# Evaluation of Push and Pull Forces and Musculoskeletal Symptoms Among Employees at an Automobile Manufacturer

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**Authors:** **Jessica Ramsey, MS, CPE**

**Sarah Hatcher, PhD**

**Brian Lowe, PhD, CPE**

**Marie Hayden, MS**

**Menekse Salar-Barim, PhD, AEP**

Analytical Support: Douglas Wiegand

Desktop Publisher: Shawna Watts

Editor: Cheryl Hamilton

Logistics: Donnie Booher, Kevin Moore

Medical Field Assistance: Jessica Rinsky

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# Introduction

## Request

Employees at an automobile manufacturer requested a health hazard evaluation about ergonomics and musculoskeletal pain related to the use of a dolly. The dolly was used to transport panoramic roofs from the dock to the assembly line.

## Workplace

At the time of our evaluation, approximately 8,000 employees worked in the automobile manufacturing plant. Forty-five employees worked with the panoramic roof dollies as part of their job duties. These employees were either on conveyance teams or assembly (line side) teams. Conveyance teams were responsible for moving automobile parts from the docks to assembly lines and workstations throughout the facility. Line side teams were responsible for assembling automobiles on the line.

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

# Our Approach

We visited the facility on three occasions. The first site visit occurred in November 2018. During this site visit, we completed the following activities:

- Measured the minimum required push and pull forces to initiate movement of the steel dolly used to transport panoramic roofs.
- Observed work practices and procedures and spoke with employees about their job tasks, concerns, and job rotation schedules.
- Interviewed 33 employees who worked with panoramic roof dollies as part of their job duties. Interviewed employees included conveyance and line side team members and team leaders. Interview topics included job tenure, job tasks, relevant medical history, musculoskeletal health symptoms, and job stress and satisfaction.

The second and third site visits occurred in December 2018, and February 2019. In December, we interviewed nine additional employees who worked with panoramic roof dollies, covering the same topics as on the first site visit. In February, we measured the minimum required push and pull forces to initiate movement of a prototype aluminum dolly used to transport panoramic roofs.

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

## Our Key Findings

### The prototype aluminum dolly decreased push and pull force requirements by 48% when fully loaded

- The minimum required push/pull force to initiate linear motion of the fully loaded steel and aluminum dollies was under 44 pounds. This is the traditional guideline to accommodate 90% of females.
- However, employees handling steel dollies under realistic production conditions, with time pressures, would very likely exceed the 44 pound limit.
- The employer constructed a prototype aluminum dolly that weighed 440 pounds (versus 860 pounds for the steel dolly). This resulted in lower push/pull forces to initiate motion of the fully loaded dolly from 31 pounds (steel dolly) to 16 pounds (aluminum dolly).

### Handholds were not within recommended guidelines

- The average height of the green marks for the dolly handling locations was 50 inches, and the distance between the green marks was 19–36 inches (Figure 1). This was higher and wider than the recommended guideline and can cause awkward shoulder postures.

Figure 1. The original steel panoramic roof dolly with green marks for suggested locations where the dolly should be handled. Photo by the National Institute for Occupational Safety and Health (NIOSH).

## More than half of interviewed employees reported work-related musculoskeletal pain

- Shoulder and lower back pain were the most commonly reported work-related and dolly-related musculoskeletal pain symptoms.
- Of the 13 interviewed employees who attributed their work-related pain to dolly use, 12 (92%) reported that it was caused or made worse by repetitive activities involving the dolly.

## On average, employees reported a moderate level of job stress

- Employees reported a lack of resources and poor workplace communication as common sources of job stress.
- Conveyance team employees also reported a recently implemented point system (which uses punitive measures to discourage certain behaviors) as a common source of job stress.

**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 employee 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.

We encourage the facility 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: Further improve the ergonomic design of the panoramic roof dolly

Why? Awkward work postures, repetitive or fast work, and high forces can result in musculoskeletal pain and disorders. These conditions can worsen over time and are associated with the following:

- Increased use of sick leave
- Lower productivity
- Lower employee morale
- Lower quality of life

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

**Replace steel dollies with aluminum dollies where they are used to transport panoramic roofs throughout the facility.**

**Provide handholds that meet the following guidelines:**

- The recommended handhold height is 36–45 inches from the floor.
- The recommended distance between handles is a maximum of 18 inches.
- Pushing the dolly is preferred to pulling.

**Require employees to use the provided air assist to help start movement of the dolly**

- Employees should be trained on when and how to refill the air tank.

## Recommendation 2: Encourage employees to continue reporting work-related health and safety concerns to their supervisor and healthcare provider

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 ergonomics improvement.

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

**Improve communication between managers and employees about employee health and safety concerns.**

- Improved communication between managers and employees will demonstrate that managers are interested in knowing about employee health and safety concerns and take them seriously.
- Employees should be informed of what actions have been or will be taken regarding their concerns, and concerns should be addressed in a timely manner.

## Recommendation 3: Identify and reduce sources of job stress among employees

Why? Job stress and other psychosocial factors (such as high workload, low social support, and low job satisfaction) can contribute to musculoskeletal pain symptoms. Research supports a strong association between psychosocial factors and work-related musculoskeletal disorders [NIOSH 1997; Warren 2001]. Psychosocial factors may cause chronic increased muscle tension, thus making soft tissues more susceptible to the effects of physical stressors.

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

**Include team members in decisions regarding changes to their work processes and procedures.**

**Develop and institute a safety program that encourages and praises safe behaviors instead of the recently started system (the "points system") which is based on punitive measures.**

- Punitive systems decrease morale, perceptions of control, and are less effective at improving safety than systems that positively reinforce or praise specific safe behaviors.
- Developing a positive safety program with a consultant may be useful. The Society for Industrial and Organizational Psychology maintains a consultant locator at https://www.siop.org/Business-Resources/Consultant-Locator.
- Regardless of the performance evaluation system used, ensure that team members are adequately trained on how their performance will be evaluated.

# Supporting Technical Information

Evaluation of Push and Pull Forces and Musculoskeletal Symptoms Among Employees at an Automobile Manufacturer

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# Section A: Workplace Information

## Employee Information

At the time of our evaluation, approximately 8,000 employees worked at the automobile manufacturing plant. In total, 45 employees' job duties included handling the panoramic roof dolly at least occasionally. This included (1) all team members and team leaders from Conveyance Team 1 on day and night shift and (2) team members and team leaders from other conveyance teams on day shift who were occasionally asked to assist with handling the dolly. In addition, Line Side Team 5 (also referred to as the "Line Side Moonroof Team") members and leaders, and team leaders from other line side teams, were invited to participate in interviews because they occasionally handle the dolly. Conveyance Team 1 was primarily responsible for handling the panoramic roof dolly. Full-time employees worked one 8-hour shift, 5 days per week. Employees reported working a median of 2 hours of overtime per week (range: 0–20 hours).

## History of Concerns About Musculoskeletal Risks and Dollies

We learned that, prior to the health hazard evaluation (HHE) request and our evaluation, the panoramic roof dolly was hooked directly to a chain of other dollies and the tugger during transport. A tugger is an electric machine used as an alternative to a fork truck because it can move more than one load at a time. To improve efficiency, the panoramic roof dolly was placed into a parent dolly that could then have additional dollies attached to it (see Figure A1).

