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Evaluation Program

Whole-Body Vibration Analysis of Golf Course Maintenance Tasks

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Authors: Jessica G. Ramsey, MS, CPE

Scott E. Brueck, MS, CIH, COHC

Desktop Publisher: Shawna Watts

Editor: Cheryl Hamilton

Logistics: Donnie Booher and Kevin Moore

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Introduction

Request

Management from a golf course requested a health hazard evaluation concerning maintenance employees' exposure to whole-body vibration. Employees reported pain or discomfort in their lower back, shoulders, neck, and knees, which they thought was related to excessive whole-body vibration while doing certain work tasks.

Workplace

The golf course consisted of 36 holes sitting on approximately 335 acres. Each hole consisted of a tee box, concrete cart path, fairway, grass and wooded rough, fairway hazards (bunkers, traps, and water hazards), and a putting green. The maintenance area consisted of an office building and partially covered structures for equipment storage.

To learn more about the workplace, go to Section A in the Supporting Technical Information

Our Approach

We visited the golf course to learn more about health concerns and to measure whole-body vibration exposures. During our site visit, we completed the following activities:

- Observed work processes, work practices, and workplace conditions.
- Measured golf course maintenance employees' exposures to whole-body vibration during two work shifts.
- Held confidential interviews with employees working during our visit.

To learn more about our methods, go to Section B in the Supporting Technical Information

Our Key Findings

Whole-body vibration exposures for most job tasks were above occupational action levels

- The whole-body vibration crest factor ratios for the job tasks we measured ranged from 12–34. Vibration with crest factor ratios greater than 9 are considered to have high impulsivity and are potentially more harmful.
- All of the job tasks we measured, except mowing the fairway, had whole-body vibration amounts that were above recommended action levels.

- Driving a golf cart on a paved golf path was above the recommended exposure limit value of 17 m/s$^{1.75}$ during the sampling period.
- Operating the top dress and Tycrop equipment for a combined total of 7 hours, put the operator at the recommended exposure limit.

Interviewed employees reported work-related pain and discomfort

- Most of the interviewed employees reported low back pain and discomfort.
- Employees also reported pain or discomfort in other areas including the shoulders, neck, and knees.
- Employees stated that original equipment seats had been replaced with other manufacturers' seats when they were worn out. This could contribute to pain and discomfort.

To learn more about our results, go to Section B in the Supporting Technical Information

Our Recommendations

The Occupational Safety and Health Act requires employers to provide a safe workplace.

Benefits of Improving Workplace Health and Safety:	
Improved worker health and well-being	Enhanced image and reputation
Better workplace morale	Superior products, processes, and services
Easier employee recruiting and retention	May increase overall cost savings

The recommendations below are based on the findings of our evaluation. For each recommendation, we list a series of actions you can take to address the issue at your workplace. The actions at the beginning of each list are preferable to the ones listed later. The list order is based on a well-accepted approach called the "hierarchy of controls." The hierarchy of controls groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or practical, administrative measures and personal protective equipment might be needed. Read more about the hierarchy of controls at https://www.cdc.gov/niosh/topics/hierarchy/.

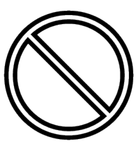
We encourage the company to use a health and safety committee to discuss our recommendations and develop an action plan. Both employee representatives and management representatives should be included on the committee. Helpful guidance can be found in "*Recommended Practices for Safety and Health Programs*" at https://www.osha.gov/shpguidelines/index.html.

Recommendation 1: Reduce exposures to whole-body vibration

Why? Strong evidence of an association between whole-body vibration and low back disorder was found in 15 of 19 studies reviewed by the National Institute for Occupational Safety and Health (NIOSH). Whole-body vibration may act in combination with other work factors, such as prolonged sitting, lifting, and awkward positions, to cause increased risk of back disorders. Most job tasks were above the recommended action level for whole-body vibration. In addition, some job tasks were also at or above the recommended exposure limit for whole-body vibration. Most employees reported pain and discomfort in the low back area.

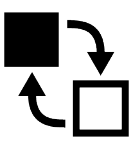
How? At your workplace, we recommend these specific actions:

Avoid driving on areas of the golf course known to be rough and uneven and take the shortest route when possible.

