CDC
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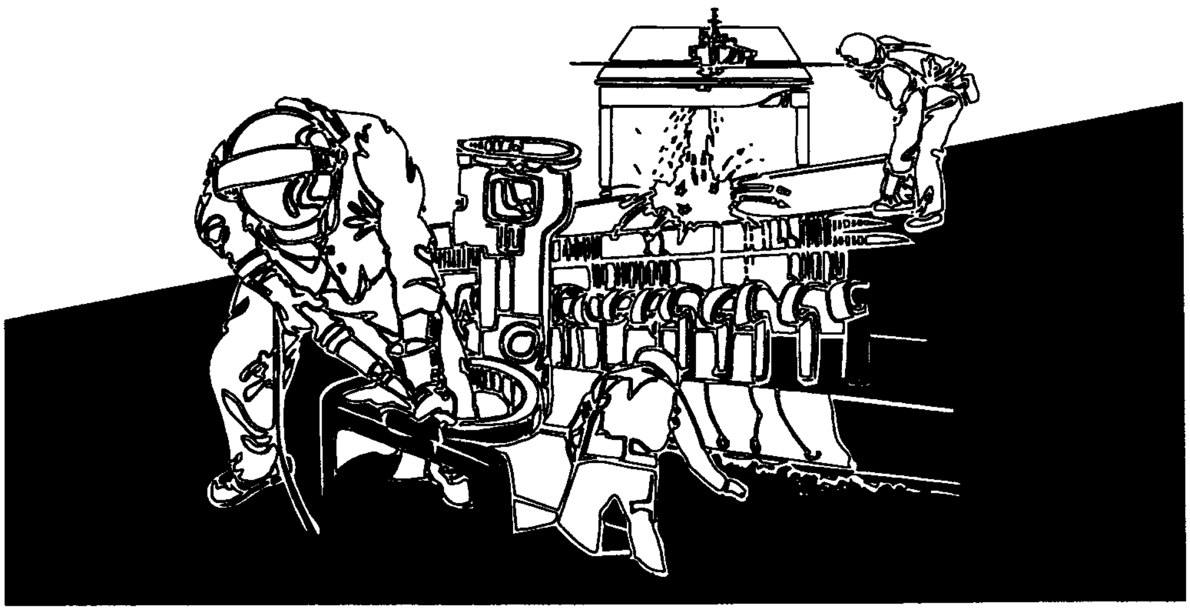
NIOSH HEALTH HAZARD EVALUATION REPORT

HETA 93-0805-2387
UNICCO
HARTFORD, CONNECTICUT



U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

PREFACE

The Hazard Evaluations and Technical Assistance Branch of NIOSH conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer and authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, medical, nursing, and industrial hygiene technical and consultative assistance (TA) to Federal, State, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

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SUMMARY

The National Institute for Occupational Safety and Health (NIOSH) received a request for a Health Hazard Evaluation (HHE) on March 22, 1993, from the Service Employees International Union (SEIU) regarding the use of a back-pack vacuum cleaner (BPVC) among employees of the UNICCO Service Company at the Travelers' Insurance complex in Hartford, Connecticut.

SEIU members have expressed concerns about BPVC use in a number of locations throughout the country, including the Travelers' Insurance complex, a series of office buildings consisting of standard, modern office space. These concerns have centered around perceived health effects of BPVC use, including musculoskeletal (primarily shoulder and back) problems, noise, heat, and vibration.

On May 12, 1993, the NIOSH investigator conducted a walk-through inspection of typical work areas in the Travelers' Insurance complex, viewed and videotaped a demonstration of BPVC use by two UNICCO employees in simulated offices, and interviewed three UNICCO employees concerning work practices and symptoms. Laboratory analysis of the BPVC, including a biomechanical assessment, and measurements of vibration, heat, and noise, was performed by NIOSH personnel. The three workers interviewed reported similar problems with the BPVC. These complaints consisted primarily of musculoskeletal (especially shoulder and back) discomfort and the sensation of excessive heat associated with the BPVC. Laboratory analysis revealed increased biomechanical stress and heat in a person wearing the BPVC compared to a person not wearing the BPVC. Noise and vibration were within recommended exposure limits. We were unable to determine the health risk posed by the combined effects of the various stressors.

