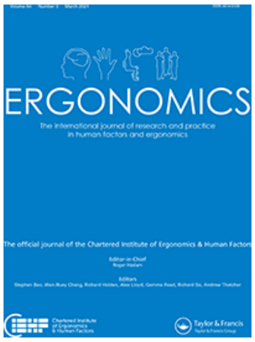

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A cross-sectional survey of musculoskeletal disorder hazard exposures and self-reported discomfort among on-shore wind turbine service technicians

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ABSTRACT

Background: Servicing and maintaining wind turbines may expose wind turbine technicians (wind techs) to musculoskeletal disorder (MSD) hazards. We aimed to characterise MSD hazard exposures and identify work elements that should be prioritised for MSD prevention efforts.
Methods: A cross-sectional online survey methodology gathered data from 144 wind techs based on a convenience, non-probability sampling approach. The survey was developed using resources from the Ontario MSD Prevention Guideline, where cognitive interviewing yielded wind tech specific modifications.
Results: Climbing was the most physically demanding task, followed by torqueing/tensioning and manual materials handling (MMH). However, working in awkward and constrained postures emerged as the task most likely to cause or aggravate discomfort.
Conclusions: Injecting ergonomic and human factors principles into wind turbine design should be a high priority. Re-engineering tools like torque tensioning devices may reduce MSD hazard exposures associated with tasks including torqueing/tensioning and MMH.

Practitioner Summary: We know little about musculoskeletal disorder (MSD) hazards associated with green jobs. By surveying wind turbine technicians, we learned that MSD hazards exists, and can be addressed by better considering human factors/ergonomics principles in the design of wind turbines and the tools required for service and maintenance operations.

Abbreviations: MSD: musculoskeletal disorder; MMH: manual materials handling; Wind techs: wind turbine technicians; CRE-MSD: centre of research expertise for the prevention of musculoskeletal disorders; CanWEA: Canadiarn wind energy association; HFE: human factors/ergonomics; ASME: American Society of Mechanical Engineers; CSA: Canadian Standards Association

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Green ergonomics; hazard identification; proactive ergonomics; physical ergonomics

Introduction

Canada's wind generation capacity has increased by 18 per cent every year for the past five years (CanWEA n.d.), and new wind farm installations are being constructed at a fast pace. As a result, wind turbine service technicians (wind techs) are in high demand to maintain a growing fleet of wind turbines (CanWEA n.d.). Wind techs perform essential job tasks related to the inspection, repair, replacement, and maintenance of critical wind turbine elements including the hub, blades, gearbox, yaw system, etc. (Milligan, O'Halloran, and Tipton 2019). Wind techs can spend up to 60 hours per year, per turbine, performing annual maintenance and servicing (Carroll, McDonald, and McMillan 2016), and an additional 7.5 hours up to 52 hours or more per turbine when performing minor repairs up to major replacements, respectively (Carroll, McDonald, and McMillan 2016). While wind techs continue to support and maintain a growing fleet of wind turbines, we know very little about how to protect and maintain a growing workforce of wind techs. Specifically, we know little about the musculoskeletal disorder (MSD) hazards that wind techs face (Jia et al. 2016; Freiberg et al. 2018), nor do we understand the physical health risks that may be related to those MSD hazard exposures. Our limited knowledge of MSD hazards and potential health risks hinders our ability to design and implement proactive MSD prevention efforts within the wind energy sector.

Understanding MSD hazard exposures and associated health risks are foundational requirements to

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inform primary MSD prevention efforts. van der Beek et al. (2017) suggest that interventions aimed at primary prevention have historically had limited success, in part because of a lack of understanding aetiological mechanisms. To improve the success of primary prevention interventions, van der Beek et al. (2017) suggest a 6-step framework for MSD prevention research beginning by understanding the incidence and severity of MSD, followed by understanding the risk factors for MSD. Consistent with this recommended best practice, the MSD prevention Guideline for Ontario (Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD) n.d., Comprehensive Step-by-Step) also prescribes steps, where hazard identification and risk assessment play an early and central role in supporting longer-term MSD prevention efforts. Emergent best practices (van der Beek et al. 2017; Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD) n.d., Comprehensive Step-by-Step) further reinforce the need to collect and describe data related to MSD hazard exposures and health risks to inform efficacious proactive MSD prevention efforts to protect the sustainability and viability of the wind tech workforce.