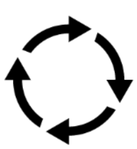


Reduce driving speeds.

Replace seats with original equipment seats, or when available, a seat that is designed to further dampen whole-body vibration.



Reduce or eliminate rough and uneven areas of the cart paths through maintenance or replacement.



Establish a schedule that rotates employees between job tasks.

Recommendation 2: Encourage employees to report health concerns they think are work-related to their supervisors

Why? Identifying symptoms early can reduce severity. Management can periodically review this information to identify common procedures that might be associated with reported musculoskeletal health symptoms and safety concerns. Management can use this information to potentially identify opportunities for improvement.

How? At your workplace, we recommend these specific actions:

Establish a symptom reporting procedure so that information about reported health concerns and symptoms is documented.

- Keep a log of employee symptoms related to work and periodically review the logs to look for trends.

Encourage employees with health concerns to get an evaluation from a healthcare provider with occupational medicine expertise familiar with the types of exposures employees have and their health effects.

- The American College of Occupational and Environmental Medicine maintains a database of providers to help locate someone in your geographic area: https://acoem.org/Find-a-Provider.

Supporting Technical Information

Whole-body Vibration Analysis of Golf Course Maintenance Tasks

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Section A: Workplace Information

Golf Course

- Initially opened in the early 1920s
- 265 acres of maintained property (i.e., cared for in regular intervals)
- 200 acres of highly maintained property (i.e., mowed weekly)
- Paved golf cart paths were approximately 50 years old

Employee Information

Number of employees at time of evaluation: 13-person crew plus an office clerk

Length of shift: Ranged from 24–40 hours per week

Union: American Federation of Governmental Employees Local 1897

Mean age: 56 years (range: 28–65 years)

Mean tenure at current job: 13 years (range: 1–40 years)

Process Description

The typical components of a golf course are shown in Figure A1. Maintenance employees were responsible for cutting grass in the tee boxes, fairways, putting greens, and roughs (the trees and taller grass along the periphery of the fairways) on a regular schedule. They also mechanically raked the sand in the bunkers (also known as sand traps) daily. The same employees performed the same tasks on a regular basis, and due to the size of the course by the time they completed the full course, it was time to start over again. Additionally, employees performed biannual core aeration, periodic fertilizing, and regular sand top dressing of the putting greens.

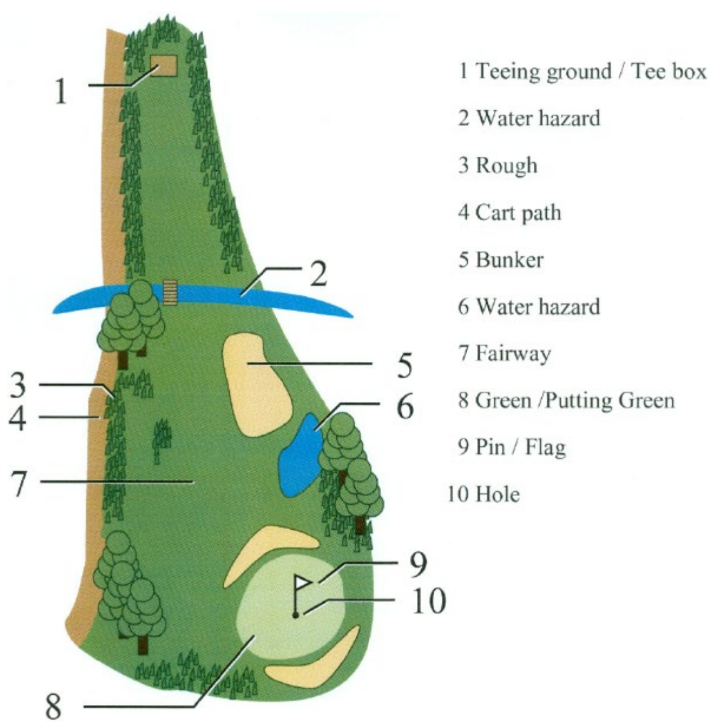

Figure A1. Typical components of each hole at a golf course. Figure by Researchgate.net.