NIOSH investigators found a number of complaints associated with the use of back-pack vacuum cleaners. Laboratory analysis of the vacuum cleaner revealed biomechanical stress and heat exposure; noise and vibration were within recommended exposure limits. We were unable, however, to determine the health risk posed by the combined effects of the various stressors.

KEYWORDS: SIC 7349 (janitorial services), back-pack vacuum cleaners, ergonomics, biomechanical stress, vibration, heat, noise

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) received a request for a Health Hazard Evaluation (HHE) on March 22, 1993, from the Service Employees International Union (SEIU) regarding the use of a back-pack vacuum cleaner (BPVC) among employees of the UNICCO Service Company working at the Travelers' Insurance complex in Hartford, Connecticut. On May 12, 1993, NIOSH conducted a site visit to meet with SEIU, UNICCO, and BPVC manufacturer representatives, and to view and videotape the use of the BPVC. Subsequently, a BPVC (Pro-Team Inc.'s Quarter-Vac™) was analyzed by NIOSH personnel in Cincinnati for biomechanical stress, vibration, heat, and noise incident to its use. This report provides the final results of our assessment of the BPVC in use by UNICCO employees at the Travelers' Insurance complex.

BACKGROUND

Facility Description

The Travelers' Insurance Corporate complex is a typical modern high-rise office building. The interior space is divided into individual offices by temporary dividers. There are formal conference rooms on most floors. Standard modern office equipment (e.g., desks, personal computers, copiers) is located on each floor.

Process Description

Employees of contract cleaning companies typically begin their workday after the offices are closed and work for approximately eight hours. The workers are responsible for a variety of tasks, including vacuuming the floors, emptying waste baskets, and removing trash. Over the past several years, the BPVC has become increasingly popular among contract cleaning companies, expanding from its original use in confined spaces such as aircraft. The BPVC typically is used 8 hours per night, 4 days per week. It is used to clean especially dirty areas throughout the office building. Workers vacuum under desks and tables, which requires periods of forward bending, as shown in figure 6. They also vacuum stretches of open hallway; this is performed in the upright position. The BPVC is plugged into a wall socket via a long extension cord which the workers bend to plug, unplug, and coil several times per shift. Workers report having two scheduled breaks during which they remove the vacuum cleaner; they also report removing the vacuum cleaner an average of once per hour (for several minutes) to rest their backs and to get a break from the heat. Reportedly, the vacuum does not become appreciably heavier as it fills with dirt; workers empty the unit an average of twice per night.

EVALUATION PROCEDURES

Ergonomic

Biomechanical Assessment
Biomechanical evaluation provides a method for predicting the magnitude of muscle, ligament, and joint forces developed within the body as a result of external loads or gravitational forces.

A biomechanical analysis was performed to identify and quantify the physical loading of the spine due to the use of a BPVC. Figure 1 shows the BPVC with approximate dimensions. To simplify the evaluation, a static, two-dimensional analysis of an average male worker was used to estimate the amount of additional loading imposed on the spine, back, and abdominal and back muscles as a result of wearing the vacuum cleaner. The biomechanical assessment evaluated two different postures, upright standing and 85 degrees of forward flexion, which were postures observed during the site visit. The cleaner weighed 15 pounds when the bag was full with typical dust and dirt. For computational purposes, the worker height and weight were assumed to be 68.7 inches and 165 pounds (i.e., average US male). Input for the biomechanical analysis consisted of estimates of body geometry and weight distribution and of BPVC geometry and weight distribution relative to the worker.