Several approaches exist to gather MSD hazard exposure and physical health risk data within an ergonomics context. Consistent with the MSD Prevention Guideline for Ontario (Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD) n.d., Comprehensive Step-by-Step) approach, self-report methods including staff feedback surveys and worker discomfort surveys provide cost-effective and reliable instruments. Similar to a job exposure matrix (e.g. Evanoff et al. 2019), staff feedback surveys invite respondents to indicate the presence of MSD hazards such as 'repeat the same movements or actions more than a few times a minute for more than 30 minutes at a time?' or 'lift, push, pull, or move heavy items?', using binary, yes/no responses. When respondents indicate the presence of an exposure, they may provide additional context about the magnitude of exposure, or specific job tasks where that exposure was present. The 1-year reproducibility of self-reported exposure data is established (d'Errico et al. 2007), supporting its utility as a useful tool to gather MSD hazard exposure data. Body maps, like the Nordic Questionnaire (Kuorinka et al. 1987), provide methods to gather respondents self-reported perception of pain or discomfort in specific body locations and are advocated to support worker-oriented ergonomic intervention (Messing et al. 2008). Body maps and associated visual analog scales or CR-10 exertion scales (Cameron 1996) can compliment MSD hazard data to begin elucidating sources of pain, discomfort, or high physical exertion. While physical examination remains as the gold standard, Nordic style body pain or discomfort maps provide a valid approach for the surveillance MSD symptoms (Descatha et al. 2007) pertaining to physical risks.

Protecting green jobs, like wind turbine service technician, by proactively addressing MSD hazards remains as both a challenge and opportunity in green ergonomics (Hanson 2013). As a first step to developing a comprehensive primary MSD prevention strategy, we need to understand hazard exposures and risks. Therefore, the purpose of this study was to identify and describe MSD hazard exposures and physical discomfort among wind techs using a cross-sectional survey-based methodology. To support and inform current ergonomics practice in the wind energy sector, we aimed to answer the question: what job tasks should be prioritised for proactive hazard identification and risk assessment? Equipped with a richer understanding of MSD hazard exposures and symptoms, consistent with best practice guidelines (van der Beek et al. 2017; Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD) n.d., Comprehensive Step-by-Step), we can delve deeper into root causes and specific mechanisms to inform the development of efficacious and effective interventions to support primary MSD prevention within the wind energy sector.

Methodology

Study design and sample

A cross-sectional online survey methodology was used to measure wind techs' self-report task related pain, discomfort and perceived exertion. The survey also gathered wind techs' feedback about potential MSD hazards associated with specific job tasks and inquired about prospective solutions that might help to address those emergent hazards.

In the absence of registry of wind techs, a convenience, non-probability sampling method was used for recruitment. Our recruitment strategy was informed by the Tailored Design Method (Dillman, Smyth, and Christian 2014) to maximise responses. Consistent with the overarching goals of the Tailored Design Method, we: developed a survey instrument that could be completed in a time efficient manner (i.e. minimise the cost of participation); provided adequate incentives for participation (i.e. offered a chance to win one of five \$100 gift cards); and, established trust with those

Table 1. Respondents listed physically demanding tasks (selected examples included) that were most demanding and also that likely caused or aggravated their discomfort. We characterised those open-ended response data into six overarching categories for additional analysis.

Category	Example response	Example response	Example response
Climbing	'Climbing the turbines'	'Climbing the ladder. 435' straight to the top'	'Climbing'
Torque/Tensioning	'Yaw spring pack torqueing'	'Any repetitive torqueing/tensioning of bolts'	'Torque yaw claws'
Manual materials handling	'Lifting bags over the crane hatch'	'Lifting bags'	'Lifting loads into nacelle'
Changing components	'Replace high speed shafts on gear boxes'	'Pitch cylinder replacement/pitch cylinder seal replacement'	'Yaw drive replacements'
Postural demands	'Crawling'	'Getting in and out of awkward work areas'	'Crawling over machinery to do work'
Other/Undisclosed	'Winter installation'	'Servicing'	'Blade greasing'

working as wind techs by using pre-survey messaging to reaffirm the value and necessity of participation to support MSD prevention within the wind energy sector.

To reach potential wind tech respondents, the Canadian Wind Energy Association (CanWEA) distributed an e-mail with the survey link to its member organisations (i.e. wind farm operations) on our behalf. In turn, member organisations were asked to re-circulate the message to their employees. Because of our recruitment approach, our sample is inclusive of wind techs working for Canadian wind farm organisations affiliated with CanWEA. In the future, the establishment of a registry of wind techs would permit the use of more direct communication methods, enable a more systematic and probabilistic sampling approach, and permit the calculation of a true response rate.

Survey instrument design

The survey instrument was developed based on existing resources made available through the Ontario MSD Prevention Guideline. Resources including the Worker Discomfort Survey (Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD) n.d., Worker Discomfort Survey), Perceived Exertion Survey (Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD) n.d., Perceived Exertion Survey,) and Staff Feedback Survey (Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD) n.d., Staff Feedback Survey) were adapted to the wind energy sector and combined into a single survey instrument, along with basic workforce profile and demographics questions (e.g. hours worked/week, height, age, experience). We used a cognitive interviewing approach (Collins 2003) to adapt the Ontario MSD Prevention Guideline resources, as necessary, to ensure that wording and language were consistent with the context and expectations of wind techs. To complete the cognitive interviewing process, a draft survey, inclusive of the as-is questions and prompts within the resources, was reviewed by a small group of five wind tech experts. Where necessary, wording was adapted to include examples specific to the wind energy sector. Additionally, in some cases additional follow-up questions were added such as, 'what is the wind turbine megawatt class rating where you perform that task' as a follow-up to the as-is Staff Feedback Survey question, 'What is the most physically difficult task you do?'