Figure A1. Tugger (orange), parent dolly (white), and empty panoramic roof dolly (gray with green). Photo by NIOSH.

Employees explained that the new parent dolly configuration required more manual handling of the dolly, which led to concerns about musculoskeletal risks and was the reason for the HHE request. Prior to our evaluation, management had attempted to reduce push/pull forces by replacing wheels with 8-inch Swivel-EAZ® crowned tread casters and installing handles on the dolly to assist with dolly handling. Additionally, a pneumatic cylinder and air tank were attached to the parent dolly that, when triggered, delivered a force to initiate movement of the dolly from the parent. However, employees still felt that the required push/pull forces could lead to injuries.

## Process Description

Conveyance team members were responsible for using powered industrial equipment (PIE) to move parts and equipment from the dock(s) to the assembly lines and workstations throughout the facility. One of the tasks for Conveyance Team 1 members included transporting automobile parts from the dock to line side assembly via a dolly, parent dolly, and standup riding tugger (Figure A1). The job of concern involved conveyance team members retrieving a loaded dolly (holding one to five panoramic roofs) from the dock and loading it into a parent dolly attached to their tugger. When conveyance team members arrived at the panoramic roof line side workstation with the loaded dolly, they first removed an empty dolly from the line side location. They then removed the loaded dolly from the parent and moved it into the spot vacated by the empty dolly. The empty dolly was then moved back into the parent dolly and returned to the dock.

Line side team members were responsible for installing specific parts in cars as the cars moved through the assembly line. The Line Side Moonroof Team was the line side team that received and installed the panoramic roofs transported on the dolly by Conveyance Team 1. Line side employees sometimes switched empty dollies with loaded dollies from a line side overflow location.

Conveyance and line side team members rotated job duties every 2 hours. Some conveyance team members reported that they occasionally performed certain tasks more frequently if a coworker had a health-related job restriction.

Conveyance and line side team leaders were responsible for determining schedules and troubleshooting equipment issues; they also filled in for team members and performed team members' job duties as needed.

The company required that conveyance team members held a PIE license, and their performance was evaluated using a license point system. Points were accumulated any time the employee violated a PIE fundamental skill or had an incident while operating PIE. Points were accumulated over a rolling 3-year period and were weighted higher for repeat violations. Points were audited monthly, and team leads provided team members of their report and coaching as necessary. After 48 points in a rolling 3-year period, the PIE operator's license was revoked, and the team member was reassigned. The procedure document for the license point system provided by management did not describe in detail the violations or incidents that lead to point accumulation. Conveyance team members explained that each PIE was equipped with a sensor that captured every collision with another object. Conveyance team members also told us that, regardless of the severity of the collision or whether the operator was at fault, the collision would result in point(s) on their PIE license audit report.

Employees reported that health and safety concerns could be reported to their direct supervisor, who was responsible for addressing the concern. If employees had a work-related health concern, they could file an Early Symptom Investigation (ESI). This led to a consult with on-site medical staff. Depending on the severity of the health concern, an ESI might lead to additional medical consultation, light duty, or a job transfer. Employees also reported that in the past, safety or equipment concerns could be reported through Safety Concern Registration System kiosks located around the facility; however, these kiosks had since been removed.

## Section B: Objectives, Methods, Results, and Discussion

The objectives of our evaluation were to:

- Measure the push/pull forces used to move the original steel and prototype aluminum panoramic roof dollies and compare them to recommended guidelines.
- Identify work practices and procedures that may cause awkward postures and repetitive motions when moving panoramic roof dollies.
- Determine the prevalence of work-related musculoskeletal pain among employees working with the panoramic roof dollies.
- Describe psychosocial factors, including perceptions of job stress and satisfaction and employees' satisfaction with how the employer addressed safety and health issues.

### Methods: Ergonomic Assessment on Dollies

- We observed both the conveyance and the line side teams moving dollies.
- We measured the handhold height, the distance between dolly handles, and the distance between other areas on the dollies where employees gripped them.
- We tested two original steel dollies. Dolly 4 was tested in three loading conditions: unloaded, loaded with two panoramic roofs, and fully loaded with five panoramic roofs. Dolly 4 was used regularly in production. We tested Dolly 1 in the unloaded condition. Dolly 1 was being used as a back-up because of complaints from employees about being difficult to steer.
- We evaluated a lighter prototype aluminum dolly in two conditions: unloaded and fully loaded with five panoramic roofs.
- We conducted all trials in an area within the facility that had flooring conditions consistent with those in all work areas. Five replications of each dolly loading condition were conducted.
- We assessed the dolly forces with casters in initial orientations aligned (parallel) and perpendicular to the direction of desired travel for Dolly 4 and the prototype aluminum dolly in one set of the five replications. All other measurements were collected without respect to caster alignment.
- We employed a NIOSH ergonomist to start the movement of the dolly from its initial resting position in the direction of push or pull. The measurement of interest was the force to initiate motion of the dolly from its rest position (initial force).
- We used a Chatillon Model MSC digital force gauge to manually apply forces in tension (pull direction) and compression (push direction) against the dolly for all measurements (see Figure B1). The attachment of the gauge in tension consisted of a wire cable looped around the rigid frame of the dolly. In compression, the attachment consisted of a circular pad designed for pushing against a surface. This push force was similarly applied to the dolly frame. The

push/pull forces were applied at the center of the dolly so as to push or pull the dolly in as straight of a path as possible.

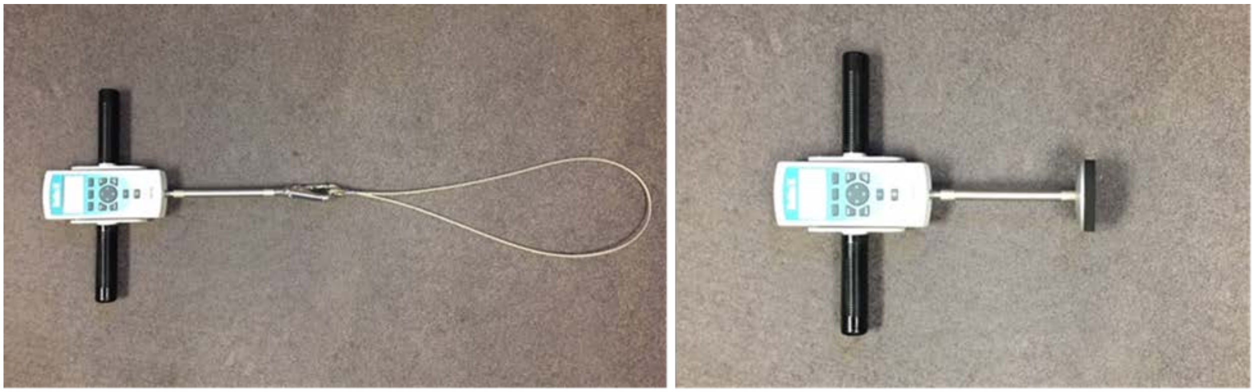

Figure B1. Force gauge attachments. Pull force attachment shown on the left (measurement in tension), push force attachment on the right (measurement in compression). Photo by NIOSH.