Section B: Methods, Results, and Discussion

Methods: Whole-body Vibration

We evaluated whole-body vibration exposure to the maintenance crew members during operation of groundskeeping equipment, tractors, and golf carts on September 3–4, 2018. We measured motions that created vibration between the seat and the operator during regularly scheduled groundskeeping operations. These motions were measured with a sensor (Larson Davis, HVM 200) that detects motion (acceleration) in three directions (axes). The sensor was embedded in a rubber seat pad oriented as specified by the International Organization for Standardization (ISO) 2361-1 [ISO 1997]. ISO 2361-1 is an accepted standard for measuring, analyzing, and reporting results for whole-body vibration of a seated operator in a vehicle cab. The sampling rate was 1,000 Hertz (1,000 samples per second). The positive z-axis was vertical upward perpendicular to the seating surface, and the positive x-axis projected anteriorly (forward) from the operator. The system was equipped with a data logger that we mounted to the side of the operator's seat using a padded pouch and wraps. We taped the seat pad to the seat and used wires to connect the sensor to the data-logger. We taped or used plastic ties to secure the wires and data logger to equipment, so the measurement system was not intrusive to the operator, see Figure B1. We used a continuous measurement approach in which the data logger was manually started, and measurements were uninterrupted.

Figure B1. Rubber seat pad with embedded triaxial sensor for measuring whole-body vibration on the groundskeeping tractor seat. Photo by NIOSH.

We collected data while the operator was seated and operating the equipment under normal conditions including any loading, transporting, idling, or a combination of operation conditions. We excluded from analysis time periods when the operator was not seated on the equipment, such as during breaks or when operators got off equipment to make adjustments or do other tasks. We asked the maintenance employees to conduct their normal work activities and routines so that typical acceleration measurements could be taken. Mowing tasks involved specific equipment for each task and data collection included driving between the areas being mowed (tee to tee, fairway to fairway, etc.) Employees typically took the shortest path between areas. NIOSH researchers measured whole-body vibration exposures for the golf cart task by driving a golf cart along the entire length of golf cart path at the course.

We evaluated the following tasks during our visit:

- Mowing the tees
- Mowing the fairway
- Mowing the rough
- Mowing the greens
- Mowing with a zero-turn machine
- Top dressing the putting greens
- Fertilizing the putting greens
- Mechanically raking the sand traps
- Driving a golf cart on the cart path

Results: Whole-body Vibration

We calculated crest factors, a measure of the impulsiveness of vibrations, using the ratio of weighted peak acceleration to weighted root mean square (rms) accelerations. Vibration that is more impulsive is potentially more harmful than vibration that is not impulsive or has very low crest factor values. The American Conference of Governmental Industrial Hygienists (ACGIH) notes that its threshold limit value (TLV) is not valid for vibration with crest factors greater than 9 [ACGIH 2022]. The crest factor ratios for the job tasks we measured were all above 9, ranging from 12–34. The crest factors for the job tasks and sampling periods in shown in Table C1.

Additionally, the ISO indicates that when crest factors are greater than 9, the basic vibration evaluation method could underestimate the severity of vibration with respect to discomfort [ISO 1997]. For whole-body vibration crest factors greater than 9, ISO standard 2631-1 suggests using the "fourth power Vibration Dose Value (VDV) method" to evaluate potential health risk from vibration because the method is more sensitive to vibrational peaks [ISO 1997]. ACGIH has an action level and TLV for VDV exposures that follow the ISO 2631-1 whole-body vibration standard [ACGIH 2022]. The VDV action level is 8.5 meters per second ($m/s^{1.75}$) and the TLV is 17.0 $m/s^{1.75}$ for exposures up to 8 hours. VDVs between the action level and the TLV indicate that employees have a potential for experiencing health effects.

The measured VDV values for the golf course maintenance tasks and sampling periods in shown in Table C2. All of the tasks, except mowing the fairway, were above the VDV action level of 8.5 $m/s^{1.75}$, ranging from 11–17 $m/s^{1.75}$. The only golf course maintenance task at or above the VDV TLV of 17 $m/s^{1.75}$ was driving the golf cart on the paved golf cart path.