The survey instrument was coded into Qualtrics software (Seattle, Washington) and pilot tested to verify that all questions were included, properly sequenced and that any skip patterns were correctly coded.

Data analysis and statistics

While many survey questions were posed in an closed format, some probes invited open-ended responses. For example, respondents were asked to identify their top three most physically demanding tasks and also to identify which tasks likely caused or aggravated their discomfort. To analyse results from the above questions, a team of two researchers reviewed the complete list of open-text responses identifying six emergent themes (Table 1). Individual responses for related open-ended questions were then coded into one of those six themes to support further descriptive analysis.

Descriptive statistics (i.e., means, standard deviations, frequencies) were used to characterise responses. Additionally, we triangulated responses related to pain and discomfort, perceived exertion,

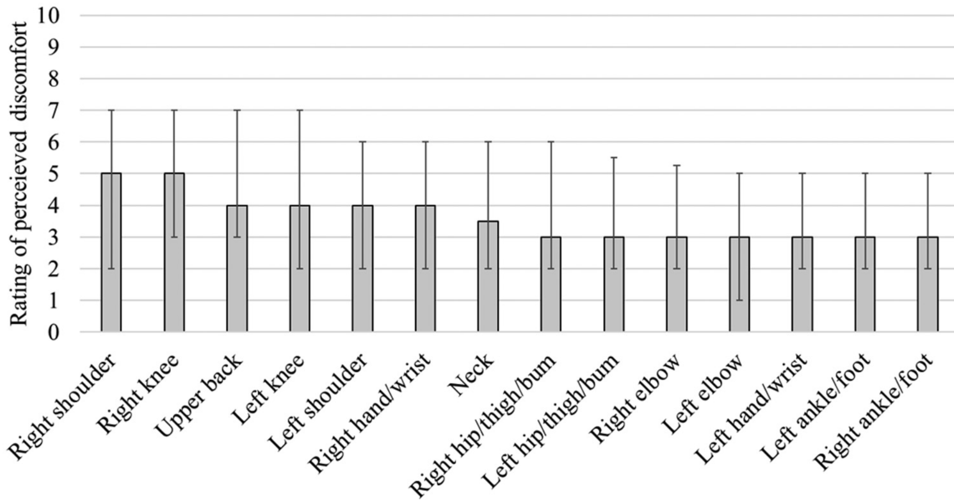

Figure 1. Median perceived discomfort score (0 low to 10 high) experienced by wind turbine technicians stratified by body region. Median values were calculated from all responses, inclusive of respondents who may have scored their discomfort as zero for a given body region. Error bars represent boundaries of lower and upper quartiles. Note that a low back category was unintentionally omitted from the body part regions when coding the body map into the Qualtrics survey software.

staff feedback and the MSD hazard identification tool to answer the question: 'what job tasks should be prioritized for proactive hazard identification and risk assessment?'

Results

We received 144 unique responses, an approximate response rate of 12% based on 1200 wind techs working in Canada at the time of our survey, as estimated by CanWEA. As a result, we are 95% confident that mean response data are within a ± 8% margin of error. The median survey completion time was 22 minutes (interquartile range of 15 to 33 minutes).

Demographics

The sample of wind techs responding to the survey included 130 males, 5 females and 9 respondents who preferred not to disclose their gender. The median age of respondents was 32 ± 9 years old, (range 20–64 years of age). Approximately half of the respondents had up to 5 years of experience (47%), where the remainder had five or more years of experience as a wind tech.

Self-report discomfort

In our survey of wind techs, 81% of respondents experienced some level of work-related discomfort in the past year. Of those reporting some level of work-related discomfort, over half responded 'yes' when asked 'Do you consider your discomfort to be a problem?' Respondents indicated their perceived level of discomfort across different regions of the body using a 10-point scale (0 is no discomfort, 10 is worst discomfort experienced). Respondents indicated a moderate level of discomfort in nearly all body areas and reported the greatest discomfort in the knees, shoulders and back (Figure 1).

Respondents were also asked to indicate the tasks or activities that likely caused or aggravated their discomfort. We classified perceived problematic tasks and activities, as indicated by wind techs, into the same categories that were used to classify heavy physically demanding tasks (Table 1). Task and activities constrained to require awkward postures were most frequently identified as the likely cause or aggravating factor regarding perceived discomfort (Figure 2).

