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Case Studies

An Ergonomic Evaluation of Snowmobiles

Dawn Tharr, Column Editor

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The National Institute for Occupational Safety and Health (NIOSH) received a request from a Senior Industrial Hygienist at the Occupational Safety and Health Administration (OSHA) for assistance in conducting an ergonomic evaluation of snowmobiles used by National Park Service (NPS) personnel. The NPS personnel, mainly rangers and maintenance workers, reported musculoskeletal disorders of the hands, arms, shoulders, and back from riding the snowmobiles for up to 10 hours per day during the winter months. A NIOSH ergonomics specialist, a medical officer, and a neurobehavioral psychologist conducted an evaluation of the ergonomic aspects of snowmobiles, and health effects of NPS personnel who routinely use them. Twenty-six NPS personnel were evaluated during the study. Two NIOSH investigators evaluated the vibration and impact accelerations for NPS personnel who used snowmobiles during the course of their work.

Background

The NPS, part of the Department of the Interior, has jurisdiction over the national parks in the United States. In recent years, national parks have experienced increasing costs due to injuries and illnesses of park personnel. The NPS requested assistance from OSHA to reduce these costs. Soon after the request for assistance, OSHA compliance officers inspected one of the national parks and found numerous violations of OSHA standards. The NPS agreed to abate the OSHA violations and entered into a three-year partnership with OSHA to develop a comprehensive safety and health program. The NPS indicated concern regarding several ergonomic issues, most notably the injuries and musculoskeletal disorders experienced by the personnel who use snowmobiles to patrol and maintain the park during the winter months.

During 1999, about 76,000 snowmobiles entered the park entrance. The large volume of snowmobiles in the park transforms the road surfaces from a smooth layer of packed snow to a path composed of “washboard” bumps and moguls. Having to patrol these roads for up to 10 hours per day during the entire winter season results in the park rangers and maintenance personnel experiencing trauma to their bodies while performing their jobs. Although the trails are groomed every evening, the volume of traffic (sometimes three times what the roads can adequately handle) often deteriorates the roads to unsafe conditions during the snowmobiling day.

During the winter of 1999–2000, the park employed 68 rangers, two biologists, and approximately 175 permanent maintenance staff.

The NPS personnel used three models of Polaris snowmobiles, powered by two-stroke gasoline engines: 1) the Trail 10, 2) the Trail Touring, and 3) the Widetrak LX. Each was equipped with a standard banana-shaped seat with an adjustable seat back, a windshield, and a steering bar similar to that found on a typical bicycle or motorcycle. The throttle (gas bar) control was located on the right side of the steering bar and was controlled by a thumb-activated lever ($2^1/_2$ inches long) mounted on a grip $4^1/_4$ inches long and $1^1/_{16}$ inches in diameter. The angle between the handgrip and the throttle lever was about 60 degrees. The brake, located on the left side of the steering bar, had the same grip as the throttle control, but was activated by the four fingers of the hand instead of the thumb. The hand grips on the steering bar were heated for the comfort of the snowmobile operator.

Methods

Ergonomics

The ergonomics evaluation included measuring the dimensions and adjustability ranges of the major components of the snowmobiles (e.g., the seat, steering bar, handle grip, and throttle), and measuring the amount of force needed to depress the throttle. The physical measurements of the snowmobiles were compared to those described in a study of Norwegian workers who used snowmobiles to herd reindeer.[1] The author of this study evaluated a number of snowmobile types and formulated dimensional and adjustability features that were believed to decrease health risks associated with snowmobile driving.

The throttle forces were measured at the half-way and fully depressed positions at mid-trigger and at the tip of the trigger with a Wagner Model FDV-50 push-pull force meter. The force measures were made on the three models of Polaris snowmobiles commonly used in the park.

Photographs and videotapes were taken of some of the rangers while they were positioned on their snowmobiles, so that upper and lower extremity postures could be measured and evaluated. The rangers also described some of the postural adjustments that they typically make to adapt to the varying conditions they encounter while performing their jobs.

Coordination/tremor tests. The coordination tests that were administered were the CATSYS 6.0.[2] These tests were selected because the safe operation of snowmobiles requires normal coordination ability. For physically demanding tasks, the coordination tests can provide a measure of fatigue if the test scores decrease by 10 to 15 percent over the course of a normal workday.

The automated battery consisted of five tests: 1) rhythmic test, right and left hand supination/pronation, slow and fast; 2) rhythmic test, right and left index finger tap, slow and fast; 3) maximum frequency, hand supination/pronation; 4) maximum frequency, finger tap; and 5) simple reaction time. The rhythmic tests required the participants to tap a circular pad (4-inch diameter) in time with a steady metronome beat (1.0 Hertz [Hz] slow test, 2.5 Hz fast test), either alternating palm side of hand to back of hand (supination/pronation), or tapping with the index finger.

The maximum frequency tests required participants to tap the pad in the same manner in time with a metronome beat that increased in frequency from 1.6 Hz to 8.1 Hz. The simple reaction time test required participants to press a handheld switch with the thumb at the sound of the metronome, which occurred randomly. The rhythmic slow tests lasted for 20 seconds; the fast tests for 10 seconds. The maximum frequency tests lasted for 12 seconds, and the reaction time tests lasted for 40 seconds.

At the end of the test administration, a numerical coordination index is calculated, which can be compared to the normal coordination index (CI) range provided with the test battery documentation. The normal CI score for the tests used is 100; scores less than 80 are one standard deviation (SD) below the mean, and scores less than 60 are two SDs below the normal mean. In addition, individual scores for two measurements — maximum frequency and reaction time — were retained for analysis using the current day's snowmobile use (hours), and lifetime use of snowmobiles (years), to determine if there was any association between exposure (snowmobile use) and coordination ability.

Test administration was fully automated. Participants were seated across from the test administrator with the test apparatus placed in front of them. Metronome sounds were delivered through earpiece sound devices. After demonstrating the tests, the administrator ran two practice trials, one for the finger tap procedure and one for the supination/pronation procedure. Additional practice trials were run if a participant was having difficulty performing the test. Test administration took about 10 minutes.