The first step of the analysis consisted of isolating the upper portion of the body with a horizontal plane passing through the L5/S1 intervertebral joint (i.e., joint between the fifth lumbar and first sacral vertebral bodies). A sketch of this isolated section is shown in figure 2, where W_T represents weight of the upper torso, head, and arms at the center of gravity of this body section; W_V represents the weight of the BPVC at the center of gravity of the cleaner; F_B represents the back extensor muscle force; F_A represents the abdominal flexor muscle force; and a triangle (Δ) represents the inter-vertebral joint between the fifth lumbar (L5) vertebral segment and first sacral vertebral segment (S1) (labeled L5/S1). The triangle symbolizes a fulcrum for a simple lever system. The forces W_T and W_V created moments (i.e., the rotational tendency caused by application of a perpendicular force on a lever arm at some distance from its axis of rotation) about the fulcrum. These moments were balanced by the muscle forces, F_A and F_B, and equilibrium was achieved. All of these forces resulted in an upward reaction force (R) at the fulcrum. The reaction force, R, represents the axial compression force on the L5/S1 intervertebral disc. (If the muscle force or compressive force is too high, the musculoskeletal tissues may be damaged and result in back discomfort, pain, or even injury.)

To simplify the analysis, free-body diagrams were developed and are shown in figures 3-5, 7 and 8. Free-body diagrams enhance the visualization of the biomechanical effects of postural changes and external loads. Based on these diagrams, mechanical equations were developed and solved to find the unknown muscle forces (F_B and F_A) and the reaction force (R). According to the laws of static equilibrium, the sum of the moments and forces must be equal to zero. Since the weights and distances were known, the muscle forces and compressive force at the fulcrum needed to maintain static equilibrium (i.e., no body movement) were calculated for each posture.

Vibration

We used an accelerometer to measure vibration in the back pack. No standards exist for local (i.e., non-whole-body) vibration. The subjects were assumed to be exposed to whole-body vibration, although not in the purest form. This was considered a reasonable conjecture since a large portion of the back was exposed to the vibration and the conditions more closely resembled whole-body vibration than segmental vibration.

In order to evaluate the potential adverse health effects due to BPVC vibration exposure, the magnitude of vibrational accelerations was measured across a spectrum of frequencies for a worker wearing the BPVC. Two types of measurements were made. The first type collected vibration data on the BPVC near the location where the device contacts the lower back. The second type measured the amount of vibration at the interface of the worker and the BPVC.

For the first set of measurements, three accelerometers were attached in an orthogonal arrangement to the support bushing near the base of the vacuum cleaner. These accelerometers collected data in all three directions. The coordinate system and accelerometer placement are shown in figure 9. Two subjects were tested in three different postures. The subjects stood erect with back at 0 (v), 45 (f), and 90 (n) degrees to the Z axis.

For the second set of measurements, a flat, rubberized, tri-axial accelerometer was positioned directly between the BPVC's hard, plastic harness plate and the subject's back. The accelerometer measured the amplitude and frequency of the vibration that was transferred between the worker and the vacuum. For this evaluation, one subject was tested in three different pos-tures, standing erect with the back at 0, flexed forward at 45 degrees, and flexed forward at 90 degrees to the Z axis. These postures simulated the full range of motion during typical working conditions.

Thermal

To assess the potential effects of heat buildup from the BPVC, an analysis was performed to determine if the BPVC significantly increased the temperature of the skin of a worker wearing the BPVC. This analysis consisted of attaching a thin, thermal skin sensor to the subject's back beneath the BPVC to record skin temperature. The experiment consisted of recording the temperature of the skin every 5 minutes for a 1-hour period after the BPVC was turned on. The measurements were made with a Yellow Springs Tele-thermometer (Model 43TA) with the subject in a quiet, sitting posture. The room temperature was approximately 73°F.

Noise
Sound measurements were performed on the BPVC to evaluate possible noise hazards to workers during operation of the BPVC. The test consisted of placing the BPVC on a mannequin in a sound-proof room and attaching a microphone to the right ear of the mannequin. Measurements were made for three conditions: (1) motor off (i.e., background); (2) motor on with the suction tube open; and (3) motor on with the suction tube blocked.

Medical
The NIOSH investigator watched and videotaped two employees using the BPVC in simulated offices. Three employees were interviewed; questionnaires designed and distributed by SEIU and returned by eight employees were reviewed.

RESULTS AND DISCUSSION

Ergonomic

Biomechanical
The free-body diagram shown in figure 3 describes the loading condition for an average male worker in an upright posture not wearing the BPVC. In this case, the weight of the trunk (W_T) was balanced over the fulcrum and the moment arm (l1) was approximately zero, which resulted in no moment. Thus, the flexor and extensor muscle and reaction forces were minimized, such that F_A and F_B were approximately equal to zero, and R was equal to W_T or 59 pounds.