VDVs are dependent on the magnitude of whole-body vibration and task duration. To show the relationship between VDV levels and golf course maintenance task duration, we scaled VDVs for task lengths up to 8 hours using the equations below, based on the highest measured VDV value from either the x-, y-, or z-axis. Figures B2–B7 show daily VDVs for golf course maintenance tasks having durations of 2–8 hours.

$$VDV_{\text{exp},x} = 1.4 * VDV_{\text{meas},x}\left(\frac{T_{\text{exp}}}{T_{\text{meas}}}\right)^{1/4}$$

$$VDV_{\text{exp},y} = 1.4 * VDV_{\text{meas},y}\left(\frac{T_{\text{exp}}}{T_{\text{meas}}}\right)^{1/4}$$

$$VDV_{\text{exp},z} = 1.0 * VDV_{\text{meas},z}\left(\frac{T_{\text{exp}}}{T_{\text{meas}}}\right)^{1/4}$$

Where:

$\text{VDV}_{\text{exp}, x, y, \text{or } z}$ = calculated VDV exposure for estimated task duration

VDV_{meas} = VDV for measurement period

T_{exp} = duration of task for estimated vibration exposure (2–8 hours)

T_{meas} = duration of measurement (hours)

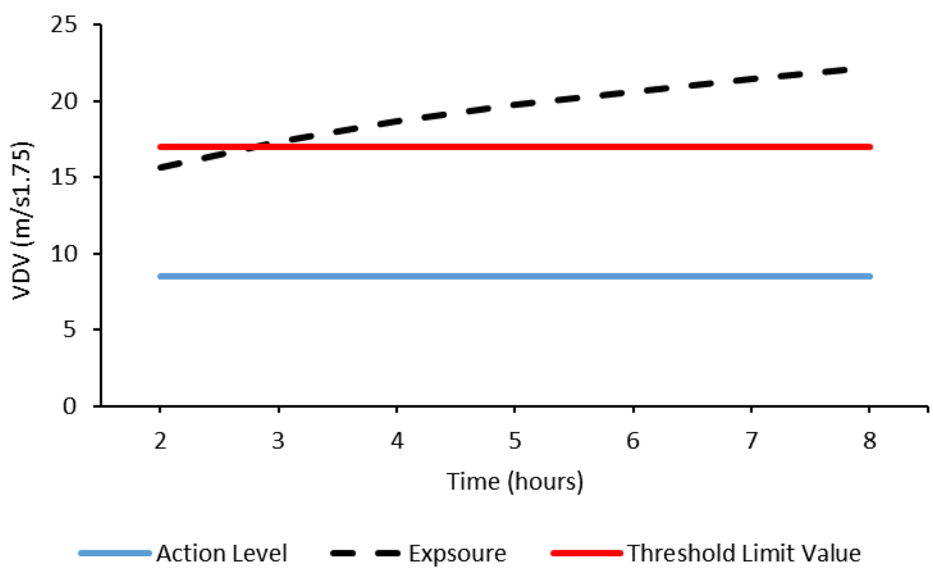

Figure B2. Graph of VDVs for up to 8 hours when mowing roughs.

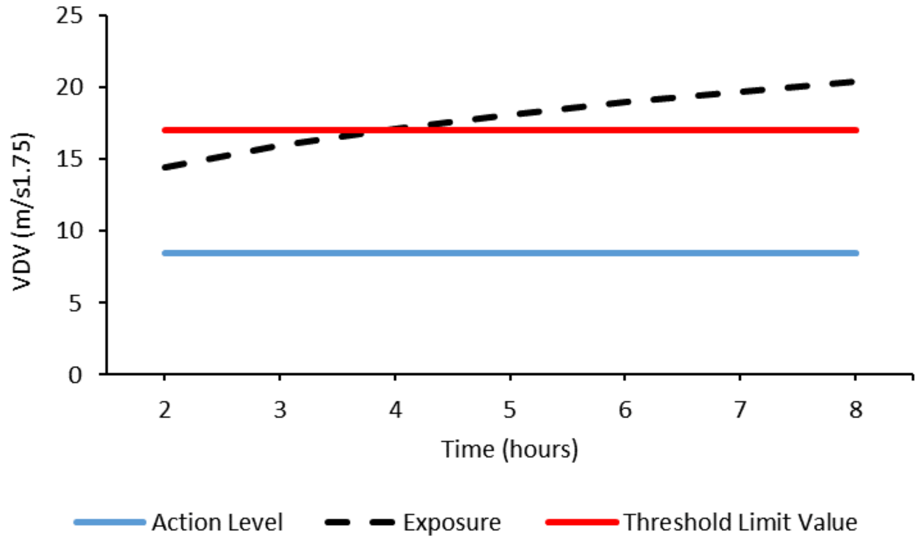

Figure B3. Graph of VDVs for up to 8 hours when mowing the tee boxes.