High physical demand tasks and ergonomic hazard exposures

Respondents were asked to identify their top three most physically demanding tasks. For each physically demanding task, respondents were asked to indicate how often they perform the task (hours per month), in what area of the turbine they perform the task, and the megawatt class rating of the turbine where they perform that task. Open-ended responses were coded into one of six themes (refer to Table 1).

Climbing was identified as the most or second most physically demanding task, more than any other

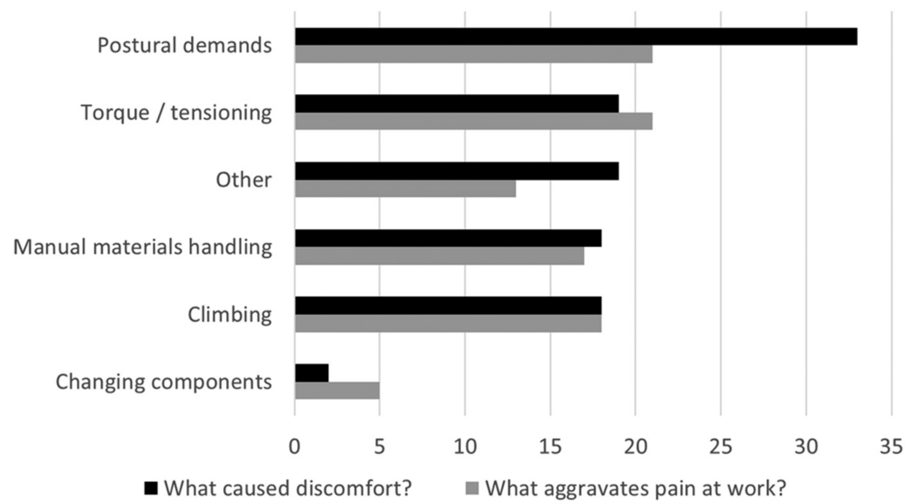

Figure 2. Number of respondents indicating a task as the likely cause or aggravating factor influencing their discomfort.

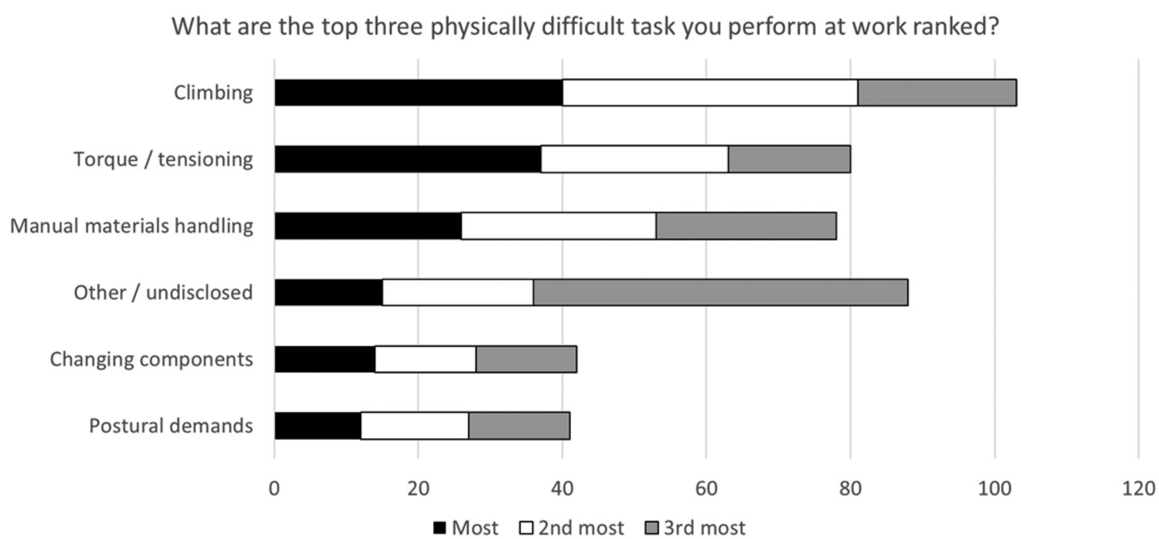

Figure 3. Number of respondents indicating a task as one of the top three most physically demanding tasks.

demand (Figure 3). On average, respondents reported spending 14 (range 1-40+) hours per month climbing. Additionally, when climbing was identified a most physically demanding task, 50% of cases referenced climbing within the inside-up tower and 51% of cases were related to climbing with a 1-2 MW class turbine. Torqueing/tensioning and manual materials handling followed climbing as the most physically demanding tasks (Figure 3). On average, respondents reported spending 16 and 17 hours per month torqueing/tensioning and performing manual materials handling, respectively. When torqueing/tensioning was identified, 62% of cases referred to work in the inside-up tower of the turbine. When manual material handling was identified, 52% of cases referred to work in the nacelle. Respondents spent the most time, on average, completing job tasks requiring postural demands (average of 23 hours per month).