Compare the loading condition in figure 3 (upright posture without BPVC) to that shown in figure 4 (upright posture with BPVC). In the case depicted in figure 4, the weight of the BPVC (W_V) was located behind the fulcrum at a distance of l3 inches, which created a positive moment that was balanced by an opposing negative moment created by the abdominal flexor muscle force, F_A. Assuming that both the BPVC moment arm (l3) and the abdominal muscle moment arm (l2) were 7 inches, the abdominal muscle force for static equilibrium was calculated to be 15 pounds. The resultant loading force (R) for this condition was equal to the sum of the applied forces $W_T + W_V + F_A$ (59 + 15 + 15), or 89 pounds. This represented a 50% increase in the compression force due to the BPVC.

We observed that the loading condition described in figure 4 will generally not occur because a person typically will lean forward slightly when something heavy is placed on the back. This slight forward lean is used to balance the load and minimize the internal forces. This is clearly shown in figure 5, which depicts a worker flexed forward slightly with the BPVC. In order to balance the positive moment created by the BPVC, the worker flexes forward about 6.5 degrees to utilize the negative moment created by the weight of the trunk (W_T). In this posture, the muscle forces and the reaction force were reduced to 0 and 74 pounds (the sum $W_T + W_V$), respectively. In this posture, the resulting increase in compression force due to the BPVC was only about 25% greater than without the BPVC. This posture would be preferred by the worker because less energy would be expended due to the limited muscle force requirements and the disc-compression force is minimized. Although the muscle and reaction forces were minimized by this continuous forward flexion, other biomechanical factors, such as ligament strain or joint misalignment, may be increased. These factors may not be readily perceived by the worker and may increase a worker's risk of musculoskeletal injury. For example, in other industries, repetitive forward bending has been shown to increase the risk of low-back pain for workers.[1]

The worker shown in figure 6 illustrates a posture of extreme forward flexion often used while wearing the BPVC. Figures 7 and 8 describe the loading conditions for two cases of extreme forward flexion. Figure 7 depicts an 85 degree forward-flexion posture while not wearing the BPVC, and figure 8 depicts an 85 degree forward-flexion posture while wearing the BPVC. For the condition in figure 7, the estimated extensor muscle force was 269 pounds and the disc compression force was 294 pounds. When the BPVC was added, the estimated extensor muscle force (F_B) was increased to 330 pounds. The compressive component of the reaction force was increased to 336 pounds, which represented a 23% increase in muscle force and a 14% increase in disc-compression force. While the absolute magnitudes of the muscle forces and disc-compression force values did not necessarily indicate a high risk of low back injury, the relative increases in their magnitudes clearly demonstrated that muscular loading was increased, which could result in fatigued or strained muscles. Moreover, regardless of the magnitude of the reaction forces, increased repetitive loading to the joint surfaces due to the BPVC may increase the risk of a cumulative injury to the spine.

A summary of the results of the biomechanical analysis is presented in table 1.

Vibration
Results are shown in tables 2 and 3. Exposure to whole-body vibration has been associated with such health effects as headaches, fatigue, lack of concentration, and gastrointestinal disturbances.[2] In addition, exposure to whole-body vibration over a number of years may result in low-back pain.[3]

The sensitivity of the human body to the whole-body vibration depends on the frequency and direction of the exposure. To determine the potential health risks associated with these vibration levels, the actual data must be frequency weighted using weighting filter curves to approximate the effective acceleration levels. The International Standards Organization (ISO) has devised frequency weighting curves for both lateral and longitudinal whole-body vibration.[4,5] Refer to figure 10 for the curves used in this study. After adjusting the results of table 3 according to the ISO curves, the peak vector sum of the acceleration components for the ranges of 0.7-5 Hz and 5-20 Hz are 0.04 and 0.12 m/sec^2, respectively. According to the ISO Dose System for Whole Body Vibration, the "fatigue-decreased" exposure limit for the BPVC vibration is determined to be 24 hours.[5] It should be noted, however, that the "reduced comfort" exposure limit is less than 24 hours. Analysis of these results seem to suggest that vibration alone does not represent a health risk, but could result in discomfort to the worker.