A tremor test was also administered as part of the CATSYS battery. Although tremor tests are traditionally used for neurological evaluations and for evidence of neurotoxicity from chemical exposures, the test is also useful as a measure of physical fatigue. Prolonged physical exertion involving the arm/hand structure will result in increased physiological tremor of the forearm. Because snowmobile driving requires the arms to be outstretched to reach the handle bars, with considerable grip force required to control the snowmobile, a potential physical fatiguing condition exists for the driver. Tremor was recorded with a two-axis micro-accelerometer embedded in the tip of a 12-centimeter (cm) by 0.8-cm device called the tremor pen, which is shaped like a pencil.

The test was administered immediately after the coordination tests. Participants were instructed to sit with their backs erect and off the back rests of the chairs. They held the pens in front of them with the tip of the pen resting between the thumb and index finger, and the rear of the pen in the saddle formed by the thumb and index finger. The pen was held horizontally in line with the forearm away from the body, with the elbow flexed 90 degrees. The non-test arm was left hanging loosely. Testing was done with both the dominant and non-dominant hands.

Two tests were run during each session, with only the second test used for data analysis. Participants held the tremor pens for about 15 seconds, during which an 8-second sample was taken. Test sessions were administered prior to the work shift and immediately after the work shift to determine if there was any change in tremor from the day's work activities, which normally includes a considerable amount of snowmobile driving.

Four primary parameters calculated by the TREMOR 3.0 software were used for data analysis: 1) tremor intensity, often called amplitude or vibration power, calculated as the root-mean-square (RMS), measured in meters per second per second (m/s^2) of acceleration in the 0.9 to 15 Hz band during the 8-second test; 2) center frequency, which is the average frequency of acceleration in the test band, so that 50 percent of the energy that drives the tremor is produced at frequencies above the center frequency, and 50 percent is produced below; 3) tremor index, calculated for each hand from five parameters (tremor intensity, center frequency, standard deviation of the center frequency, harmonic index, and standard deviation of the harmonic index); and 4) combined index for both hands.

Vibrotactile sensitivity test. This test was selected to determine the effect of the hand-arm vibration produced by snowmobiles on vibration perception thresholds. Previous research found a significant relationship between vibration exposure (measured in hours) and increased vibration perception thresholds (i.e., impaired vibrotactile sense), starting with threshold changes (increases) at the higher frequencies and then spreading to the lower frequencies.[3] The study group included reindeer herders using snowmobiles who had a high lifetime exposure to vibration. Disturbances of the vibrotactile sense can indicate early signs of vibration-induced nerve injury.[4]

The test device used was the Brüel & Kjær Model 96-27 Vibrometry System. This fully automated system produces a mechanical stimulus (sinusoidal vibration) at a chosen frequency to the pulp of a finger tip; the participant indicates perception of the vibration by means of a handheld button similar to that used in a hearing test. The vibrometry system includes software that produces a tactilogram or vibrogram, which is similar to the audiogram used in hearing testing.

The tactilogram prints the expected normal values, which are included as part of the software package provided with the vibrometry system. A participant's result can be compared to these normal values. In effect, each participant serves as his/her own control. Tests were conducted before the work shift to determine the baseline vibrotactile sense for the participant and at the end of the work shift to determine if a threshold shift had occurred.

Participants were seated at a small table across from the test administrator. Before testing, the room temperature and the participant's finger temperature were measured. Finger temperatures of 28° celsius (C) are needed before testing can begin. Some participants held their hands in warm water to achieve the minimum finger temperature. The right middle finger and the right small finger, respectively, were tested to assess the median and ulnar nerves. The right hand was chosen because the throttle control on a snowmobile is located on the right grip handle. The software was configured to test vibration at four frequencies: 31.5 Hz, 125 Hz, 250 Hz, and 500 Hz.

Participants placed their right arm on an ascending armrest with the palm lying open on a circular pad, allowing the fingers to hang freely above the vibrating post. The test finger was then placed on the vibrating post with the finger slightly curved and resting lightly on the post. Participants controlled the intensity of vibration with the handheld button, tracking back and forth between levels of stimulus perception and non-perception. The perception threshold at each frequency was defined as the midpoint between the upper and lower difference thresholds (ΔDL), measured in decibels (dB) relative to 10^{-6} m/s^2. Headphones producing the sound of ocean waves were worn during testing to mask the vibrator and ambient noise.

Participants were tested prior to the work shift in the morning and immediately after the work shift in the afternoon. At the beginning of the morning session, two practice trials were administered to familiarize the participants with the test procedures. Practice trials were not repeated in the afternoon session. The middle finger was tested first, followed immediately by the little finger. Each test session lasted about 10 to 12 minutes.

In addition to the tactilogram produced by the software, the mean threshold and standard deviation values for each test at each frequency were retained for analysis. Standard reference values in the software were normalized for 30 years of age, so adjustments were made according to the criteria developed by Lundström.[5] For frequencies of 125, 250, and 500 Hz, reference means were increased by 0.3 dB/year for each year over 30, and by 0.1 dB/year for the 31.5 Hz frequency. Individual scores were retained for analysis using the current day's use of snowmobiles (in hours) and lifetime use of snowmobiles (in years) to determine if there was any association between snowmobile use and vibration sensitivity.

Whole-body vibration. The previously referenced Norwegian study evaluating reindeer herders who rode snowmobiles also measured the vertical vibration accelerations that these workers experienced while riding these machines.[1] At 40 miles per hour, the author measured peak accelerations of 50 m/s^2, approximately 5 g's. The article also states that peak loads exceeding 10 g's have been measured during snowmobile driving.

Whole-body vibration exposures were measured on park rangers who rode snowmobiles during their daily tours. These vibration acceleration data were collected with two Shock and Vibration Environmental Recorder (SAVER) units (Dallas Instruments, Monterey, CA). The recorders are self-contained and incorporate accelerometers, analog and digital circuitry, batteries, and data storage and readout. The units were rigidly bolted into a metal box that kept snow away from the recorders. The units recorded vibration levels from triaxial accelerometers in the X (side-to-side), Y (front-to-back), and Z (up-and-down) directions for a seated park ranger on a snowmobile. The unit was placed in the metal basket behind the seat cushion and firmly connected to the snowmobile with two hose clamps.