Respondents also identified their frequency of exposure to ergonomic hazards. Over 50% of respondents reported exposure to each MSD hazard (Figure 4) on a daily basis. Exposures including working in a

Figure 4. Frequency of exposure to possible musculoskeletal disorder hazards.

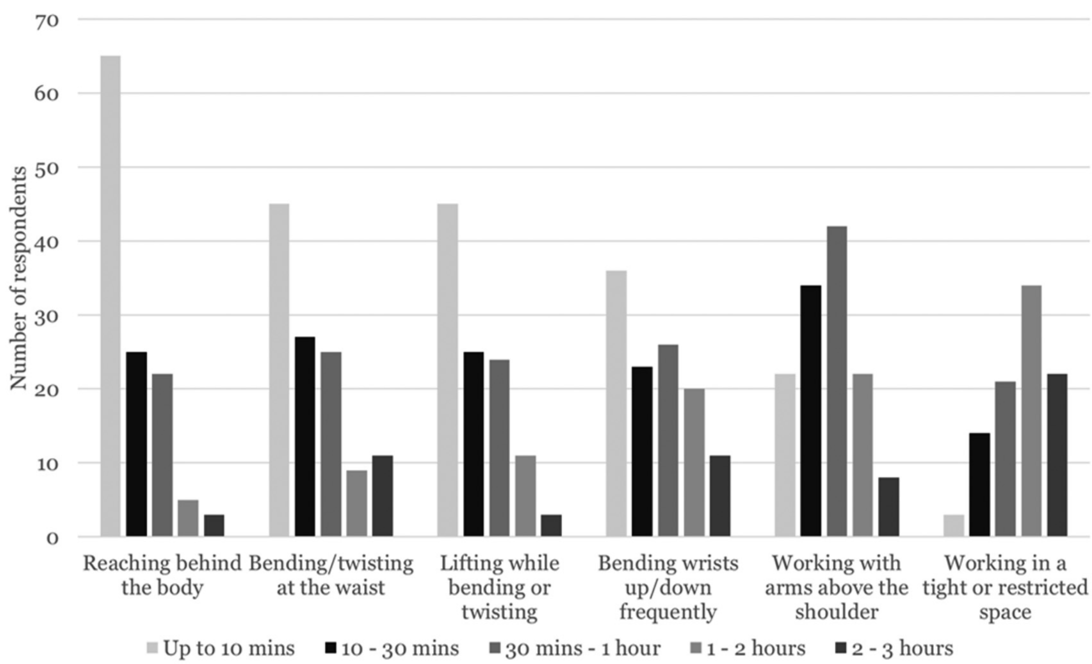

Figure 5. Reported average duration of each exposure to associated ergonomic hazards.

tight or restricted space, bending/twisting at the waist, bending wrists up/down frequently and working with arms above the shoulder were experienced daily for most respondents (Figure 4).

Respondents also indicated their average duration of exposure to each MSD hazard. When considering exposures including reaching behind the body, bending/twisting at the waist and lifting while bending or twisting, responses were distributed towards lower durations (Figure 5). Conversely, when considering exposures including bending wrists up/down frequently, working with arms above the shoulder and working in a tight or restricted space responses were distributed towards moderate and longer durations (Figure 5).

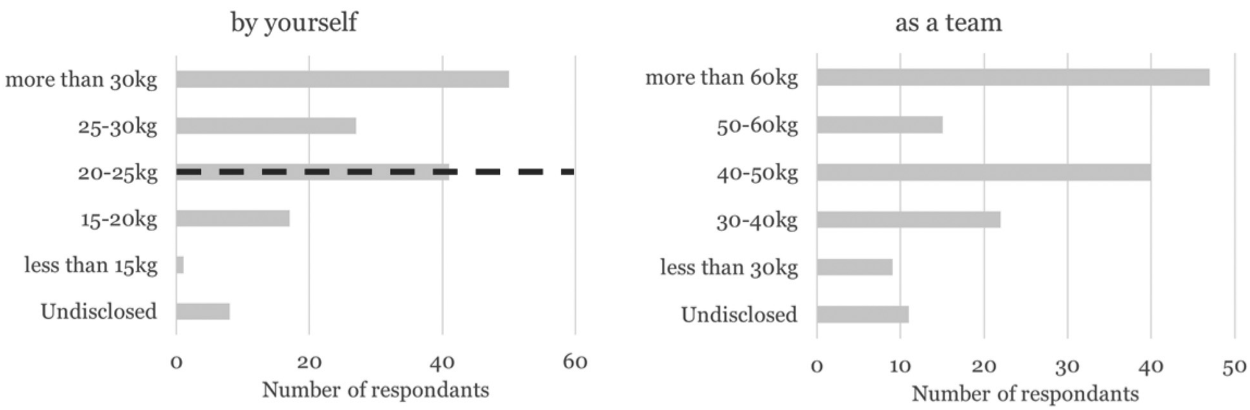

Figure 6. The maximum weight lifted by a wind turbine technician working alone (left pane) or as a team (right pane). The dashed line indicates the maximum recommended weight of 23 kg (Waters et al. 1993) for lifting under ideal conditions.