- We interfaced the auxiliary analog voltage output (± 2 volts) signal of the force gauge with a 14-bit data acquisition system controlled through National Instruments Labview 2010 software on a laptop computer. The voltage output of the force gauge was previously calibrated to units of force using standardized test weights.
- We attached three wireless triaxial Delsys Trigno accelerometer units to the dolly to sample acceleration at the same time as the force measurements. The accelerometers were fastened with tape to vertical members of the dolly frame, oriented with the accelerometer z-axis in the anterior/posterior (push/pull) direction of dolly travel. Acceleration in the y-axis was in the lateral direction (perpendicular to push/pull). Measurements were limited to these two axes (planar motion only). The sampling rate was 1,000 hertz for all signals.
- We identified the initial motion of the dolly by visual observation of the accelerometer time history. The Labview software was designed with a cursor that can be manually scrolled along the time series to the visually-discernable inflection point in the acceleration profile corresponding to the onset of gross motion of the dolly. The corresponding time value in the force time history was noted, and the associated push/pull force magnitude at that time was documented. An example is shown in Figure B2. Acceleration unit is raw voltage output of the sensor. Force unit (tension or compression corresponding to pull or push) is in pounds (lb).

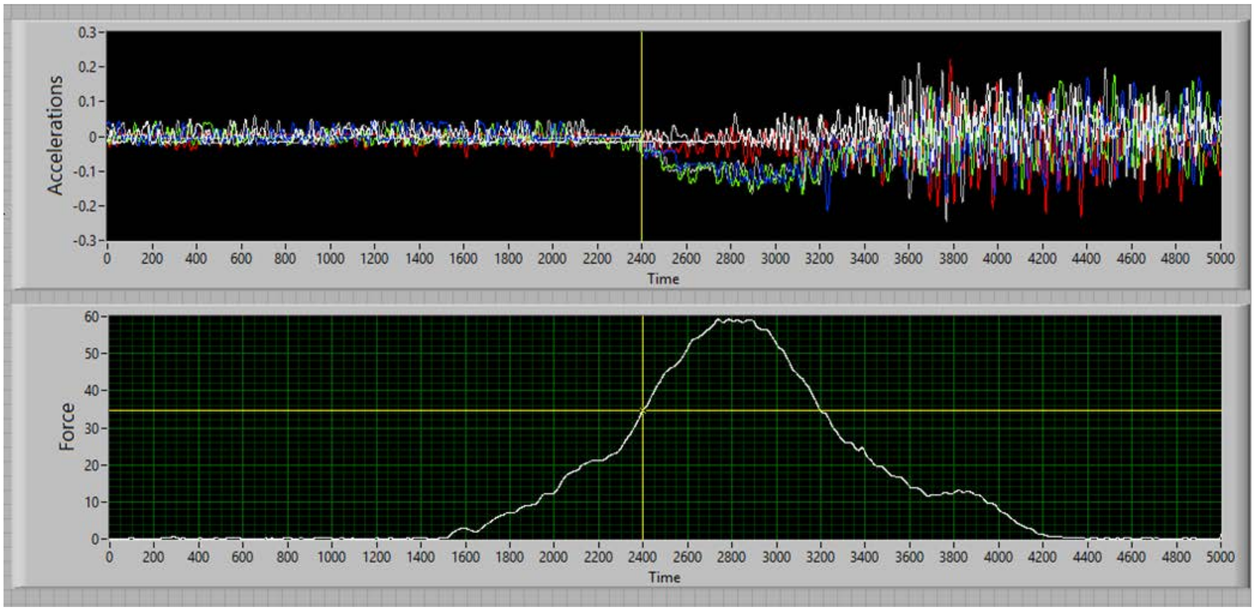


Figure B2. Example of the visual identification of initial dolly motion at 2.4 seconds (x = 2,400). In the top panel, the cursor in the plot of the acceleration time history was manually scrolled to a visually-discernible point. In the bottom panel, the cursor in the force time history is linked to the x-axis index, and the y-axis (force) is displayed at that x-axis (time). The x-axis time units are seconds × $10^3$ corresponding to a 1,000 hertz sampling rate.

## Results: Ergonomic Assessment on Dollies

The average time between Conveyance Team 1 employees' visits to the line side or the dock area was 10 minutes. The Conveyance Team 1 employees handled the dollies on average for 54 seconds at line side and for 38 seconds in the dock area.

Management used green paint to mark where employees should grip the dolly when moving it. The handles and green (good) marks for handling averaged 50 inches in height. The handle diameters were ¾ inch, and the distances between the handles or handling locations ranged 19–36 inches.

The unloaded steel dolly weighed 860 lb, and the unloaded aluminum dolly weighed 440 lb. When they were fully loaded (5 panoramic roofs), the steel dolly weighed 1,340 lb, and the aluminum dolly weighed 920 lb. The remainder of the weights are provided in Table C1.

We used the psychophysical guidelines by Snook and Ciriello [1991] to evaluate the pushing force of the dolly. The Snook and Ciriello tables provide acceptable pushing forces based on the handle height of the container, the frequency of the push, and the distance the container is pushed. The task variables measured at this facility were between suggested categories in the Snook and Ciriello tables. We interpolated to improve the accuracy of applying the observed pushing task to the data contained in the tables. Ergonomic guidelines traditionally design job tasks that are acceptable to 75% of women. This facility had internal guidelines that would be acceptable to 90% of women, therefore we used those values for this evaluation. Figure B3 shows the recommended pushing guidelines.