All of the measured snowmobiles were manufactured by Polaris. They included a 1998 model with a 488-cubic-centimeter (cc) engine and 10-inch suspension; a 1999 480-cc, 10-inch suspension model; and two 2000 models, one with a 550-cc engine and 10-inch suspension, and the other a 500-cc, 12-inch suspension model. Based on the data collected during a test run, the investigators decided to download data after four hours because the high number of shocks encountered by the park rangers filled the memory capacity of SAVER units long before the end of their work shift.

The SAVER units were set to record and store acceleration data on all three channels for four seconds after being triggered by a shock or jolt that exceeded 1 g, the acceleration of gravity (9.81 m/s^2). The three-channel unit could store 1,346 separate events.

Medical

The medical evaluation consisted of a confidential structured interview with each study participant. Demographic and job-specific information such as name, age, job title, job description, years of experience, work history, and work- and nonwork-related symptoms and health problems were collected during the interview.

Evaluation Criteria

Ergonomics

Overexertion injuries and musculoskeletal disorders such as low back pain, tendinitis, and carpal tunnel syndrome are often associated with job tasks that include 1) repetitive, stereotyped movement about the joints, 2) forceful manual exertions, 3) lifting, 4) awkward and/or static work postures, 5) direct pressure on nerves and soft tissues, 6) work in cold environments, or

7) exposure to whole-body or segmental vibration.[6–9] Specific to this study, there is evidence in the literature of risk of injury to the spine from the shock vibration of driving snowmobiles, particularly at high speeds.[10]

The risk of injury appears to increase as the intensity and duration of exposures to these factors increases and recovery time is reduced.[11] Although personal factors (e.g., age, gender, weight, fitness) may affect an individual's susceptibility to overexertion injuries/disorders, studies conducted in high-risk industries show that the risk associated with personal factors is small compared to that associated with occupational exposures.[12]

In all cases, the preferred method for preventing/controlling work-related musculoskeletal disorders (WMSDs) is to design jobs, work stations, tools, and other equipment to match the physiological, anatomical, and psychological characteristics and capabilities of the worker. Under these conditions, exposures to task factors considered potentially hazardous will be reduced or eliminated.

The criteria used to evaluate the ergonomic aspects of the snowmobiles were the joint angle and adjustability features recommended in the Norwegian study of different snowmobile types used to herd reindeer, and the force needed to depress the thumb-controlled accelerator. The peak acceleration levels reported in the Norwegian study were used as a comparison for the levels measured at this park.

Results

Ergonomics

Snowmobile measurements. Table I compares the component measurements and adjustability ranges of the park's Polaris snowmobiles to the guidelines for desirable component features and body joint angles developed by Tostrup as a result of his study of Norwegian reindeer herders. In general, the Polaris snowmobiles used by the NPS personnel had the features and adjustability to achieve the postures specified by the design criteria. One notable deficiency was in the throttle design of the Polaris snowmobile, which was thumb-controlled. Tostrup recommended a gas bar design that could be depressed by all fingers and placed on both sides of the steering bar. The Polaris steering bar could not typically be grasped with a neutral wrist posture. However, Tostrup made no mention of a seat back support, which was a fully adjustable feature of the NPS machines.

Throttle control forces. Table II shows the forces needed to depress the throttle on the three snowmobiles tested. Force measures were taken from two locations on the thumb lever (at the tip and at the middle), and at halfway depressed and fully depressed ($3^1/_2$ inches) positions.

The lowest forces occurred when depressing the throttle halfway and at the tip. As a safety measure, the throttle is designed to be easiest to depress at low speeds, becoming progressively more difficult as the throttle is further depressed. Most of the rangers and maintenance personnel indicated a thumb location somewhere near the middle of the thumb lever, and that most of the time, particularly during pursuit or emergency situations, the throttle is fully depressed.

Data available in the literature indicate that average palmar pinch (thumb

TABLE I

Comparison of dimensions and features of the Polaris snowmobile to the guidelines found in the Norwegian study by Tostrup

Dimension/feature	Norwegian study guideline	Polaris snowmobile	Comparison result
Seat	19 inches high, medium soft material, narrow between the knees, hip angle $<90^\circ$, knees 40°–45° when seated	15 inches high, padded seat, banana shape	Polaris seat meets criteria for design and postural targets
Steering bar	Height of 31 inches to enable shoulder angle $= 45^\circ$, elbow joint 60°–70°, hand position neutral, adjustable in height	Height $=$ 28 inches, adjustable in maintenance shop only	Polaris meets the postural guidelines except for wrist, steering bar not adjustable by operator
Distance of steering bar to body when seated properly	19 inches	19 inches	Polaris meets criteria
Gas bar	Give gas using all fingers, placed on both sides of steering bar	Thumb-operated, mounted on right side of steering bar	Polaris does not meet design criteria for placement or activation
Seat back	Not mentioned, no design recommendation	90° tilt adjustability, can be adjusted from 35–45 inches from steering bar	Polaris exceeds the design criteria

TABLE II
Forces to depress throttle (pounds)

	Trail 10	Trail touring	Widetrak LX
Half-depressed, mid-throttle	5.7	6.5	7.2
Half-depressed, tip of throttle	3.2	3.3	5.2
Fully depressed, mid-throttle	13.2	16.6	14.9
Fully depressed, tip of throttle	10.7	11.1	10.4

pad-to-pads of index and middle fingers) strengths for men between 30 and 39 years old average 26.3 pounds with a range of 20–32 pounds; the same pinch force data for women indicate an average of 17.7 pounds with a range of 13–26 pounds.[13] Data available from the University of Michigan, where pinch strength was measured as a function of angle, indicate that male strengths ranged from 16.5 to18.9 pounds as the angle of the thumb ranged from zero to 60 degrees, and from 12.3 pounds to 14.2 pounds for women under the same conditions.[14]

Worker postures and general comments. In general, the design of the seat and the steering bar, and the adjustability of the seat back allowed for the recommended body segment postures outlined by Tostrup. However, when rangers were asked to sit on their snowmobiles in their preferred position, the chosen seat back position often resulted in shoulder postures of about 90 degrees flexion (instead of 45°), elbow joint at about 180 degrees (instead of 60°–70°), and the hands in non-neutral postures. This is because most of the rangers tended to sit far back on the seat to allow for clearance between the steering bar and the bulky equipment and heavy clothing they wear during their regular duties.