Lifting, pushing, pulling, and moving heavy objects are also known MSD hazards. One in three respondents indicated lifting objects weighing more than 30 kg on their own (Figure 6 – left pane). Lifting in teams of two, one in three respondents indicated lifting more the 60 kg (Figure 6 – right pane).

Wind techs lift, push, pull, and move many different objects. When asked to list the heaviest item, respondents included a range of objects that were classified into five categories: tool bags/service kits, parts/components, equipment/tools, motors/fans, and other/undisclosed. Tool bags/service kits, parts/components, and equipment/tools were most often selected as the heaviest items (Figure 7).

Respondents were asked to indicate their level of concern about suffering an injury as a result of their exposures to MSD hazards. Over 50% of respondents indicated that they were very concerned, or concerned about awkward postures, heavy lifting and repetition (Figure 8).

Opportunities and ideas for improvement

To identify what wind techs' believed could be improved we invited them to share their top three suggested improvements. Over 50% of respondents changes related to space, clearance or access within their top three suggested improvements (Figure 9). This finding corroborates the findings reported in Figure 8 where respondents indicated the greatest amount of concern with awkward postures and, Figure 2, identifying postural demands as the mostly likely cause or aggravating factor influencing discomfort. A complete list of anonymized survey responses is provided as an Supplementary Appendix.

Discussion

This study provides novel findings that inform a more comprehensive description of wind techs MSD hazard exposures and physical discomforts. In their scoping review, Freiberg et al. (2018) noted that health research in the wind turbine sector has focussed primarily on noise related outcomes, delivering a strong call-to-action for more MSD related research to better understand hazards and risks to wind energy sectors workers. Despite that call-to-action, a knowledge gap still persists. Our only insights about ergonomic hazard exposures come from a survey of wind techs focussing specifically on low back pain (Jia et al. 2016). Based on results from the Washington State Ergonomics Tool, which was embedded in their survey, lifting objects weighing more than 4.5 kg twice per minute or more, was identified as a workplace factor associated with low back pain prevalence (Jia et al. 2016). Our results compliment and extend findings by Jia et al. (2016). By broadening the focus to pain and discomfort at any body region, and by providing wind techs with more freedom to self-identify tasks that they deem to be problematic we provided workers with a stronger voice in the identification of MSD hazards process (Messing 2014). In addition to reaffirming MSD hazard exposures related to lifting (Jia et al. 2016), our findings also reinforce the need to consider workspace layout and design (related to space restrictions and awkward postures), torqueing/tensioning tasks, and ladder climbing requirements to

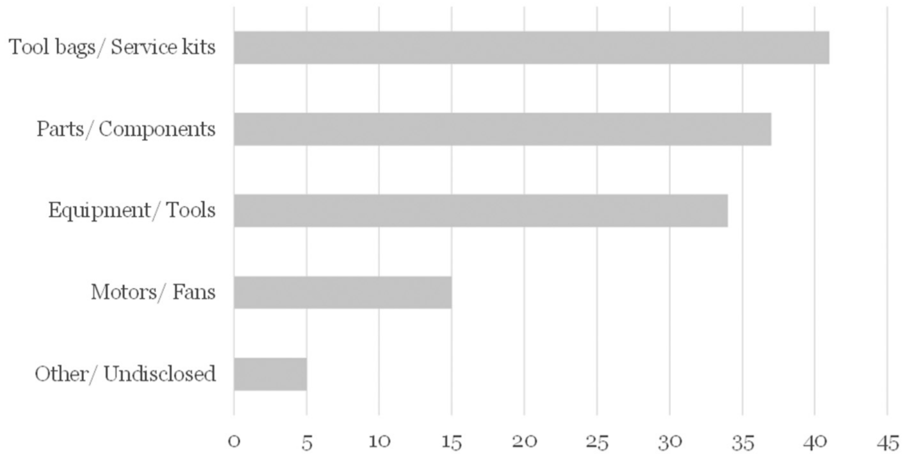

Figure 7. Number of respondents indicating an object as the heaviest lifted, pushed, pulled, or moved.