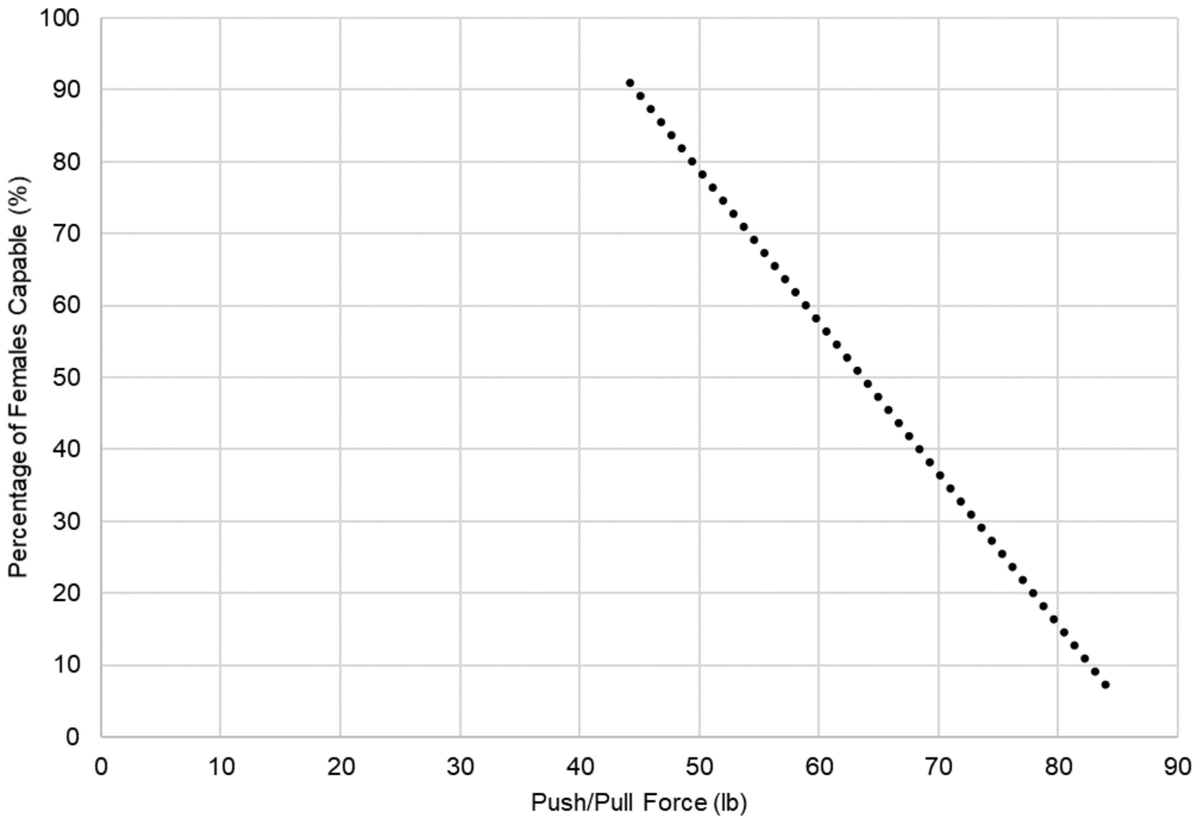


Figure B3. Psychophysical data for push/pull force acceptability (females) derived from Snook and Ciriello [1991]. The regression line is derived from 44 lb equating to 90% capable, 53 lb equating to 75% capable, and 64, 73, and 84 lb equating to 50%, 25%, and 10% capable, respectively.

Orientation of casters on Dolly 4 with five panoramic roofs had little effect on the initial push/pull force (Figure B4). The mean pull force for both the aligned and perpendicular orientation of the casters was 29 lb (standard deviations of 1.6 when aligned and 3.3 when perpendicular). The push forces varied slightly. The mean push force when the casters were aligned was 30 lb (standard deviation of 1.3). The mean push force when the casters were perpendicular was 28 lb (standard deviation of 1.6). All other results were computed without respect to caster alignment.

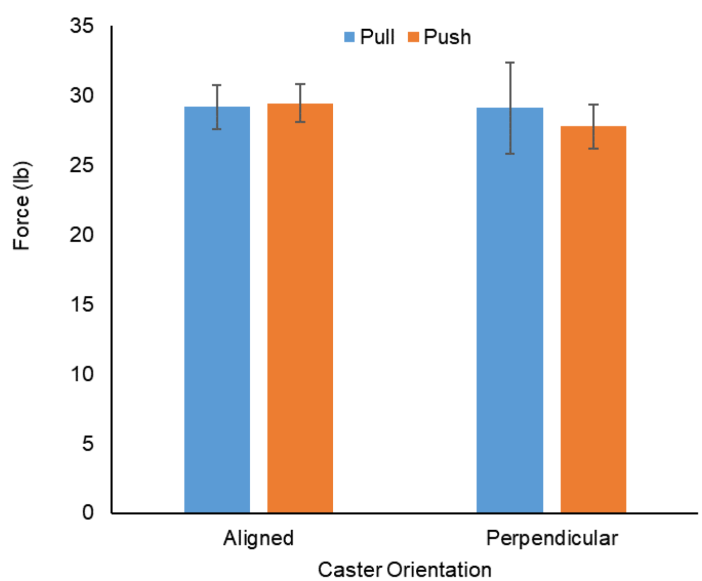


Figure B4. Steel Dolly 4 with 5 panoramic roofs showing the effect of initial orientation of casters on the fully loaded dolly.

Mean initial forces and standard deviations for the original steel dollies are shown in Figure B5. When unloaded, Dolly 4 had a mean pull force of 28 lb (standard deviation of 2.8) and a push force of 24 lb (standard deviation of 1.3). When fully loaded with five panoramic roofs, the pull force of Dolly 4 increased to 31 lb (standard deviation of 2.7), and the push force increased to 28 lb (standard deviation of 1.4). The mean pull force for the unloaded Dolly 1 was 30 lb (standard deviation of 2.5), and the push force was 25 lb (standard deviation of 2.4). A statistical test (pooled standard deviation) conducted on the differences between Dolly 4 and Dolly 1 indicated that the values were not statistically significantly different, with $P > 0.05$.

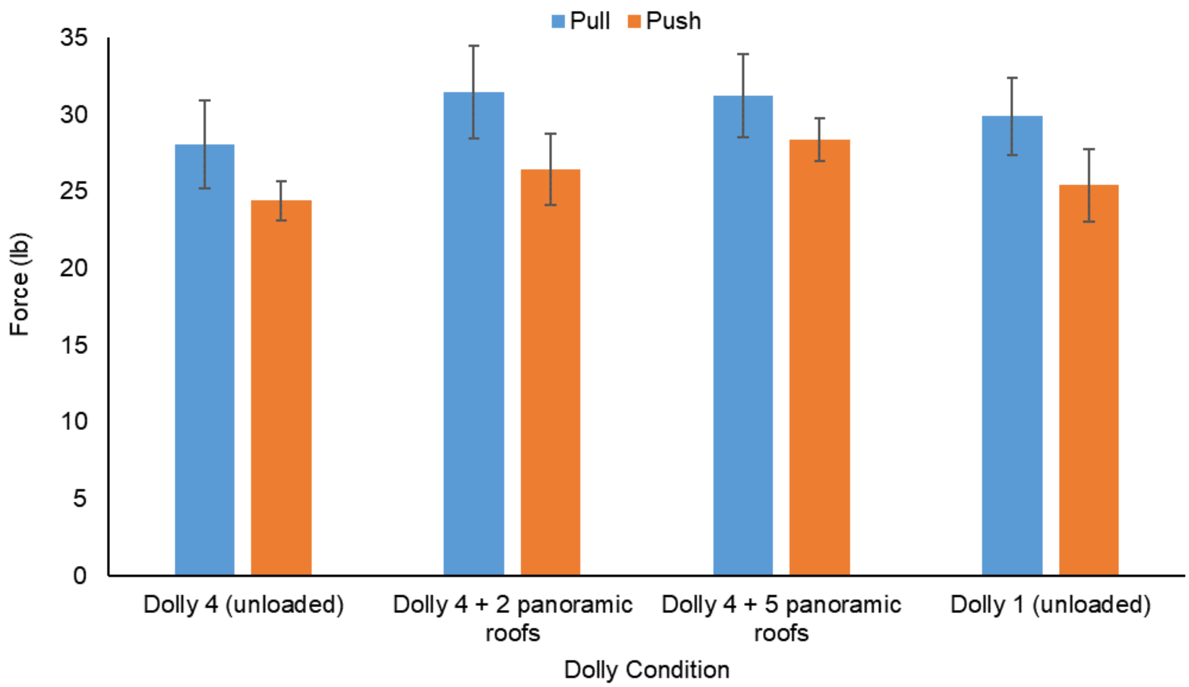


Figure B5. Mean ± standard deviation initial force for push and pull. Dolly 4 refers to the primary dolly tested. Dolly 1 refers to a back-up dolly that was not in use on the date of the original testing.