Discussions with rangers and maintenance personnel led to the conclusion that the throttle control needed to be improved to eliminate the discomfort and fatigue associated with having to activate the throttle with the thumb. Several rangers indicated that it would be beneficial if the steering bar could be moved closer to the body and lowered, without having to move the seat back closer. This feature would allow the arms to be used more effectively in stabilizing the body position on the seat as the snowmobile is driven, particularly under bumpy road conditions. When the arms are fully outstretched (90° shoulder flexion), the rangers' position on the snowmobile can be stabilized only by exerting force with the hands, which are already busy activating throttle and brake controls.

Coordination / tremor / vibrotactile sensitivity tests. Twenty-six park service employees were tested on the coordination, tremor, and vibrotactile sensitivity tests. These employees were not chosen in any random or systematic manner; rather, they were the ones on duty and available at the various study locations during the time of the NIOSH evaluation. Four of these 26 did not use snowmobiles for their work, but case-control statistical analyses were not performed because there were too few of them to be matched to those who routinely rode snowmobiles, and there were differences in age that may have caused a misinterpretation of the results. Moreover, one of the four had a preexisting medical condition that may have further influenced the interpretation of comparative statistics. One other worker was not available for afternoon testing. Therefore, complete data were available from 22 workers for the morning (a.m.) tests and 21 workers for the afternoon (p.m.) tests.

Eighteen of the 22 workers who routinely use snowmobiles rode snowmobiles on the day they were tested. The amount of time each worker spent on his/her snowmobile on the test day was recorded. The estimated number of lifetime hours of snowmobile use was obtained from 17 of these 18 workers using a follow-up questionnaire sent to all study participants after the NIOSH site evaluation had been completed.

The questionnaire also asked for lifetime hours operating other vibrating equipment. The number of hours operating other vibrating equipment was minimal in comparison to the number of snowmobile hours reported, so these data were not used in any subsequent analysis. The time on snowmobile and lifetime exposure data were also important for comparing the results of this study to the Norwegian study conducted on workers using snowmobiles. Table III provides information on current day and lifetime snowmobile use, gender, age, finger temperature, and room temperature, all used in the subsequent analysis.

General linear models were used to compare the a.m. ($n = 22$) and p.m. ($n = 21$) scores of the workers reporting regular snowmobile use in their park service work. This analysis was somewhat limited because the group included some workers who did not use a snowmobile on their test day. The results are summarized in Table IV (Tremor), Table V (Vibrotactile), and Table VI (Coordination).

The average tremor indices for the right hand (99.5–95.4), the left hand (96.2–90.4), and the combined index for both hands (97.8–92.9) all decreased from the a.m. to the p.m. tests and were less than a normal score of 100, but the decreases were not statistically significant. The lower the score on the tremor index test, the poorer the performance on this test. One of the tremor measurement components (center frequency–right hand) showed a statistically significant change from a morning value of 7.4 Hz to an afternoon value of 6.5 Hz ($p = 0.003$), likely contributing to the index decreases from a.m. to p.m., but this measurement has no particular relevance when considered by itself. Nonetheless, it is noteworthy that the right hand activates the thumb-controlled throttle on the snowmobile. No vibrotactile measurements showed a significant change, and only one coordination measurement (pronation/supination–right hand) showed a significantchange ($p = 0.04$). The pronation/supination frequency score increased from 3.8 to 4.9, which

TABLE III
Demographic and measurement variables of park service employees used in data analysis

Category	Number of participants	Mean (SD)	Minimum	Maximum
Exposed workers	22 (a.m. tests) 21 (p.m. tests)	NA	NA	NA
Gender/age	4 female 19 male	38.2 (7.34) years	25 years	52 years
Lifetime use of snowmobile	17	1986 (2072) hours	48 hours	7560 hours
Time on snowmobile on day of testing	18	3.36 (1.92) hours	1 hour	7 hours
Room temperature	23	a.m. 19.3°C (2.2) p.m. 20.4°C (2.5)	15°C 18°C	24°C 29°C
Finger temperature	23	a.m. 29.2°C (1.4) p.m. 29.9°C (2.5)	27°C 27°C	32°C 34°C

NA = not applicable.
SD = standard deviation.

TABLE IV
Analysis of morning and afternoon tremor tests on all park service workers who used snowmobiles as a work vehicle

Measurement	Test time	N	Hand	Mean (SD)	P-value, for time of day difference
Tremor intensity	a.m.	22	Right	0.11 (0.01)	0.93
	p.m.	21		0.11 (0.01)	
Root mean square (RMS)	a.m.	22	Left	0.12 (0.01)	0.51
	p.m.	21		0.13 (0.01)	
Tremor center frequency (expressed in Hertz)	a.m.	22	Right	7.4 (0.34)	**0.003**
	p.m.	21		6.5 (0.33)	
	a.m.	22	Left	7.3 (0.31)	0.31
	p.m.	21		7.0 (0.32)	
Tremor hand index	a.m.	22	Right	99.5 (5.1)	0.55
	p.m.	21		95.4 (4.9)	
	a.m.	22	Left	96.2 (4.9)	0.32
	p.m.	21		90.4 (5.8)	
Tremor-total index for both hands	a.m.	22		97.8 (4.1)	0.31
Tremor-total index for both hands	p.m.	21		92.9 (4.4)	

N = number of study participants.
SD = standard deviation.
Note: Values shown in bold are statistically significant.

is an indication of better performance, likely due to a learning effect. There was no similar learning effect for the left hand.

The analyses for exposure effects were performed using regression analysis, with lifetime snowmobile use and the time on the snowmobile between the a.m. and p.m. tests as the continuous measures of exposure. Age was used as a covariate in all the analysis models, while room temperature and finger temperature were covariates for the vibrotactile measurement analyses.

