set at $p< 0.05$.

RESULTS AND DISCUSSION

Biomechanical Assessment of Postural Stability

Sensory Organization Test (SOT)

The results of the mean equilibrium scores obtained from each of the six sensory conditions of SOT and the composite equilibrium scores are presented in Table 3. A score of 100% represents perfect stability and 0% indicates sway that exceeds the limits or stability, or a fall [15]. No statistically significant differences were observed in the mean equilibrium scores across the six sensory conditions for the baseline and three types of respirators. There was also no statistically significant difference in the composite equilibrium scores across the four experimental conditions.

The sensory organization test is designed to examine the subjects' ability to use their visual, vestibular and somatosensory inputs for postural orientation. Although CDP is a clinical test of balance, the different testing conditions of the sensory organization test have analogies in the work environment. SOT1 (eyes open/fixed support surface) is equivalent to normal working environmental situations. SOT2 or the eyes closed/fixed support surface condition is equivalent to an individual working in dark environments. SOT4 through 6 are analogous to an individual working on very uneven/unstable surface conditions combined with the preceding corresponding visual conditions utilized during SOT1-3.

The results of the SOT analysis in this study indicated no significant decrement in postural stability between the baseline (no-respirator) condition and the three types of respirator, across the six sensory conditions, suggesting that the respirators had no significant impact on the subjects' postural stability. These data also suggested that the different types of respirators did not adversely affect the visual and somatosensory inputs of the subjects sufficiently to reduce their balance abilities. The magnitudes of the body sway increased across the testing conditions from SOT1-SOT6 as is typically seen in normal individuals. The latter is attributed to the fact that redundant sensory information is reduced or is inaccurate [16].

Table 4. Mean ± standard deviation of the motor control latency test (MCT) (Number of subjects = 15)

Parameter	Baseline	Half-mask	Full-face	SCBA*	*P***
Backward Latencies					
Small right leg	139 ± 11.6	139 ± 14.5	118 ± 11.9	138 ± 11.4	NS***
Small left leg	141 ± 15.5	141 ± 16.8	129 ± 10.5	138 ± 12.6	NS
Medium right leg	133 ± 13.9	133 ± 15.8	135 ± 16.4	136 ± 14.0	NS
Medium left leg	139 ± 14.4	137 ± 13.9	138 ± 16.1	139 ± 13.0	NS
Large right leg	132 ± 10.8	135 ± 14.5	133 ± 13.4	135 ± 17.2	NS
Large left leg	133 ± 12.3	135 ± 14.6	135 ± 14.6	133 ± 12.3	NS
Forward Latencies					
Small right leg	143 ± 16.3	147 ± 16.6	145 ± 16.4	141 ± 13.8	NS
Small left leg	143 ± 14.9	141 ± 9.50	145 ± 14.1	141 ± 13.0	NS
Medium right leg	145 ± 18.0	135 ± 14.0	139 ± 16.6	137 ± 16.2	NS
Medium left leg	142 ± 16.1	137 ± 13.4	140 ± 16.9	138 ± 16.9	NS
Large right leg	131 ± 10.6	132 ± 14.2	133 ± 14.8	133 ± 11.6	NS
Large left leg	133 ± 9.80	131 ± 14.6	134 ± 15.9	131 ± 11.9	NS

*SCBA=self-contained breathing apparatus; **P=probability; ***NS=not significant ($p > 0.05$)

The results of this study have no direct comparisons with previous research [9], who examined postural sway following baseline, light, moderate and heavy workload conditions performed on a bicycle ergonometer, with and without a full-face respirator. In their research, the total length of sway was obtained under feet together, eyes closed conditions while standing on foam. This is equivalent to SOT 5 in CDP. The researchers found no statistically significant differences in sway between the non-respirator and respirator condition prior to initiation of the exercise session, which is consistent with the results of our study. Furthermore, Seliga et al. [9] found that the total length of sway increased in a linear fashion with increasing workloads for the respirator condition, while there was no increase in sway during the non-respirator condition until the heaviest workload. In their study, a non-significant interaction was found between loading and respirator usage, suggesting that respirator usage during physically demanding exercise may have an adverse affect on balance.

Motor Control Latency Test (MCT)

The results of MCT are presented in Table 4. No statistically significant differences were observed in the response latencies for the small, medium and large translations in either the forward or backward directions across the four experimental conditions. The results of the weight symmetry data (Table 5) also did not exhibit a statistically significant difference between the baseline and three respirator conditions.

The motor control latency test may be considered analogous to environmental conditions in which there is a slippery support surface and/or the surface begins to slide. As a consequence, the worker needs to exert appropriate and timely automatic postural responses in the lower extremity musculature to regain balance.