A comparison of the push/pull forces for the original steel dolly and the prototype aluminum dolly are shown in Figure B6. The prototype aluminum dolly unloaded had a mean pull force of 8.9 (standard deviation of 0.9) and a mean push force of 9.5 lb (standard deviation of 0.9). When fully loaded with five panoramic roofs, the pull force increased to 15.9 lb (standard deviation of 1.4) and the push force to 17.5 lb (standard deviation of 1.9). The minimum force to initiate motion of the fully loaded prototype aluminum dolly was approximately half that of the fully loaded original steel dolly.

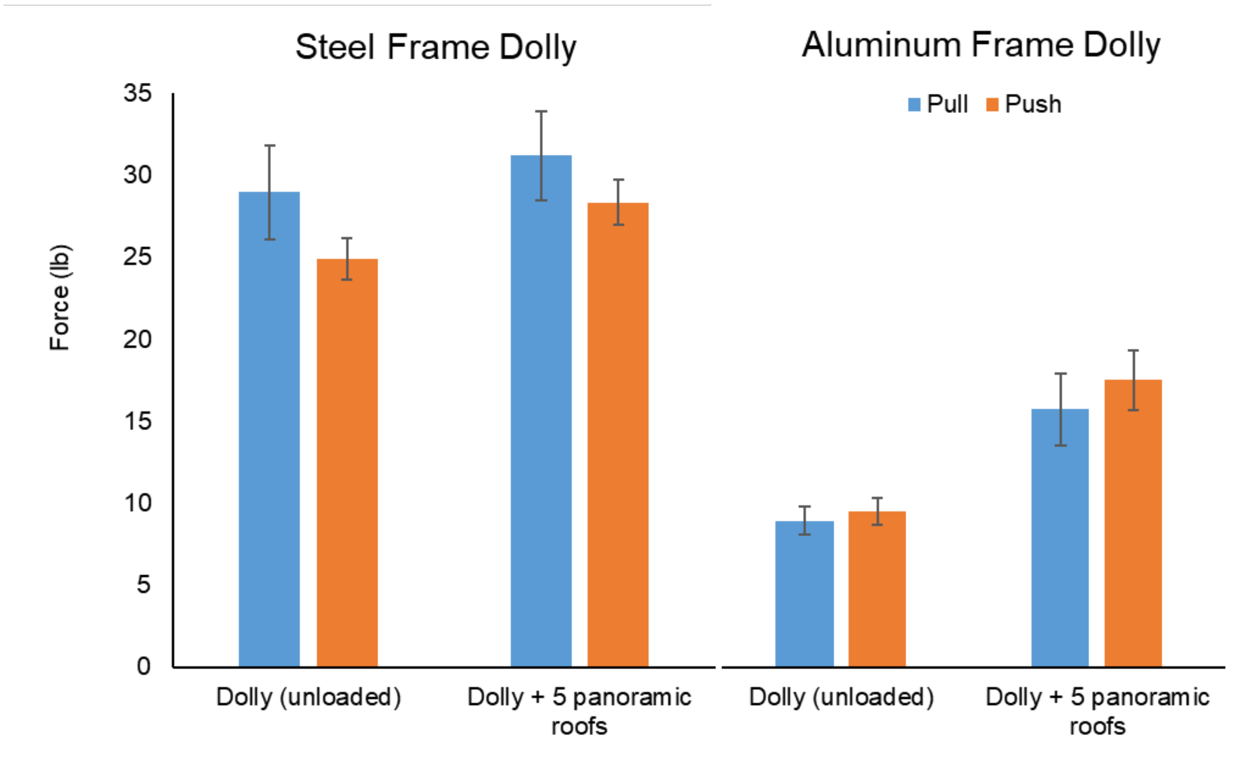


Figure B6. Comparison of minimum initial force to initiate motion of the original steel Dolly 4 (left) versus the prototype aluminum dolly (right).

## Methods: Employee Health

- We worked with management to identify employees who manually handled dollies used to transport panoramic roofs as a part of their job. We invited all 45 employees present during our site visits to participate in voluntary confidential medical interviews.
- We asked interview questions that covered topics including demographic characteristics, work history, musculoskeletal health symptoms and perceived causes, pain severity, relevant medical history, and job stress and satisfaction.
- We defined musculoskeletal pain as body pain lasting a whole day or more during the past 12 months. We asked employees who had been working in their current position for less than 12 months to report any body pain lasting a whole day or more since they started working in their current position.
- We recorded reported pain severity on a scale of 1 (mild pain) to 4 (unbearable pain).
- We defined work-related musculoskeletal health symptoms as musculoskeletal pain lasting a whole day or more that the employee reported was (1) caused by an accident or injury that occurred at work or (2) caused or worsened by repetitive activities at work.

- We defined pain attributed to dolly use as any musculoskeletal pain that employees reported was caused by an accident or injury involving the dolly or was caused or exacerbated by repetitive activities related to dolly use.
- We stratified musculoskeletal pain prevalence by team because different teams had different responsibilities regarding dolly handling. Team members and leaders who were not a part of Conveyance Team 1 or the Line Side Moonroof Team (the teams who primarily handled the dolly as a part of their regular job duties) were grouped together because they handled the dolly less frequently.
- We focused on musculoskeletal pain in the back, neck, and upper extremities. However, if employees self-reported pain in their lower body, we collected information about lower body pain symptoms. Because musculoskeletal health symptom interview questions asked specifically about the upper body and were not asked systematically for the lower body, only upper body pain symptoms were reported in calculations of pain prevalence.
- We assessed psychosocial factors, including job stress, job satisfaction, workplace communication, and trust in management, using a combination of scaled and open-ended responses.
    - We asked employees to describe their level of job satisfaction as "not satisfied at all," "not too satisfied," "somewhat satisfied," "satisfied," or "very satisfied." Among employees who had ever reported a health or safety concern to management, this scale was also used to describe their level of satisfaction with how the concern was addressed. We grouped responses into the categories "somewhat satisfied, not too satisfied, or not satisfied at all" and "satisfied or very satisfied." We calculated the number and percent of responses in each category.
    - We asked employees who had ever reported a health or safety concern to management to describe why they were satisfied or not satisfied with the response. We coded these open-ended responses into common themes.
    - We asked employees to rate how strongly they agreed with statements about communication and trust in management on a scale of 1 (strongly disagree) to 5 (strongly agree). We grouped responses into the categories "agreed or strongly agreed," "neither agreed nor disagreed," and "disagreed or strongly disagreed." We calculated the number and percent of responses in each category.
    - NIOSH defines job stress as the harmful physical and emotional responses that occur when job demands do not match the capabilities, resources, or needs of employees [NIOSH 1999]. We read this definition to employees and asked them to rate their perceived level of job stress on a scale from 0 (no stress) to 10 (a lot of stress). Responses of 0–3 indicated low job stress, 4–6 indicated moderate job stress, and scores of 7 or greater indicated high job stress [Clark et al. 2011]. We also asked employees to describe the aspects of their work that influenced how they described their level of job stress. We coded these open-ended responses into common themes.