Table VII presents the analysis results of lifetime hours versus the a.m. test scores. The a.m. scores were used as a representation of the long-term effects of snowmobile use, not influenced by any snowmobile use on the day of testing. The right hand tremor index (t value −3.03, p value = 0.009) and the combined tremor index (t value −3.30, p value = 0.005) varied significantly with lifetime snowmobile use hours. The negative t values indicate that as lifetime exposure hours increased, index scores decreased, which means lower performance on the test (more tremor). This relationship occurred primarily on the right hand, although the left hand index showed a similar, but not significant (t value −1.74, p value = 0.10) relationship. The right hand index score and the combined mean tremor index score for the 17 park service employees used in this analysis were, respectively, 100.4 (range: 61–158) and 98.6 (range: 69–133). The majority of the test scores were close to the normal mean of 100 and within the range of one standard deviation (SD) of 20. Four of 17 employees tested had scores below one SD (e.g., 80) on these two measures.

Table VIII presents the analysis using time on snowmobile hours versus the difference between the a.m. and p.m. test scores. The difference score represents changes between the morning and afternoon test scores that are attributable to hours on the snowmobile. The tremor combined hand index was significant (t value = 2.24, p value = 0.041), indicating that as the reported time on the snowmobile on the day of testing increased,

TABLE V
Analysis of morning and afternoon vibrotactile tests on all park service workers who used snowmobiles as a work vehicle

Vibrotactile measurement frequency	Test time	N	Finger	Mean (SD) in decibels	P-value, for time of day difference
31.5 Hertz	a.m.	22	Middle	109.3 (1.3)	0.42
	p.m.	21		110.3 (1.1)	
	a.m.	22	Small	111.0 (1.2)	0.57
	p.m.	21		110.4 (1.0)	
125 Hertz	a.m.	22	Middle	105.0 (2.1)	0.55
	p.m.	21		106.5 (1.6)	
	a.m.	22	Small	107.5 (2.0)	0.17
	p.m.	21		105.2 (1.7)	
250 Hertz	a.m.	22	Middle	115.5 (2.1)	0.71
	p.m.	21		116.2 (1.6)	
	a.m.	22	Small	114.8 (2.1)	0.18
	p.m.	21		112.7 (1.8)	
500 Hertz	a.m.	22	Middle	135.3 (2.0)	0.21
	p.m.	21		132.9 (1.5)	
	a.m.	22	Small	134.8 (2.2)	0.08
	p.m.	21		131.5 (1.6)	

N = number of study participants.
SD = standard deviation.

TABLE VI
Analysis of morning and afternoon coordination tests on all park service workers who used snowmobiles as a work vehicle

Measurement	Test time	N	Hand	Mean (SD)	P-value, for time of day difference
Maximum pronation/ supination (expressed in Hertz)	a.m.	22	Right	3.8 (0.5)	**0.04**[A]
	p.m.	21		4.9 (0.3)	
	a.m.	22	Left	4.3 (0.3)	0.55
	p.m.	21		4.5 (0.3)	
Maximum finger tapping (expressed in Hertz)	a.m.	22	Right	5.6 (0.2)	0.10
	p.m.	21		5.0 (0.4)	
	a.m.	22	Left	4.5 (0.3)	0.38
	p.m.	21		4.8 (0.3)	
Reaction time (expressed in milliseconds)	a.m.	22	Right	220.8 (8.2)	0.29
	p.m.	21		228.8 (8.7)	
	a.m.	22	Left	229.5 (9.3)	0.36
	p.m.	21		237.6 (9.3)	
Coordination index	a.m.	22		99.3 (6.4)	0.82
Composite score from all tests	p.m.	21		100.4 (6.1)	

[A]Shows an improvement in scores.
N = number of study participants.
SD = standard deviation.
Note: Values shown in bold are statistically significant. Only maximum test scores are reported because results of slow and fast tests are contained in the coordination index and the composite score for all tests.

so did the difference between the a.m. and p.m. score. The morning score mean was 98.6, and the afternoon score mean was 92.5 (the lower the index score, the poorer the performance on this measure). There was also a statistically significant relationship between time on the snowmobile and the left hand reaction time difference score (t value −2.14, p value = 0.05). The group mean reaction time increased from an a.m. value of 226.2 milliseconds (msec) to a p.m. value of 240.6 msec, indicating a decreased performance in this measure. Vibrotactile test results were not related to same-day hours of snowmobile use.

Whole-body vibration. All snowmobiles in the park were required to remain on the posted roads and observe a 45 mile per hour speed limit. The roads were groomed every night by a vehicle that smoothed and packed the snow. On the days of this survey, the weather conditions were relatively mild, with temperatures just below freezing. Park officials stated that this caused the road conditions to deteriorate quickly as the heavy snowmobile traffic entered and traveled throughout the park. The roads were characterized as very bumpy and rough, with moguls approximately 18 inches apart and eight to 12 inches high. This washboard condition made riding the snowmobile extremely uncomfortable at any speed. The only time that the NIOSH investigators experienced favorable riding conditions was early in the morning before the recreational snowmobilers entered the park on the freshly groomed roads.

Because of the severe jolting of the snowmobile rider, as observed by the NIOSH investigators, the initial analysis of the acceleration data looked at the peak levels for each four-second event recorded by the SAVER units. Five different snowmobiles were instrumented for vibration analysis while the rangers patrolled park roadways. Eight different sampling periods were recorded during the survey. Individual measurement periods were generally three to four hours in length. During a measurement period, 488 to 1,347 separate four-second time periods were captured that had a