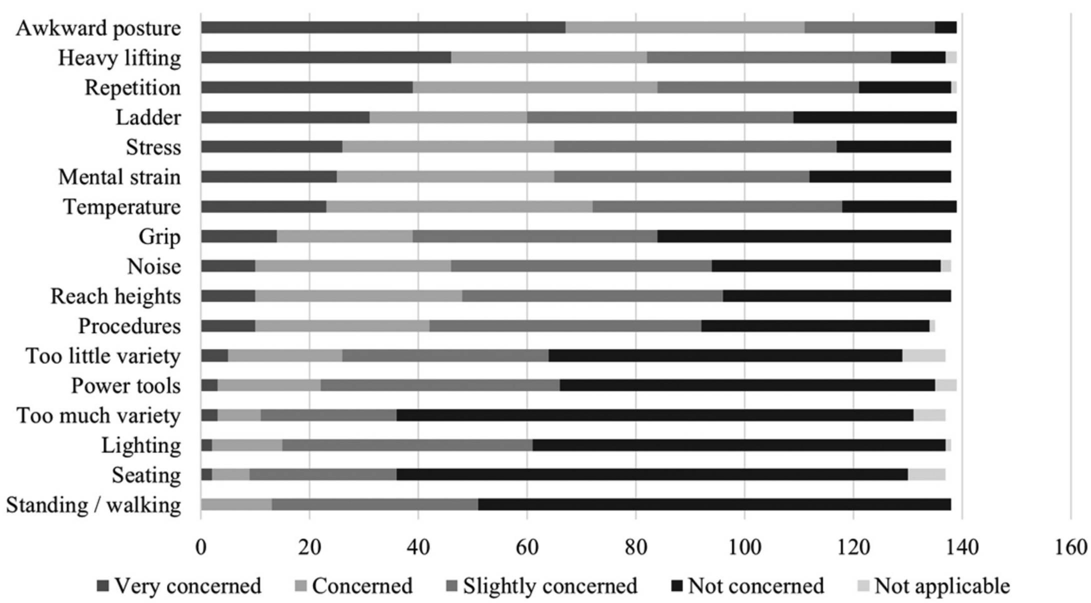

Figure 8. Respondents perceived level of concern for injury related to exposures to each listed ergonomic hazard.

maximise the benefits of emergent proactive ergonomics programs for wind techs.

Respondents self-reported discomfort scores provide evidence that MSD prevention efforts to support wind techs should be a high priority. Although not indicative of specific pathology, self-reported discomfort that is above 2on a 0-10 scale may be a useful predictor of future musculoskeletal pain (Hamberg-van Reenen et al. 2008). Hamberg-van Reenen et al. (2008) demonstrated that individuals reporting body discomfort were more likely to suffer future back, neck and shoulder pain as measured using a Nordic Questionnaire, consistent with similar results reported by Werner et al. (2005). In our survey of wind techs, 81% of respondents experienced work-related discomfort in the past year, where the median values for respective body regions ranged from 3 to 5, and where the interquartile range (25th–75th) ranged from 1 to 7 on a 10-point scale. The magnitude of median responses is likely important, considering that respondents were given the anchors of no discomfort ('0') and worst discomfort ever ('10'). While difficult to directly comment on an individual's perception of discomfort, or whether respondents may have misinterpreted between pain and discomfort, median responses approaching the mid-point of the scale

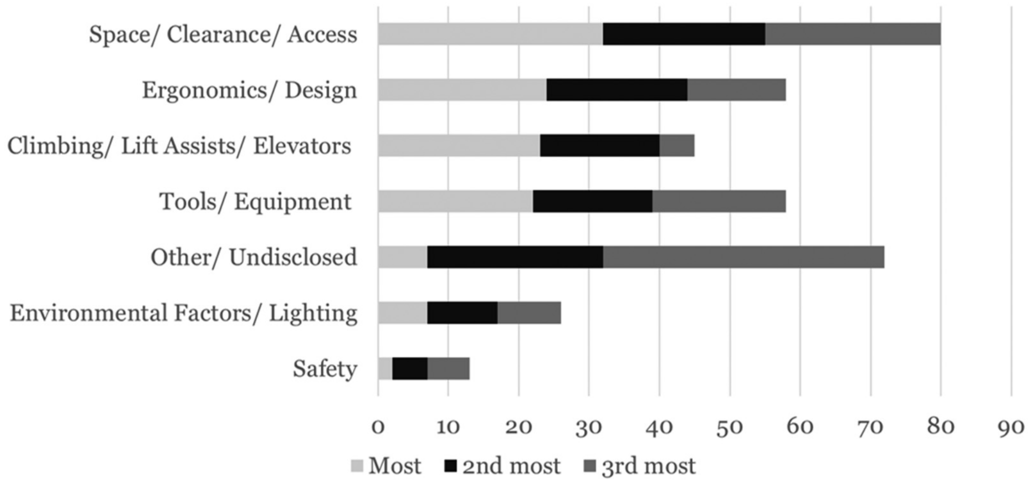

Figure 9. Number of respondents indicating a task as one of the top three opportunities for improvement.