- We reviewed the facility's Occupational Safety and Health Administration (OSHA) Form 300 Logs of Work-Related Injuries and Illnesses from January 1, 2018, through November 9, 2018, for employees working in the area of the facility we evaluated. We also matched the roster of names provided by management to the OSHA Log entries.
    - Because employees reported that the dolly was implemented as a work process on or around August 2018, we specifically reviewed OSHA Logs after August 1, 2018, using date as a proxy for potential dolly-related entries. We summarized entries by whether the entry was dated after August 1, 2018.

## Results: Employee Health

### Demographics and Work History

Of the 45 employees who worked with the dolly and were present during our visits, 42 (93%) participated in the voluntary confidential medical interviews. During the first site visit in November 2018, we interviewed 33 employees. During the second site visit in December 2018, we interviewed an additional 9 employees. Two employees declined to participate. Another employee did not speak with us. We are not aware of any differences in work practices between the two site visits. The same steel dollies were in use during both of the first two site visits.

Of the 42 interviewed employees, 35 (83%) were male. The median age of interviewed employees was 44 years (range: 23–64 years). Employees worked at the facility a median of 14.5 years (range: 6 months–30 years) and worked on their current team a median of 3 years (range: 1 month–21 years). At the time of our site visits, 24 (57%) of the 42 interviewed employees worked during day shift, and 18 (43%) worked during night shift. The 42 interviewed employees included 27 (64%) team members and 15 (36%) team leaders. Of these interviewed employees, 13 (31%) were assigned to Conveyance Team 1, 14 (33%) were assigned to Line Side Team 5, and 15 (36%) were assigned to another conveyance or line side team.

Employees on conveyance and line side teams reported variations in how they handled the dolly. This included variations in whether employees kept the dolly close to their body, used one hand or both, and whether they used the compressed air tank assist to help initiate the movement of the dolly out of the parent dolly.

### Musculoskeletal Pain Symptoms, Causes, and Medical History

Twenty two (52%) of the 42 interviewed employees reported work-related musculoskeletal pain lasting a whole day or more during the past 12 months (Table C2). This included 14 (33%) employees with reported work-related shoulder pain, 11 (26%) with reported work-related lower back pain, and 6 (14%) with reported work-related neck pain. Employees also reported work-related pain in one or both hands, elbows, and the upper back. Of the 22 interviewed employees reporting work-related pain lasting a whole day or more, 11 (50%) reported work-related pain in two or more locations.

Among the 42 interviewed employees, 5 (12%) reported that pain was caused by a work-related accident or injury, and 21 (50%) reported that their pain was caused or made worse by work-related repetitive activities. Thirteen (31%) of the 42 interviewed employees reported work-related musculoskeletal pain that they attributed to dolly use (Table C2). Of these 13 employees, 12 (92%) reported that their pain was caused or made worse by repetitive activities involving the dolly. Of the 42 interviewed employees, 9 (21%) employees reported dolly-related shoulder pain, 6 (14%) reported dolly-related low back pain, 6 (14%) reported dolly-related neck pain, and 5 (12%) reported dolly-related pain in two or more locations.

Among the 13 interviewed Conveyance Team 1 employees, 69% reported work-related musculoskeletal pain, while 50% of Line Side Moonroof Team employees and 60% of employees of other teams reported work-related musculoskeletal pain (Table C3). The prevalence of work-related shoulder pain was 46% (6/13) among Conveyance Team 1 employees, 29% (4/14) among Line Side Moonroof Team employees, and 40% (6/15) of employees from other teams. Lower back pain was greatest among Conveyance Team 1 employees.

Among the 22 employees with self-reported work-related pain lasting a whole day or more, 7 (32%) reported ever having a musculoskeletal diagnosis in the same body part as their work-related pain. Diagnoses included impingement syndrome, epicondylitis, hand or wrist tendinitis, fracture, and lumbar discectomy. We were not able to determine whether the musculoskeletal diagnoses were related to work activities, and diagnosis date information was incomplete.

Among the 25 employees who reported any musculoskeletal pain lasting a whole day or more during the past 12 months (regardless of whether or not the pain was work-related), 8 (32%) rated the severity as 3 or greater. Of the 42 interviewed employees, 24 reported musculoskeletal pain and responded to other questions related to pain severity or the impact of pain on their quality of life. Of these 24 employees, 9 (38%) saw a doctor or other healthcare provider for the pain, 9 (38%) reported that their pain interfered with normal home activities, and 8 (33%) reported that their pain interfered with their normal work activities. Four (17%) of these 24 employees reported that their pain led to a job restriction or transfer. However, fewer than three employees reported being away from work for more than 1 day because of their pain.

### Psychosocial Factors

Among the 42 interviewed employees, the average job stress score was 3.8, indicating moderate job stress overall. The average job stress score among team members was 4.3, and the average job stress score among team leaders was 3.1. Twenty-five (59.5%) employees reported low job stress, ten (23.8%) reported moderate job stress, and seven (16.7%) employees reported high job stress. Based on open-ended responses, the most common sources of job stress were workload and time pressure, a recently-implemented point system for the conveyance team members, and poor communication. Specifically, team members expressed that they were not included in discussions regarding the design of new work processes and equipment, and that new work processes, equipment, or tasks were introduced without adequate advanced notice.

Thirty-one interviewed employees had ever reported a health or safety concern to management. Of these, 13 (42%) said they were somewhat satisfied, not too satisfied, or not satisfied at all with how the report was addressed. Employees reported that they were less than satisfied with the way their health or safety concern was addressed because of the way management responded, the timeliness of the response, or poor communication. When asked whether management communicated how the reported health or safety concern would be addressed, 16 (52%) employees responded "no."

When asked how strongly they agreed with a set of statements about workplace communication, on a scale of 1 to 5, 23 (55%) of the 42 interviewed employees agreed or strongly agreed that there is sufficient opportunity to discuss and deal with safety issues in meetings within the workplace, and 25 (60%) employees agreed or strongly agreed that there is open communication about safety issues within the workplace (Figure B7). However, when asked how strongly they agreed with the statement "employees are regularly consulted about workplace health and safety issues," 16 (40%) employees said they disagreed or strongly disagreed.