TABLE VII
Analysis of morning test scores with lifetime exposure hours

	Panel A: Tremor; No. of participants = 17; Covariate = age							
	Intensity mean (slope)	t value (p-value)	Center frequency mean (slope)	t value (p-value)	Hand index mean (slope)	t value (p-value)	Combined index mean (slope)	t value (p-value)
Right hand	0.11	0.94	7.2	−0.03	100.4	−3.03		
	(0.00)	(0.36)	(−0.00)	(0.97)	(−0.01)	**(0.009)**		
Left hand	0.12	−0.78	7.2	−0.18	97.0	−1.74		
	(−0.00)	(0.45)	(−0.00)	(0.86)	(−0.01)	(0.10)		
Both hands							98.6	−3.30
							(−0.01)	**(0.005)**
	Panel B: Vibrotactile; No. of participants = 17; Covariates = age, room, and finger temp							
	Intensity mean (slope) 31.5 Hz	t value (p-value)	Intensity mean (slope) 125 Hz	t value (p-value)	Intensity mean (slope) 250 Hz	t value (p-value)	Intensity mean (slope) 500 Hz	t value (p-value)
Middle finger	108.3	−0.91	104.1	−0.16	114.1	−0.91	134.9	0.38
	(−0.00)	(0.38)	(−0.00)	(0.87)	(−0.00)	(0.38)	(−0.00)	(0.71)
Small finger	110.4	0.22	106.1	−0.17	113.9	−2.00	133.9	−0.47
	(−0.00)	(0.83)	(−0.00)	(0.86)	(−0.00)	(0.79)	(−0.00)	(0.65)
	Panel C: Coordination; No. of participants = 17; Covariate = age							
	Pronation/ supination mean (slope)	t value (p-value)	Finger tap mean (slope)	t value (p-value)	Reaction time mean (slope)	t value (p-value)	Coord. index mean (slope)	t value (p-value)
Right hand	3.85	1.05	5.68	−1.77	217.8	−0.33		
	(0.00)	(0.31)	(−0.00)	(0.10)	(−0.00)	(0.75)		
Left hand	4.31	0.02	4.34	0.23	226.2	−0.75		
	(0.00)	(0.99)	(0.00)	(0.81)	(−0.00)	(0.46)		
Both hands							101.6	−0.08
							(−0.00)	(0.94)

Note: Values shown in bold are statistically significant.

peak acceleration level of at least 1 g, the trigger threshold set for the SAVER instrument. These peak accelerations occurred at a rate of 276.5 peaks per hour while the NPS rangers were patrolling the park on their snowmobiles. Median (50th percentile) peak acceleration levels ranged from 3.13 to 4.71 g's for the eight sampling periods. Maximum peaks were measured at up to 14.9 g's for one snowmobile. Seventy-fifth and 90th percentiles were calculated for each of the eight sampling periods. These statistics represent the maximum peak level or less that the rider experienced during the measurement period 75 percent and 90 percent of the time, respectively. The peak accelerations ranged from 3.51 to 5.72 g's for the 75th percentile statistic, and from 3.96 to 6.78 g's for the 90th percentile.

Medical

Demographics and snowmobile use. Confidential medical interviews were conducted at ranger stations with 26 employees. There were 19 males and seven females, ranging in age from 25 to 54 years (average 39 years), who had worked at the park from two months to 16 years (average 7 years). Four participants reported that they did not drive a snowmobile; two drove snowmobiles only occasionally; 13 reported that they drove snowmobiles for 10 to 40 percent of their work time; and seven reported that they drove snowmobiles 50 to 75 percent of their work time.

Many of the park workers had experience at other national parks or at other jobs not related to the park service. Fourteen of the participants were rangers who patrolled the snowmobile trails, four were maintenance workers who routinely used snowmobiles, and eight were assigned to other jobs such as visitor-use assistants, researchers, biologists, and planning assistants. One participant, included in the "other" category, was a ranger (district supervisor) who used a

TABLE VIII

Analysis of morning-afternoon difference test scores with time on snowmobile exposure hours

Panel A: Tremor; No. of participants = 17; Covariate = age

	Intensity mean (slope)	t value (p-value)	Center frequency mean (slope)	t value (p-value)	Hand index mean (slope)	t value (p-value)	Combined index mean (slope)	t value (p-value)
Right hand	0.001	−0.06	−0.77	−0.27	−3.88	1.53		
	(−0.00)	(0.95)	(−0.05)	(0.79)	(5.10)	(0.15)		
Left hand	0.012	−0.30	−0.18	−0.66	−4.61	1.41		
	(−0.00)	(0.76)	(−0.11)	(0.52)	(4.64)	(0.18)		
Both hands							−0.33	2.24
							(4.95)	**(0.041)**

Panel B: Vibrotactile; No. of participants = 17; Covariates = age, room, and finger temp

	Intensity mean (slope) 31.5 Hz	t value (p-value)	Intensity mean (slope) 125 Hz	t value (p-value)	Intensity mean (slope) 250 Hz	t value (p-value)	Intensity mean (slope) 500 Hz	t value (p-value)
Middle finger	1.28	1.46	1.39	−0.90	0.17	−1.51	−3.28	−0.85
	(0.95)	(0.17)	(−1.43)	(0.39)	(−1.79)	(0.15)	(−1.09)	(0.41)
Small finger	−0.78	−0.23	−3.00	−0.67	−2.78	0.21	−4.56	−0.34
	(−0.13)	(0.82)	(−0.20)	(0.88)	(0.24)	(0.83)	(−0.45)	(0.74)

Panel C: Coordination; No. of participants = 17; Covariate = age

	Pronation/ supination mean (slope)	t value (p-value)	Finger tap mean (slope)	t value (p-value)	Reaction time mean (slope)	t value (p-value)	Coord. index mean (slope)	t value (p-value)
Right hand	0.85	0.03	−0.72	0.12	9.28	0.26		
	(0.01)	(0.98)	(0.03)	(0.90)	(1.26)	(0.80)		
Left hand	0.22	0.63	0.15	−0.15	8.83	−2.14		
	(0.14)	(0.54)	(−0.04)	(0.89)	(−10.55)	**(0.05)**		
Both hands							−0.22	0.29
							(0.85)	(0.77)

Note: Values shown in bold are statistically significant.

snowmobile to conduct park business such as driving to meetings, but not for patrolling the snowmobile trails. The four visitor-use/planning assistants rode snowmobiles infrequently.