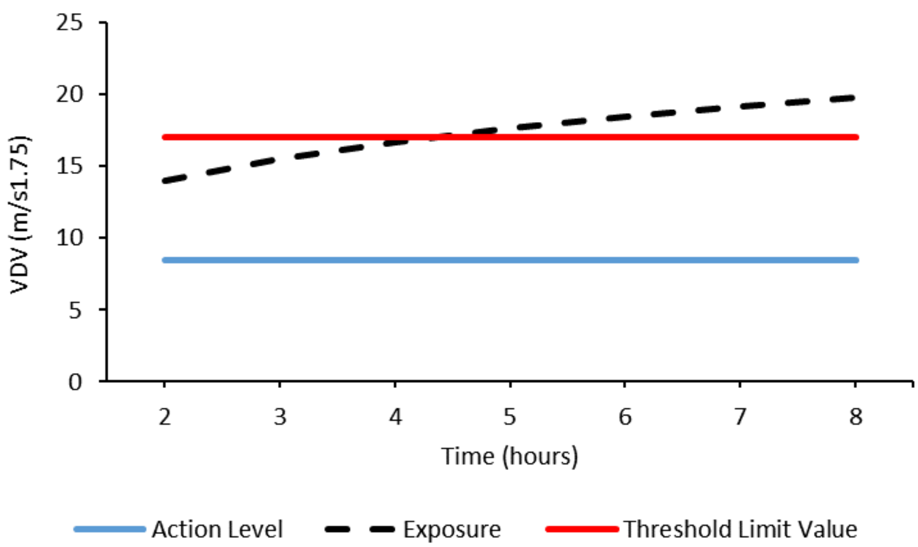

Figure B4. Graph of VDVs for up to 8 hours when operating the zero-turn mower.

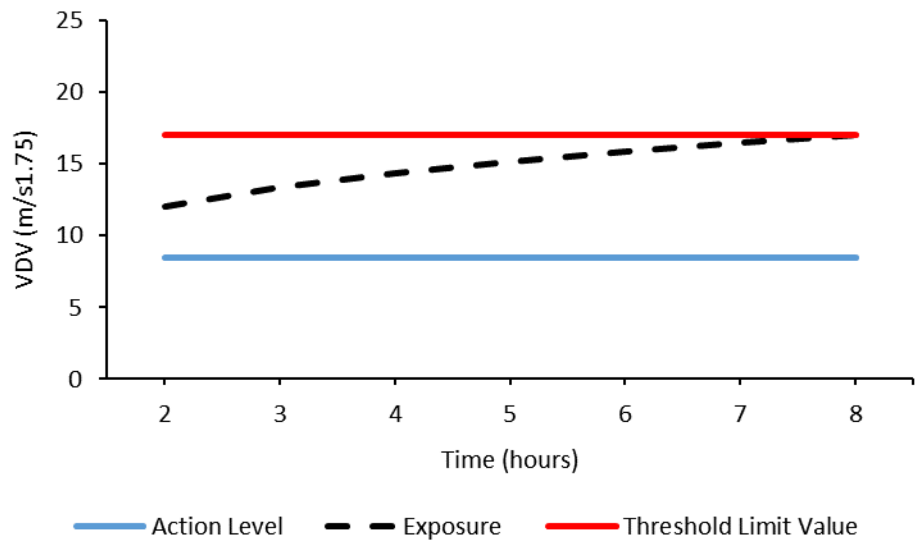

Figure B5. Graph of VDVs for up to 8 hours when mowing the fairways.