Thermal
The results of the evaluation are displayed graphically in figure 11. The starting temperature was 93.5°F and the final temperature was 95.0°F. Although there was only a slight increase in temperature during the 1-hour period, when the subject was asked about his perception of the temperature, he indicated that the BPVC "felt warm."

Noise
None of the sound measurements exceeded 80 db, which is considered safe for exposures up to 32 hours.[6]

Medical
The three workers interviewed reported musculoskeletal discomfort in the neck, shoulder, upper and lower back which they related to the use of the BPVC. Two of the three workers interviewed stated that the BPVC caused their mid-backs to become hot and to perspire heavily. One of the workers stated that the vibration of the BPVC was uncomfortable, especially in the shoulders and lower back.

The workers surveyed by SEIU reported headaches, earaches, back pain and strain, joint pain, and "kidney problems."

The workers seemed to be uncertain about the proper use of the vacuum; the video taken showed that the workers were unaware of the proper wearing and adjustment of the unit. Many reported receiving little or no training in its use.

CONCLUSIONS

The workers had a number of complaints related to the BPVC, including musculoskeletal pain and discomfort, excessive heat, excessive vibration, and excessive noise. These complaints were expressed by the workers interviewed by NIOSH as well as by those polled by SEIU. Laboratory evaluation of the BPVC revealed potential physiologic bases for these complaints. For example, depending on the posture of the worker wearing the BPVC, the BPVC may cause a 14%-50% increase in the vertebral-disc compression force, compared to that in a worker in the same position without the BPVC. Additionally, in order to compensate for the added weight of the BPVC, workers must adopt an awkward posture while wearing the BPVC. Despite this, the NIOSH investigators could identify no health hazard based on any of the factors observed (posture, motion) or measured (weight, heat, vibration, noise). That is, the measured exposures did not exceed any published standard nor is it apparent that BPVC use would lead to such health outcomes as disc herniation, nerve damage, or hearing loss. However, these factors (particularly biomechanical stress, vibration, and heat) may interact to create a situation more hazardous than any individual factor acting alone. In addition, these stressors may contribute to increased job dissatisfaction even in the absence of a clear health hazard.

The introduction of new equipment or new technologies into the workplace should create a healthier environment for the workers or at least create no new hazards. At this point, it is unclear whether the BPVC represents a hazard. However, given the number and type of worker complaints related to the BPVC, careful evaluation, by the workers and management, of this equipment and the reasons for its introduction into a given workplace is warranted. In those workplaces in which the BPVC is in use or being considered, following these two recommendations may reduce the number of complaints associated with its use:

a.) Train the workers in the proper use of BPVC. Periodically monitor its use and fit, as well as workers' health complaints and comfort, to ensure continued proper use.

b.) Allow the workers some flexibility in choosing the appropriate equipment for the task. One worker reported a number of difficulties using the BPVC in a confined space. These difficulties resolved when an upright unit was used.

REFERENCES

1. Snook SH, Campanelli RA, Hart JW. A study of three preventive approaches to low-back injury. Journal of Occupational Medicine. 1978;20(7):478-481.

2. Taylor W, Wasserman DE. Occupational vibration. Chapter 21. In: Zenz C, ed. Occupational Medicine Principals and Practical Applications. 2nd ed. Chicago: Year Book Medical Publishers, Inc, p. 326, 1988.

3. Hulshof C. Whole-body vibration and low-back pain. A review of epidemiologic studies. Int Arch Occup Environ Health. 1987;59:205-220.

4. International Standards Organization Draft Proposal 5349. Guide for the measurement and evaluation of human exposure to vibration transmitted to the hand, 1980.

5. International Standards Organization ISO 2631-1978. Guide for the evaluation of human exposure to whole-body vibration, 1978.

6. Berger EH, Ward WD, Morrill JC, and Royster LH eds. Noise & Hearing Conservation Manual. American Industrial Hygiene Association, pp. 546-547, 1988.