Symptoms and health problems. Table IX summarizes the symptoms and health problems reported by the NPS personnel. Ten of the 14 rangers reported back pain. Most said that their back pain was worse in the winter; one experienced back pain only in the winter. Three rangers had sore thumbs that they attributed to depressing the throttle on the snowmobile (two right thumb, one unspecified), and three reported finger numbness. Each of the four maintenance workers experienced back pain, and two reported numb fingers, which they attributed to frostbite. The one maintenance worker who had carpal tunnel syndrome had undergone surgery for the condition 18 years prior to the NIOSH evaluation. Eight interviewees had seen a healthcare provider for musculoskeletal problems that they attributed to work. The most common health complaint reported by the workers having jobs other than ranger and maintenance worker was headache. All three cases occurred among the four visitor use assistants who worked at the park.

Discussion

In general, the comparison of the results of the whole-body vibration measurements, the diagnostic tests, the medical interviews, and the analysis of postures and grip forces while operating the snowmobiles to limits described by researchers as acceptable, suggests that using snowmobiles has caused musculoskeletal problems among the park personnel. Eight of the 18 interviewed

TABLE IX
Work-related symptoms and health problems by work group

Symptom	Rangers N = 14	Maintenance N = 4	Other N = 8
Headaches	1		3
Back pain	10	4	1
Shoulder pain	4		1
Knee pain	2		1
Elbow pain/tendinitis	2		
Sore thumb	3		
Finger numbness	3	2	1
Carpal tunnel syndrome		1	

rangers and maintenance workers who used snowmobiles reported thumb pain or finger numbness, suggesting that snowmobile use had a detrimental effect on their hands.

The tremor and coordination test results suggest that snowmobile use causes hand fatigue. More study participants may have led to a stronger association between these tests and the routine use of snowmobiles.

The vibrotactile tests did not show a significant relationship between sensory functions and lifetime snowmobile hours, but some of the participants showed abnormal results at various frequencies during the tests. Many of the study participants reported fewer hours of lifetime snowmobile use than the comparison group found in the literature. In a study where vibrotactile sensitivity was found to diminish with reported lifetime hours of snowmobile use, the hours ranged from 8,400 to 16,900 hours, while the hours reported by the participants averaged 1,986 hours, with the highest reported being 7,560 hours.[15]

Another factor that may have affected the results, and thus the ability to predict the effects of snowmobile use on vibrotactile sensitivity, was the temperature of the participants' fingers. Although the required fingertip temperature (28°C) was achieved at the beginning of testing and was controlled for in the statistical analyses, it was not always possible to maintain the workers' fingertip temperatures during testing because the average room temperature at the various testing locations was less than 20.5°C.

The forces to fully depress the throttle were about half the strength capability of a middle-aged male and 80 percent that of a comparable female, but when evaluated at 60 degrees, which is the initial position of the gas lever with respect to the handlebar, the pinch forces averaged 79 percent of maximum capability for males, and about 100 percent for females. These hand forces are appreciable and demonstrate the need for some type of relief for the thumb. However, strength consideration alone as a percent of maximum capability is not the most appropriate way to evaluate the task of continuously depressing the throttle.

Design of work tasks that involve force application require proper recovery time between exertions to avoid fatigue. For a moderate force task (50% of maximum strength), a recovery time of about twice the exertion time is required to avoid muscle fatigue.[16] Such a work-recovery pattern is not possible during operation of a snowmobile, so it is not surprising that a number of study participants reported hand pain and showed hand function decrements. Moreover, it is impossible to know how much pinch grip force is being applied to the steering handle during times of high-speed operation on deteriorated roads when an operator is at continuous full throttle while simultaneously working to maintain a controlled position on the snowmobile with the arms outstretched at shoulder height.

There is at least one after-market device available that enables the throttle to be activated by the four fingers of the right hand instead of the thumb.[17] Called the Cruisemate, the mechanism attaches to the right grip and allows the snowmobile operator to choose between the thumb and the four fingers of the right hand to depress the throttle. According to the manufacturer, the Cruisemate does not alter any factory throttle mechanisms or safety features. The attachment is available for a number of snowmobile types, including the Polaris models used by the park.

Except for the design of the throttle control, and minor differences in the height of the seat and the steering bar, the Polaris snowmobiles used by the NPS have the adjustment features needed to achieve component configurations and associated postures recommended by some researchers. However, the component adjustments chosen by the rangers to accommodate constraints of their jobs, such as the wearing of bulky clothes and other equipment required for the job (radio, holster, and pistol), result in postures of the shoulder and elbow that are far outside the recommended limits. In these situations, the snowmobiles do not have the necessary features or adjustment in suspension components to significantly reduce the jolts the riders experience on the deteriorated trails.

The diameter of the hand grip (just over an inch) is smaller than the generally recommended 1.5 inches, and the wearing of gloves when riding further increases the amount of grip force the operators must exert to stabilize themselves and maneuver the snowmobile.[18] The vertical and horizontal locations of the steering bar can be adjusted, a preference expressed by many of the NPS personnel, but it must be done in the maintenance garage, and the chosen position cannot be adjusted in the field. The steering bars of the snowmobiles were left in the standard position because NPS personnel are not assigned to a particular snowmobile; rather, they use any snowmobile available at the time they are on duty.

Over the past few years, the NPS has been developing a winter use policy for snowmobiles in the national parks. The main issues supporting the need for a snowmobile policy have been the noise and pollution that result from the high volume of recreational snowmobile traffic sustained by the parks each year. The noise and pollution mainly affect the wildlife in the park, but the volume of traffic causes rapid deterioration of the roads, which affects the health of the patrolling rangers and other park personnel, in terms of both the time they must be on their snowmobiles and the trail conditions under which they must work.

Anticipating that changes in snowmobile use are inevitable throughout the NPS, some manufacturers have begun to develop cleaner, quieter machines, some with other features that could improve the health of park rangers and maintenance personnel, as well as recreational users. The product of one such manufacturer was observed by the NIOSH team while conducting the evaluation.[19] Features of this machine include a quieter, less-polluting four-stroke engine, a steering wheel, a bucket seat, and a foot-controlled accelerator and brake.

The features that improve the ergonomics of the machine are 1) the bucket seat, which has an adjustable suspension to improve support of the back and posture of the hips, legs, and arms; 2) the steering wheel, which is of sufficient diameter to minimize grip forces while driving; and 3) the foot controls, which eliminate the hand forces required to operate the throttle and brake. The model observed and driven by two of the NIOSH investigators seemed to provide an acceptable solution to all of the ergonomic problems associated with the conventional two-stroke machines, except for the shocks sustained from driving on severely deteriorated roads.