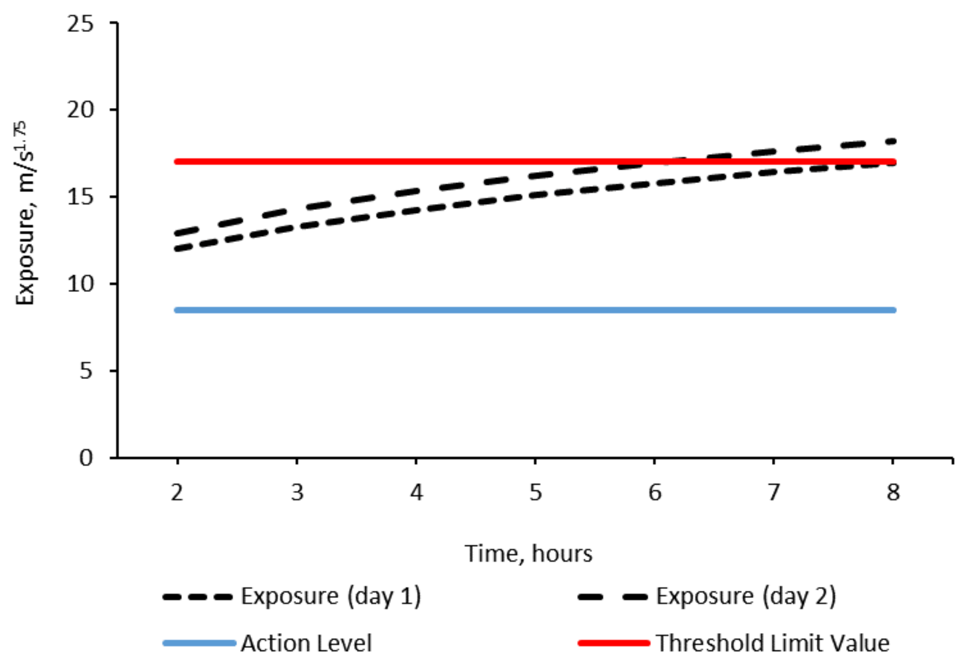

Figure B6. Graph of VDVs for up to 8 hours when using the Sandpro.

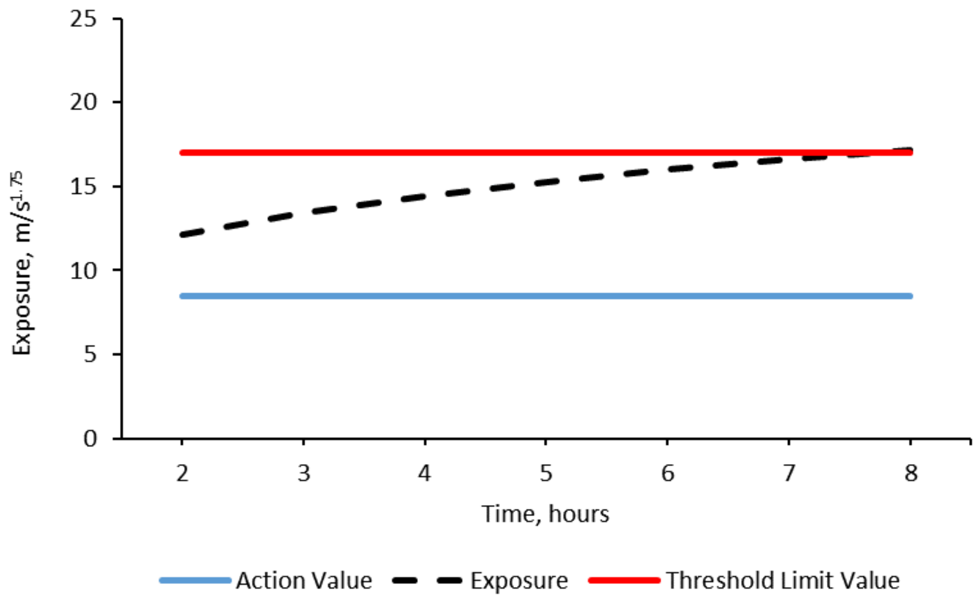

Figure B7. Graph of VDVs for up to 8 hours when using the fertilizer equipment.