The results of forward and backward motor control

Table 5. Mean ± standard deviation of the motor control latency test (MCT) related to weight symmetry (Number of subjects = 15)

Parameter	Baseline	Half-mask	Full-face	SCBA*	*P***
Backward latencies					
Small weight symmetry	106 ± 12	104 ± 6.7	102 ± 8.9	100 ± 10	NS***
Medium weight symmetry	105 ± 11	104 ± 7.4	101 ± 8.9	101 ± 9.0	NS
Large weight symmetry	106 ± 11	104 ± 8.2	102 ± 8.6	101 ± 11	NS
Forward latencies					
Small weight symmetry	105 ± 11	103 ± 8.0	101 ± 9.4	101 ± 9.0	NS
Medium weight symmetry	106 ± 12	103 ± 9.2	103 ± 8.9	100 ± 11	NS
Large weight symmetry	106 ± 10	104 ± 8.4	102 ± 10	100 ± 12	NS

*SCBA=self-contained breathing apparatus; **P=probability; ***NS=not significant ($p > 0.05$)

Table 6. Mean ± standard deviation of the adaptation test (ADT) (Number of subjects = 15)

Parameter	Baseline	Half-mask	Full-face	SCBA*	*P***
Toes up	57 ± 11	62 ± 17	60 ± 14	61 ± 15	NS***
Toes down	47 ± 9.3	48 ± 13	49 ± 8.1	48 ± 5.7	NS

*SCBA=self-contained breathing apparatus; **P=probability; ***NS=not significant ($p > 0.05$)

translations indicated no differences in the subjects' ability to respond to an unexpected perturbation across the no-respirator and three respirator conditions. These data suggested that the respirator had no adverse affect on the automatic postural responses used by the subjects to respond to an unexpected perturbation. These results are not unexpected since the translations are primarily triggered by the somatosensory inputs, which were not affected by use of the respirator. These findings are in conflict with the contention made by Seliga et al. [9] who suggested that the increased sway while wearing a respirator, following exercise, was related to workload induced proprioceptive fatigue. The weight symmetry scores also indicated no significant differences across the four experimental conditions, suggesting no disruption in weight distribution on both lower extremities.

Adaptation Test (ADT)

The results of the toes up and toes down ADT are presented in Table 6. The results of the mean toes up sway energy scores across the four experimental conditions indicated no significant difference in the mean scores across the four conditions. Similar results were observed during the toes down condition.

The adaptation test resulted in the ankles moving quickly and unexpectedly into extreme ankle dorsiflexion (toes up condition) and plantarflexion (toes down condition). This type of situation may occur when a worker is standing or walking on uneven terrain. The results of this study suggest that, since there were no differences in the toes up and toes down scores across the four experimental conditions, a worker's ability to stand or walk on uneven surfaces is not affected by the use of the respirator.

Perception of Comfort Survey

The results of the subjects' perceived comfort while wearing the three types of respirators are presented in Table 7. Only the percentage of responses in agreement (including agree and strongly agree) are presented in this table.

The results of the Fisher's Exact Test indicated that the full-face and SCBA were perceived to be more difficult to wear than the half-mask respirator. The SCBA was perceived to be significantly heavy and affected ease of movement significantly more than the half-mask respirator. The SCBA was also perceived to be significantly heavier than the full-face respirator. No significant differences were observed between the conditions of comfort, ease of breathing, difficulty balancing, effecting vision, skin/body irritation, pressure on the body or disorientation.

The results of the perception of comfort survey are consistent with previous studies in which, depending on their level of training and the conditions of the work environment, 25 to 60% of workers did not accept their respirator as comfortable or acceptable [3-4]. The subjects in this study perceived the SCBA as being too heavy, hard to wear and affecting the ability to move, relative to the half-mask respirators and full-face respirators. These findings are consistent with those of Seliga et al. [9] who found that perceived exertion was higher while wearing a respirator than without a respirator. Consistent with the objective data obtained from the Equitest, the subjects did not perceive respirator usage to have any significant adverse affect on their ability to maintain balance.

Table 7. Summary results of "Perceived Comfort Questionnaire" showing percentage of subjects agreeing and strongly agreeing with the statement (Number of subjects = 15)

Statement	Respirator		
	Half-mask	Full-face	SCBA
Is uncomfortable	60	60	67
Thinks respirator is too heavy	13	20**	67***
Feels respirator is hard to wear	0*	40	53***
Cannot breath easily with respirator on	47	67	40
Cannot move easily with respirator on	0	13	27***
Has difficulty balancing with respirator on	0	0	20
Feels respirator limits vision	27	27	33
Believes respirator irritates skin/body	33	20	20
Feels respirator puts pressure on body	27	33	40
Feels disoriented with respirator on	7	27	20

* Half- mask is significantly ($p \leq 0.05$) different from full-face; ** Full-face is significantly ($p \leq 0.05$) different from SCBA (self-contained breathing apparatus); *** SCBA is significantly ($p \leq 0.05$) different from half-mask

Overall, the preceding results suggest that the use of the half-mask respirator, full-face respirator and SCBA had no significant impact on the subjects' abilities to utilize their visual, vestibular and somatosensory inputs over the baseline (no-respirator) condition. In addition, use of the respirators had no significant effect on the subjects' ability to use the automatic postural responses to linear forward and backward support surface perturbations or perturbations causing ankle rotations. The perception survey however, indicated that the subjects perceived the SCBA to be more difficult to wear than the other three conditions.