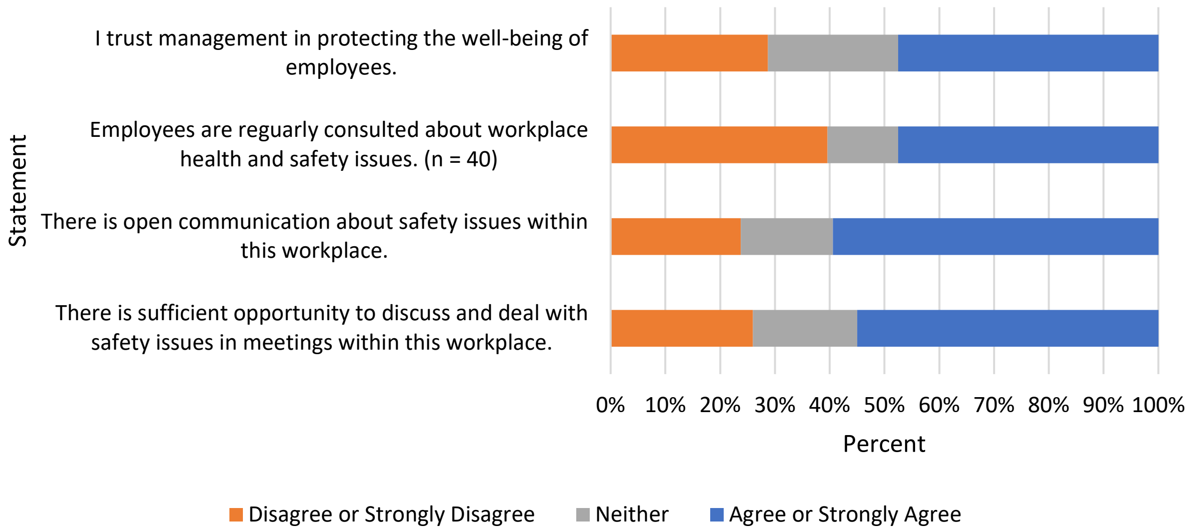


Figure B7. Employee perceptions of issues related to trust in the workplace and workplace communication regarding employee health and safety (n = 42 unless otherwise noted). Forty interviewed employees responded to the statement "Employees are regularly consulted about health and safety issues."

### Document Review

Of the 797 OSHA Log entries during 2018, 17 (2.1%) were recorded among employees working in the area of the facility we evaluated. Among these 17 entries, 5 were dated after August 1, 2018, and included injuries due to strains of the abdomen, knee, or back. Only one of these employees was on the roster of 45 employees who worked with the dolly during our site visit. Upon further review of the OSHA Log entry and interview responses for this employee, the injury did not appear to be related to dolly use. None of the entries identified the specific equipment used when the injury occurred.

## Discussion

Considering the standard deviation of the measurement, the fully loaded (five roofs) original steel dolly had a minimum initial force that could exceed 44 lb which is the level acceptable to 90% of the female population.

The initial force reflects combined characteristics of the mechanical system of the cart, casters, and flooring condition and is independent of technique of the team member. However, the initial force is not reflective of dynamic conditions. Time pressures that may exist in the work process could not be simulated in the test measurements. It is difficult to replicate the highest levels of force to accelerate (or decelerate) the dolly that an employee might exert. The input of force under more realistic working conditions is dependent on individual technique with different acceleration characteristics. Therefore, the input of force under dynamic conditions will always exceed the minimum required levels reported here. This variation in technique was described in the medical interviews. For example, some employees emphasized keeping the dolly close to their body, while others preferred to use the momentum of the dolly and casters to spin the dolly on an axis using one arm. It is likely that such variations in technique, combined with time pressure on the job, will lead to a required initial force that exceeds the 90% female population guideline.

The push and pull forces of the aluminum dolly were less than that of the original steel dolly (Dolly 4). We observed similar steel dollies being used for panoramic roofs on other makes/models in different parts of the facility. We did not measure the push/pull forces on those dollies. However, because of the reduction in push/pull forces with the prototype aluminum dolly, management should consider incorporating them in the different parts of the facility.

Force requirements of the fully loaded (with five roofs) prototype aluminum dolly were less than that of the unloaded original steel dolly (Dolly 4), even though the weight of the fully loaded aluminum dolly was slightly higher than that of the unloaded steel dolly (920 lb versus 860 lb). This finding was unexpected; however, the casters on the prototype aluminum dolly were newer, which could account for this difference.

Prior to our first site visit, management installed a compressed air tank to the parent dolly. This air tank was meant to help initiate movement of the dolly out of the parent. When pressurized properly, the air tank would push the dolly more than half way out of the parent. We did not use the air assist during measurements of push/pull force. During our observations, the air tank was either not used or the air pressure in the tank was low and did not provide much assistance. Additionally, the hose connection to refill the tank was difficult to attach, and employees did not refill the tank on a consistent basis. These observations were consistent with employee interviews, during which employees reported varying dolly handling techniques, including varied use of the compressed air assist.

During employee observations, employees mentioned that Dolly 1 (back-up dolly) was more difficult to move. The performance of these steel dollies could have differed because of maintenance needs or effects of other mechanical wear and tear. However, the mean push/pull forces of Dolly 1 and Dolly 4 were similar, and we did not identify differences between the two steel dollies that would have affected their performance or push and pull force requirements.

We evaluated the effect of caster orientation on the initial push and pull force of Dolly 4 and the prototype aluminum dolly because we were concerned that caster orientation could influence push and pull forces. For example, when the casters were oriented perpendicularly to the push/pull force direction, the initial force of motion detected may have been the initial swivel of the dolly frame and payload, rather than the actual initial rolling of the caster wheel. In contrast, when the casters were aligned in the push/pull force direction, the initial force of motion would not include force related to caster swivel. However, we found that initial push or pull force was not dependent on the orientation of the casters. The caster design appears to minimize the effect of their initial orientation on the push/pull force.

Work-related lower back pain lasting a whole day or more was commonly reported among Conveyance Team 1, Line Side Moonroof Team, and other conveyance team employees. When reviewing the medical literature, only a small percentage of back pain cases have a clinically identified cause, and in the majority of cases, the cause is probably muscle strain and cannot be determined objectively [Riihimaki 1999]. A nationally representative health survey found that the 3-month weighted prevalence of low back pain among the U.S. working population was 26.4%, while the weighted prevalence of work-related low back pain (defined as any low back pain attributed to work by a health professional) was 5.6% [Luckhaupt et al. 2019]. The overall prevalence of low back pain in the U.S. working population is similar to the 26% prevalence of work-related low back pain reported by interviewed employees in our evaluation.

NIOSH has used a stricter definition of pain lasting one week or more in previous studies related to musculoskeletal disorders (MSDs) [Dickinson et al. 1992; Guo et al. 1995; Lu et al. 2014; Waters et al. 2011]. In contrast, the nationally representative health survey did not require a pain duration to identify low back pain [Luckhaupt et al. 2019]. We decided to use the definition of pain lasting a whole day or more to increase the sensitivity of our case definition. It is possible that the case definition used in this evaluation led to an overestimate of musculoskeletal pain among employees.