For the golf course maintenance tasks we evaluated, Figure B8 shows when VDV exposures would reach the VDV TLV of 17.0 $m/s^{1.75}$. The TLV for driving a golf cart was exceeded after 30 minutes. The TLVs were reached in 2.8 to 4.3 hours when using the rough mower, tee mower, and zero turn mower. The TLVs for using the Sandpro equipment, fertilizer spreader, and fairway mower were reached in 6.0 to 8.0 hours. Use of the top dress equipment would not reach the TLV during an 8-hour work shift.

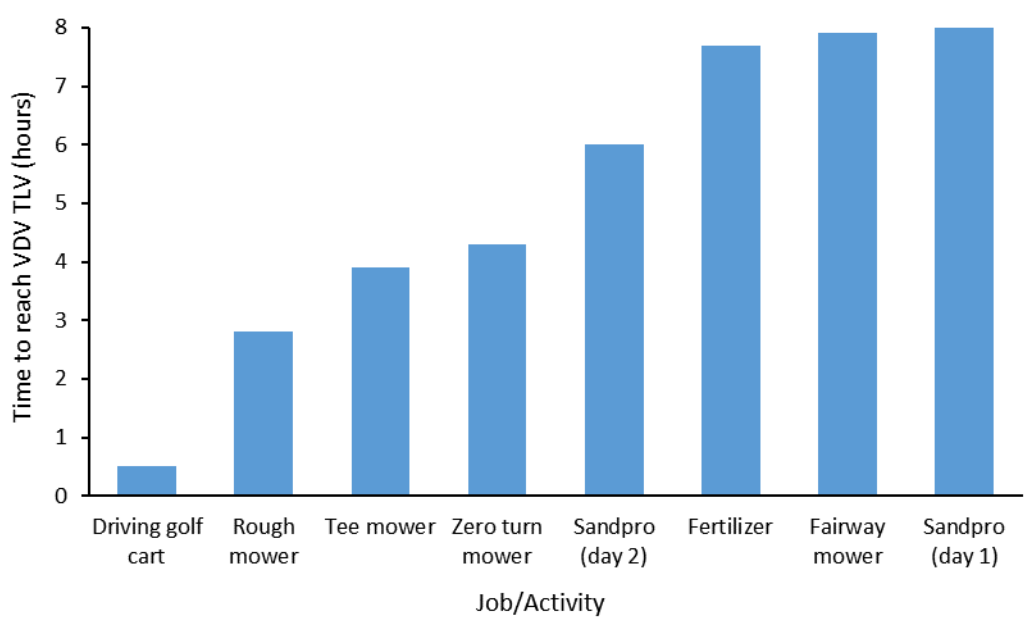

Figure B8. Time (hours) for golf course maintenance activities to reach the VDV TLV of 17 m/s1.75 (the top dress is not included in the figure because the VDV would not reach the TLV during an 8-hour work shift).

Additionally, we calculated an overall daily VDV when more than one task was performed per day. First, we calculated the partial VDVs for each task and each axis. Then, a daily VDV was calculated from the partial vibration exposures for each axis, using the following calculation:

$$\mathrm{VDV}j = [\mathrm{VDV}j1^4 + \mathrm{VDV}j2^4]^{1/4}$$

The daily VDV is the highest axis of VDV*x*, VDV*y*, and VDV*z*. Table C3 shows the operator's daily whole-body vibration exposure when performing multiple tasks. All the tasks are above the action level, however one set of tasks, operating the top dress and Tycrop equipment for a total of 8.5 hours, would put the operator at the VDV exposure limit.

Methods: Informal Interviews

We invited employees to participate in confidential interviews. We collected 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.

Results: Informal Interviews

We interviewed eight employees during our site visit. All the employees were male, ranging in age from 28–66 years (median 56 years). The employees had worked at the golf course from 1–40 years (median 13 years). Job titles of the interviewed employees included gardener, tractor operator, maintenance worker, and pest controller. Seven of the eight employees (88%) reported lower back pain/discomfort the last 12 months. Other areas where employees reported pain or discomfort included shoulders (50%), neck (38%), and knees (38%). Three of the interviewed employees had visited a doctor or healthcare provider for their pain or discomfort. Two of those three employees were told by their doctor that their condition was work-related. Additionally, employees reported that the original equipment seats had been replaced on various equipment, sometimes with another manufacturer seat.