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1. SEIU
2. UNICCO
3. Pro-Team
4. OSHA Region I

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Table 1 *Summary Results of Biomechanical Analysis*

Loading Condition	Muscle Force (lbs)	Disc Compression (lbs)
Upright/No BPVC	0	59
Upright/With BPVC	15	89
6.5° Flex/With BPVC	0	74
85° Flex/No BPVC	269	294
85° Flex/With BPVG	330	336

***Table 2** Measurement of Average Direct Vibration (M/sec^2)*

Freq (Hz)	x	y	z
0-5	0.100	0.491	0.098
120	0.001	6.704	0.006
167 or 193	0.003	-	-

***Table 3** Measurement of Average Indirect Vibration (M/sec^2)*

Condition	Frequency (Hz)/ Direction					
	.7-5			5-20		
	Direction			Direction		
	x	y	z	x	y	z
Standing	.006	.010	.006	.058	.096	.108
45° Flexion	.023	.006	.030	.102	.122	.120
90° Flexion	.008	.017	.007	.126	.143	.137
Working	.018	.007	.010	.132	.110	.269

***Figure 1** Sketch of the BPVC showing the approximate dimensions.*

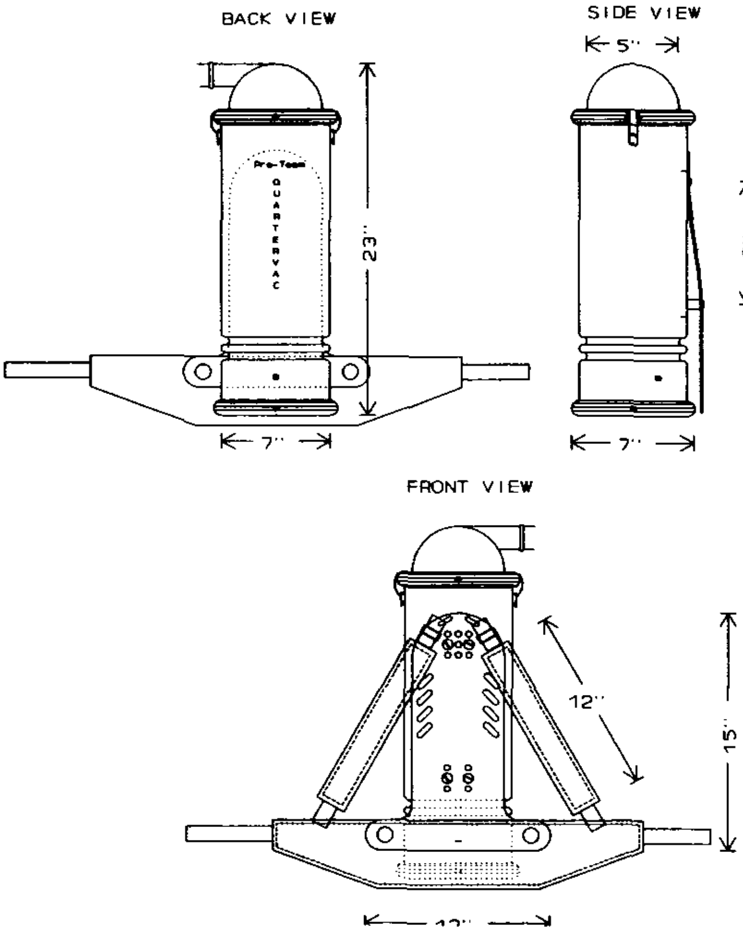

***Figure 2** Sketch of horizontal cut through the L5/S1 intervertebral joint showing internal and external biomechanical forces.*