It is possible that the musculoskeletal pain reported by interviewed employees was related to ergonomic factors of the steel dollies. We found that the initial push/pull force for the original steel frame dolly (Dolly 4) in the fully loaded condition could be unacceptable for more than 10% of the female population. In addition, the height and width of the dolly handholds were higher than recommended [Humantech 2009]. Of the 42 interviewed employees, 31% had work-related pain that they attributed to dolly use. The majority (92%) of these employees reported that their pain was caused or made worse by repetitive activities involving the dolly. Therefore, improving the ergonomic design of the dolly or modifying job tasks might lead to a reduction in self-reported musculoskeletal pain among employees. However, it is important to note that interviewed employees performed many job tasks that could potentially contribute to musculoskeletal pain. For example, interviewed employees operated material handling equipment like forklifts, and previous HHEs have found that forklift operators are at an increased risk of developing neck and back pain [NIOSH 2018]. In addition, interviewed employees worked in their current positions for a median of 14.5 years (range: 6 months–30 years), and musculoskeletal pain might be the result of previous or recurring injuries that were unrelated to the dollies.

On average, employees reported a moderate level of job stress, and 17% of interviewed employees reported high job stress. Psychosocial factors may be associated with MSDs in the workplace [Lu et al. 2014; National Research Council 2001; Waters et al. 2011]. Psychosocial factors are associated with chronic increased muscle tension, thus making soft tissues more susceptible to the effects of physical stressors. Psychosocial factors may also raise awareness of MSD symptoms and affect reporting behavior [NIOSH 1997]. For example, the interactive effects of psychosocial factors (e.g., high workload, low social support, and low job satisfaction) and physical stressors are related to the development of musculoskeletal pain in the lower back [De Beeck and Hermans 2000; Leka et al. 2010]. One of the sources of job stress among conveyance employees was the "license point system" for PIE operators. In this system, employees accumulated points when accepted work practices thought to be safe were violated; this type of system is a system using a "negative" or "punitive" approach. Shifting to an incentive- or rewards-based approach, while still maintaining standards for safe PIE operation, might decrease job stress levels among conveyance employees. A combination of ergonomic, job design, and psychosocial interventions may result in decreased job stress and musculoskeletal pain.

Employee interview results suggest that communication between management and employees can be improved. Among employees who had ever reported a health or safety concern to management, over half responded that management did not communicate how they would address the concern. In addition, 38% of interviewed employees said that they disagreed or strongly disagreed with the statement "employees are regularly consulted about workplace health and safety issues." The employer should regularly consult with employees about their health and safety concerns and explain to employees how the concerns will be addressed or why no specific action will be taken in response to the concern. Doing so may strengthen positive perspectives of the employer's willingness to care for the well-being of the employees and lead to improvements in safety systems [Vecchio-Sudus and Griffiths 2004]. Employee involvement in decision-making is associated with greater job satisfaction, positive perceptions of work, and lower turnover [Kain and Jex 2010].

Among the 25 interviewed employees who reported any musculoskeletal pain lasting a whole day or more in the past 12 months, only 9 (36%) saw a doctor or other healthcare provider for the pain. While this might suggest a lower pain severity, 4 of these employees rated the severity of their pain in at least one body part as 3 or more (on a scale of 0 to 4). Seeking care from a qualified healthcare provider when musculoskeletal pain symptoms begin might help reduce pain severity among employees.

## Limitations

We did not measure the force required to sustain motion of the steel or aluminum dollies at a constant velocity. It was difficult to push the dolly straight with the force gauge applying point force. Further, we did not observe employees pushing or pulling the dolly over distances. Therefore, our measurements of initial force might underestimate the force required to initiate motion of the dolly during more realistic work activities. We did not measure handling forces that reflect rotation of the dolly or high acceleration conditions.

In addition, we did not assess push/pull forces exerted on the dolly by team members; rather, NIOSH ergonomists created motion on the dollies to measure push and pull forces. It is possible that some variation in measurement resulted from having a different ergonomist push and pull the dollies during this measurement. However, the initial required force is considered independent of the technique of the individual handling the dolly.

The design of this evaluation was cross sectional, and our interview relied on self-reported musculoskeletal symptoms and diagnoses. Cross-sectional studies measure exposures and health outcomes at a single point in time and are unable to measure a temporal relationship between exposure and health outcome. In addition, we relied on self-reported musculoskeletal pain lasting a whole day or more rather than the stricter definition of musculoskeletal pain lasting a week or more. This definition, combined with the heightened awareness of employee concerns regarding the steel dolly, might have led to an over-estimate of the prevalence of musculoskeletal pain among interviewed employees.

We were not able to conduct all interviews during the same site visit, but results were pooled for analysis purposes. We are not aware of any changes in work processes and procedures between the first and second site visits that would have impacted our evaluation of musculoskeletal pain among interviewed employees.

## Conclusions

The push/pull forces for the original steel dollies were generally within the recommended psychophysical guidelines. However, taking into consideration the standard deviation, the forces may exceed the guidelines under realistic working conditions. The prototype aluminum dolly substantially reduced the push/pull forces. The work-related musculoskeletal pain reported by 52% of employees—most commonly in the shoulder and lower back—might be related to the ergonomic design characteristics of the dolly. However, psychosocial factors and other activities at work or outside of work may also contribute to work-related musculoskeletal pain. Improved communication between managers and employees regarding occupational safety and health issues will likely improve the overall safety climate in this workplace.

## Section C: Tables

Table C1. Weight comparison (in lb) of the original steel dolly to the prototype aluminum dolly

| Condition | Original steel dolly | Prototype aluminum dolly |
|---|---|---|
| Empty | 860 | 440 |
| 1 panoramic roof | 956 | 536 |
| 2 panoramic roofs | 1,052 | 632 |
| 3 panoramic roofs | 1,148 | 728 |
| 4 panoramic roofs | 1,244 | 824 |
| 5 panoramic roofs (fully loaded) | 1,340 | 920 |

Table C2. Musculoskeletal pain that lasted a whole day or more reported by interviewed employees (n = 42)

| Musculoskeletal pain location | Work-related pain<br>No. employees (%) | Pain attributed to dolly use<br>No. employees (%) |
|---|---|---|
| Any pain | 22 (52) | 13 (31) |
| Shoulder | 14 (33) | 9 (21) |
| Low back | 11 (26) | 6 (14) |
| Neck | 6 (14) | 6 (14) |
| Hand | 5 (12) | 3 (7) |
| Other (elbow, upper back) | 4 (10) | 3 (7) |

Table C3. Work-related musculoskeletal pain lasting a whole day or more, reported by interviewed employees, by body site and team (n = 42)

| Musculoskeletal pain location | Conveyance Team 1<br>(n = 13) | Line Side Moonroof Team<br>(n = 14) | Other teams<br>(n = 15) |
|---|---|---|---|
| | No. (%) | No. (%) | No. (%) |
| Any pain | 8 (62) | 6 (43) | 8 (53) |
| Shoulder | 5 (38) | 3 (21) | 6 (40) |
| Lower back | 6 (46) | 2 (14) | 3 (20) |
| Neck | 3 (23) | 2 (14) | 1 (7) |
| Hand | 1 (8) | 3 (21) | 1 (7) |
| Other (elbow, upper back) | 2 (15) | 1 (7) | 1 (7) |

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