Although differences in postural stability were initially anticipated, there may be several explanations for the lack of any significant differences between the respirator and no-respirator conditions. The subjects in this study were healthy younger (mean = 32.3 years) volunteers who might have had sufficient balance reserve to be physically capable of compensating for the alterations and/or lack of their sensory and motor inputs induced by the testing procedures while wearing each of the different types of respirators. Normal aging has shown to cause changes in the visual, vestibular, and somatosensory systems as well as changes in motor responses. Associated increases in postural sway have also been observed [17]. As a result, it could be suggested older or less healthy workers may exhibit greater impairments in postural control when respirators are applied.

This study did not examine the effect of work-shoes on the subjects' postural stability. Since proprioceptive inputs tend to be the dominant input utilized by most individuals for postural stability [18], the lack of a respirator effect may have been attributed to the subjects being tested in bare feet and consequently allowing them to use this input when visual inputs were degraded. The effect of a fatiguing job task on the workers postural stability was not addressed either.

CONCLUSIONS

Half-mask respirators, full-face respirators or SCBA did not produce any differences in postural stability over a baseline (no-respirator) in this group of healthy subjects. The data do, however, indicate that the subjects expressed concerns with comfort and perceived postural stability.

ACKNOWLEDGMENTS

The authors' appreciation is extended to Sadik A. Khuder, Ph.D. for assisting in statistical analysis, to the subjects for their participation in this study and to Mahboubeh Akbar-Khanzadeh, MSOH, for her help with manuscript preparation. The authors declare that there is no conflict of interest.

REFERENCES

1. LaBar G, OSHA plans updates of PPE rules. *Occupational Hazards* 1990 (June); pp 51-53.
2. Morgan W. Psychological problems associated with the wearing of industrial respirators. *Am Ind Hyg Assoc J* 1983; 44:671-676**.**
3. Akbar-Khanzadeh F, Bisesi MS, Rivas RD. Comfort of personal protective equipment. *Applied Ergonomics* 1995; 26:195-198.
4. Akbar-Khanzadeh F. Factors contributing to discomfort or dissatisfaction as a result of wearing personal protective equipment. *Journal of Human Ergology* 1998; 27:70-75.
5. Zimmerman NJ, Eberts C, Salvendy G, McCabe G. Effects of respirators on performance of physical, psychomotor and cognitive tasks. *Ergonomics* 1991; 34:321-334.
6. Louhevaara V, Smolander J, Tuomi T, Korhonen O, Jaakkola J. Effects of an SCBA on breathing pattern, gas exchange, and heart rate during exercise. *J Occup Med* 1985; 27:213-216.
7. White MK, Hodous TK, Hudnall JB. Physiological and subjective responses to working in disposable protective coveralls and respirators commonly used by the asbestos abatement industry. *Am Ind Hyg Assoc J* 1989; 50:313-319.
8. Wilson JR, Raven PB, Zinkgraf SA, Morgan WP, Jackson AW. Alterations in physiological and perceptual variables during exhaustive endurance work while wearing a pressure-demand respirator. *Am Ind Hyg Assoc J* 1989; 50:139-146.
9. Seliga R, Bhattacharya A, Succop P, Wickstrom R, Smith D, Willeke K. Effects of workload and respirator wear on postural stability, heart rate, and perceived exertion. *Am Ind Hyg Assoc J* 1991; 52:417-422.
10. Caretti D, Bay-Hansen LA, Kuhlmann WD. Cognitive performance during respirator wear in the absence of other stressors. *Am Ind Hyg Assoc J* 1995; 56:776-781.
11. Shumway-Cook A, Horak FB. Assessing the influence of sensory interaction of balance. *Physical Therapy* 1986; 66:1548-1550.
12. Horak FB, Clinical measurement of postural control. *Physical Therapy* 1987; 67:1881-1885.
13. Nashner LW. Neurophysiology of the balance system and dynamic platform posturography. In: *Dizziness and balance disorders*. I K Arenberg (ed). Kugler Publications, New York 1993; pp 363-375.
14. Horak FB, Nashner LW. Central programming of postural movements: adaptation to altered support-surface configurations. *J Neurophysiology* 1986; 55:1369-1381.
15. Equitest System (Version 4.0) *Data Interpretation Manual*. NeuroCom International Inc. 1991.
16. Mirka A, Black FO. Clinical application of dynamic posturography for evaluating sensory integration and vestibular dysfunction. *Neurologic Clinics* 1990; 8:351-359.
17. Cohen H, Heaton LG, Congdon SL, Jenkins HA. Changes in sensory organization test scores with age. *Age and Ageing* 1996; 25:29-44.
18. Diener HC, Dichgans J, Guschlbauer B, Bauer M. Role of visual and static vestibular influences on dynamic posture control. *Human Neurobiology* 1986; 5:105-113.