The large, frequently occurring peak accelerations observed during the analysis of the whole-body vibration data limit the data from being analyzed according to many of the health-effects evaluation criteria.[20–22] A traditional time-weighted analysis in instances where there are large peak accelerations may underestimate the hazard and must be analyzed using higher order methods.[21] A suitable analogy to characterize the effect of frequently occurring, high-magnitude peak levels is the comparison of impact noise such as gun shots, to continuous noise such as would be encountered in an office or industrial environment.

The peak acceleration levels measured in this evaluation agree with the data reported in the Norwegian snowmobile study.[1] The median peak values ranged from 3.51 to 5.72 g's, which are comparable to the 5 g's reported in the Tostrup article. The Tostrup report also states that peak accelerations of up to 10 g's were seen, which is in close proximity to the maximum of 14.9 g's measured in this evaluation. During a self-reported health survey of reindeer herders, Tostrup found that they had a high prevalence of musculoskeletal disorders of the lumbar back, neck and shoulder, and arm and knee.[23] Since the accelerations measured on the rangers were comparable to, and in some cases higher than, what Tostrup measured, it is possible that the rangers and maintenance personnel would have similar occurrences of musculoskeletal disorders.

The personal observations of the NIOSH investigators who collected the data and rode these vehicles for four days throughout the park led them to conclude that the park personnel experience an uncommonly rough ride while patrolling and commuting to locations where maintenance is required. The SAVER units filled their memory capacities in less than four hours, which indicates that the rangers experience many of these high-level shocks daily. The finding that the ride is perceived to be smoother on freshly groomed roads does offer relief to the park personnel if the roads can be maintained in this condition throughout the day.

Although a provisional winter use plan for the national parks has been released, it contains a four-year implementation period and a solicitation for comments from the public.[24] As such, the final form and extent of the policy is not yet known. If recreational snowmobiles are banned, the problems experienced by NPS personnel using snowmobiles will be largely solved. If only snowmobiles meeting certain noise and pollution standards are allowed, the problem may be reduced somewhat by the aforementioned newer generation of snowmobiles that have car-like seating and controls, if that is the type the NPS decides to use. If conventional snowmobiles are severely limited in the park, the problems of the NPS personnel may be solved by spending fewer hours on the snowmobiles under deteriorated road conditions. The final winter use policy that is implemented will dictate the best course of action for the NPS to protect its personnel who use snowmobiles.

Conclusions

1. The force to depress the throttle control on the steering bar is appreciable, and not sustainable for continuous use, as is the usual practice when rangers patrol the trails and maintenance workers perform their daily activities. Awkward postures of the hand and wrist result as the rider searches for an alternative grip on the throttle to alleviate accumulated muscle fatigue.
2. Current snowmobiles have adjustment features that enable a comfortable seating position, but as practically used, the reach to the handlebar causes awkward postures of the shoulder and arm, and hand forces to grip and control the throttle control are high and increased by the small diameter of the steering control.
3. The snowmobiles do not have the components or suspension adjustment features necessary to appreciably reduce the jolts that riders experience during typical snowmobile use.
4. The results of the vibrotactile sensitivity tests, the coordination tests, and the tremor tests were not conclusive, but were consistent with the symptoms reported by the park personnel. The test results suggest that snowmobile use,

particularly depressing the throttle control with the thumb, fatigues the muscles of the hands and arms.

5. The jolts sustained by NPS personnel while riding snowmobiles for long hours under conditions of severely deteriorated roads are extremely high, may be associated with the musculoskeletal symptoms reported by the workers and amplify the effects of the design shortcomings of the snowmobiles used in the park.

Recommendations

As noted in the Discussion section, the ultimate strategy for reducing the health effects of park personnel who use snowmobiles in the course of their work will depend on the eventual NPS winter use policy. The following recommendations were offered to address the conditions under which snowmobiles were used at the time of this evaluation:

1. Provide custom-configured snowmobiles for personnel who choose them. Workers could be assigned to their own snowmobile or to a pool of snowmobiles configured within their specifications. (This may reduce the pain and discomfort experienced by the rangers and maintenance personnel.) The most important feature to adjust is the steering bar, which if moved closer to the body with grips oriented to provide for neutral wrist positions while in typical use, would reduce grip forces and improve shoulder and arm postures.
2. Redesign the throttle control mechanism so that the activation method does not require palmar pinch forces involving the thumb. The solution is not obvious, but a method involving more of the fingers or control by either hand would better distribute forces, and is the method described in the Norwegian study discussed in the body of this report. As noted in the Discussion section, there is at least one manufacturer of a device that provides relief to the thumb by allowing the snowmobile operator to choose between the thumb and the four fingers to activate the throttle. Other attachable devices or redesigned throttle controls may be available from other manufacturers.
3. Increase the diameter of the handle grip to 1.5 inches to reduce grip forces while riding. Handle diameter can be increased with larger slide-on grips, or by wrapping the grips with tape. Whatever method is chosen, the remedy should not diminish the heating capabilities of the grip handles.
4. Groom the most heavily used roads in the park more frequently to enable the rangers and maintenance personnel to travel on the smoothest roads possible to minimize shocks and jolts when riding. An alternative is to reduce the number of snowmobiles allowed in the park so that the roads will maintain a smoother surface for a longer time period.
5. Consult with snowmobile manufacturers with the goal of specifying/developing a suspension system that will significantly reduce the jolts sustained by the park personnel. Options might include operator-adjustable springs and shocks, or adjustable air seats for the snowmobiles.
6. Familiarize NPS personnel with the signs and symptoms of common musculoskeletal disorders such as carpal tunnel syndrome, tendinitis, and vibration-induced finger numbness (vibration white finger) so that problems can be detected early to minimize their severity.
7. Limit the time that each NPS worker, particularly the rangers, spends on a snowmobile each day. It is not known exactly what exposure time is protective of the workers, but periods of up to 10 hours per day should be avoided.

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