Discussion

In the United States, an estimated 7 million employees are exposed to whole-body vibration at work [Wasserman et al. 1974]. Exposure can cause chronic effects that affect employee health [Cohen et al. 1977]. Most of the known chronic effects of whole-body vibration are concerned with changes in the spine and back of affected workers. Strong evidence of an association between whole-body vibration and low back disorder was found in 15 of 19 studies reviewed by NIOSH. Whole-body vibration may act in combination with other work factors, such as prolonged sitting, lifting, and awkward positions, to cause increased risk of back disorders [NIOSH 1997]. We found that golf course maintenance employees were exposed to whole-body vibration levels above the VDV action level. Because the seat of equipment may need to be replaced several times during its lifespan, it is important to replace with a seat that could provide vibration dampening. A previous health hazard evolution noted a relationship between driving speed and vibration level [NIOSH 2013]. Although we did not measure speed during this evaluation, reducing speed could reduce the employee's whole-body vibration exposure. Additionally, we noted that maintenance employees drove the shortest distance between the areas they were mowing. Measurements included driving mowers from tee to tee, including the golf cart path and other rough surfaces. When possible, traveling over rough surfaces such as the cart path and the rough between fairways should be avoided to reduce vibration exposure.

Limitations

Whole-body vibration measurements can only document the equipment that was used and the areas of the golf course that were maintained during our visit. We did not collect data on the entire course, except for the golf cart paths. Therefore, results may be higher or lower on various days depending on the terrain of the different areas of the course. Additionally, results may vary depending on the equipment with a different operator.

Conclusions

Most job tasks we evaluated were above the whole-body VDV action level, above which employees have a potential for experiencing health risks. Additionally, employees reported pain or discomfort in their lower back, shoulders, neck, and knees. We provided recommendations to assist with minimizing whole-body vibration exposures. These recommendations included reducing the amount of time spent on equipment, taking paths that are known to cause less vibration, and providing proper replacement seats on equipment.

Section C: Tables

Table C1. Whole-body vibration frequency weighted peak acceleration, frequency weighted root mean square acceleration, and crest factor values measured for golf course maintenance tasks

Job/Activity	Frequency weighted peak acceleration (m/s^2)	Frequency weighted root mean square acceleration (m/s^2)	Crest factor (no units)
Top dress	20	0.58	34
Sandpro (Day 1)*	25	0.8	31
Top dress	14	0.53	26
Fertilizer	19	0.98	19
Tee mower*	21	1.1	19
Sandpro (Day 2)	18	1	18
Driving golf cart	23	1.4	16
Rough mower	19	1.2	16
Tycrop	16	1.1	15
Zero turn mower*	16	1.2	13
Fairway mower	12	1	12

* Task measurement did not include time during equipment idling and breaks.

Table C2. VDV results for golf course maintenance tasks during the site visit based on measured whole-body vibration and cumulative task duration

Job/Activity	Measurement period (start–stop time)	Cumulative sample duration (minutes)	VDV ($m/s^{1.75}$)
Driving golf cart	13:00–13:31	31	17
Sandpro (Day 1)*	05:35–11:05	285	15
Top dress (Day 1)	05:44–13:01	437	15
Rough mower	08:21–11:33	192	15
Tee mower*	05:27–08:47	180	14
Fertilizer	05:47–08:46	179	13
Zero turn mower*	09:19–11:08	81	13
Tycrop	05:28–06:55	87	13
Sandpro (Day 2)	09:19–10:58	99	12
Top dress (Day 2)	05:23–08:14	171	11
Fairway mower	12:08–13:16	68	8.2
VDV action level			8.5
VDV threshold limit value			17

* Task measurement did not include time during equipment idling and breaks.

Table C3. VDV results for two different golf course maintenance tasks during day of site visit

Jobs	Total time (hours)	Axis with highest VDV	VDV ($m/s^{1.75}$)
Top dress 1 + Tycrop	7.00 + 1.50	z	17
Top dress 2 + Rough mowing	2.85 + 3.20	z	16
Fertilizer + Sandpro 2	3.00 + 1.65	z	15
VDV action level			8.5
VDV threshold limit value			17

Section D: References

Methods

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Discussion

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Promoting productive workplaces through safety and health research

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