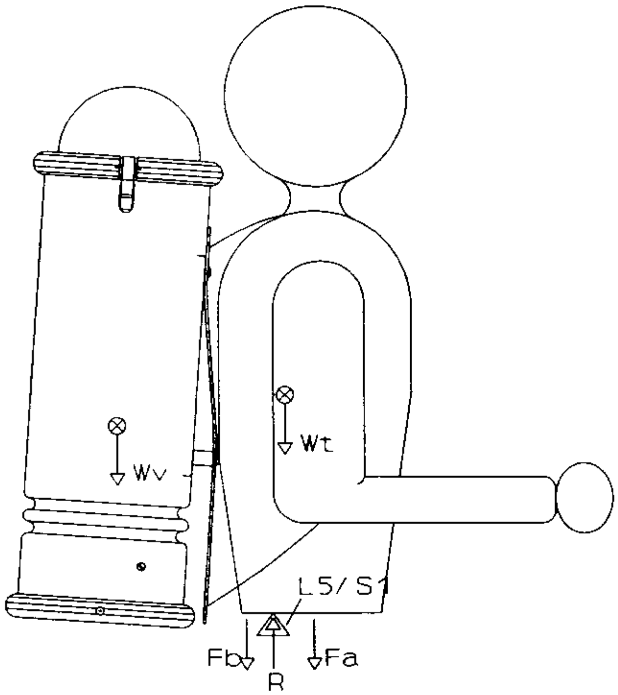

Figure 3 *Free body diagram describing upright posture without BPVC.*

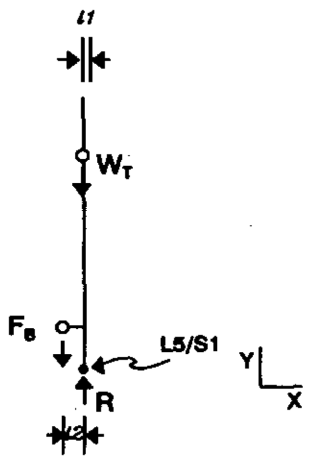

Figure 4 *Free body diagram describing upright posture with BPVC*

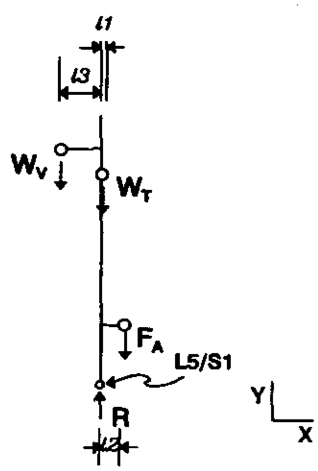

Figure 5 *Free body diagram describing 6.5 degree forward flexion adjustment in posture to compensate for BPVC.*

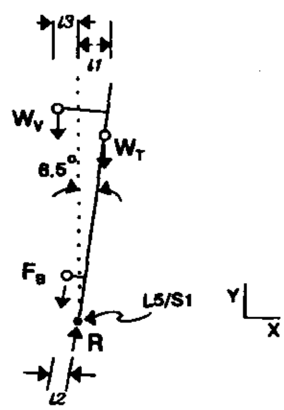

***Figure 6** Video image of worker wearing the BPVC.*

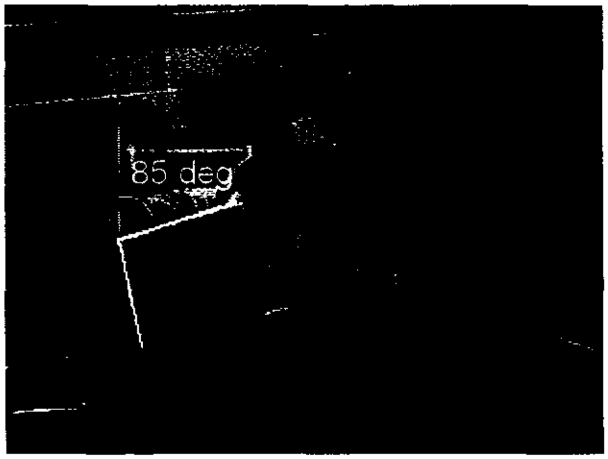

Figure 7 *Free body diagram describing 85 degrees of forward flexion without BPVC.*

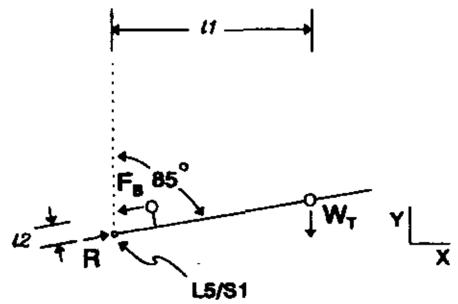

Figure 8 *Free body diagram describing 85 degree forward flexion with BPVC.*