(e.g. knees, back, shoulders), using the aforementioned anchors, raises some cause for concern. Considering the magnitude of median responses, the results of Hamberg-van Reenen et al. (2008), and that over 50% of those reporting discomfort feel that their discomfort is a problem, the high prevalence of discomfort reporting among wind techs may foreshadow a significant future MSD problem, if left unchecked.

While this study was not designed to specifically quantify causal factors, results highlight prospective MSD hazards that should be more fulsomely investigated and controlled where necessary. When asked to identify their top three physically demanding tasks, wind techs' responses were rank-ordered as (1) climbing, (2) torqueing/tensioning, and (3) manual materials handling. However, when juxtaposed against responses related to wind techs' perceived level of concern for specific MSD hazards and wind techs' indication of tasks that have likely caused or aggravated their discomfort, postural demands/awkward postures stood out more so than other factors. For this reason, further investigation and intervention to address workspace layout issues is warranted as a high priority.

Survey responses triangulate to support that turbine workspace layout should be a key focal point within a multi-pronged MSD prevention program for wind techs. Wind techs noted that they spend considerable time in tight or restricted spaces, listed awkward postures as the most 'very concerning' ergonomic hazard, most often identified postural demands as a causal or aggravating factor in their perceived discomfort, and lastly listed space/clearance/access as their top 'preferred change'. However, workspace layout is primarily driven by wind turbine design. Considering the results of our survey, it is likely important that human factors/ergonomics (HFE) principles are more prominently considered within the design of wind turbines. For reference, the Canadian Standards Association (CSA) standard Z1004-12 (Canadian Standards Association (CSA) 2012) reaffirms the importance of considering ergonomics in design, drawing attention specifically to the importance of considering how design will impact on operation and maintenance. This includes designing to mitigate MSD hazard exposures to those responsible for performing operations and maintenance, supporting previous claims by Hanson and Thatcher (2019) who also nicely summarise the need for enhanced consideration of HFE principles into design, noting specific examples related to the greasing points, which can effect both posture and repetition based physical demands. While American Society of Mechanical Engineers (ASME) standards including a forthcoming update to ASME section 17.8 (Donoghue, 2016) regarding elevators and wind turbines are slowly becoming more inclusive of HFE principles, it is important that such principles are also considered and applied to the design of the interior workspace and layout of the wind turbine, particularly the nacelle. Ensuring the inclusion of HFE professionals on technical standards committees may provide a viable means to ensure that HFE considerations are more fulsomely considered.

Novel wind turbine designs that better consider the workspace layout needs of wind techs who must maintain the safe operation of those turbines is paramount; however, considering MSD prevention related to aspects of work including climbing, torqueing/tensioning, and manual materials handling is also important. The identification of climbing, torqueing/tensioning, and manual materials handling as physically demanding is consistent with similar findings based on off-shore wind techs (Milligan, O'Halloran, and Tipton 2019). The only differences between the physically demanding tasks identified by on-shore wind techs in our study and off-shore wind techs, as reported on by Milligan, O'Halloran, and Tipton (2019) was the addition of 'transferring from a vessel to the turbine' and 'hauling a casualty up the turbine' tasks. This may not be surprising since those additional tasks are indeed specific to off-shore wind turbine maintenance. The overlapping findings regarding the physicality of tasks including climbing, torqueing/tensioning, and manual materials handling reinforce the importance of focussing attention to these activities when considering MSD prevention programs for wind techs.

Climbing was identified as the most physically demanding task by wind techs responding to our survey. Where some turbines have elevator systems (typically newer or larger turbines), many older or smaller turbines (i.e. 1-2 MW class turbines) still require ladder climbing to navigate within the turbine. With reference to off-shore turbines, wind techs may climb distances ranging from 80 m to 120 m, multiple times per day (Milligan, O'Halloran, and Tipton 2019), at rates between 30 and 67 rungs per minute (Milligan, O'Halloran, and Tipton 2020). As a result, following a 120 m climb, Milligan, O'Halloran, and Tipton (2020) observed significant decreases in grip strength and endurance post-climb in addition to altered climbing movements, when faced with multiple climbs. These changes were attributed to fatigue (Milligan, O'Halloran, and Tipton 2020). With respect to a potential MSD prevention approach, control via substitution of ladders with elevators (where feasible) would likely help mitigate the physical demands of climbing; however, this intervention will likely be most useful in smaller or older turbines that may not have climb assist functionality. Additionally, Milligan, O'Halloran, and Tipton (2020) provide evidence that experienced wind techs may climb with more energetically optimised strategies, suggesting that early training interventions as an administrative control may also be efficacious. Emerging evidence also highlights the potential for 'climb assist' technologies to serve as engineering controls (Barron et al. 2017), to decrease the physicality associated with climbing.

Wind techs are required to torque and tension bolts when maintaining or replacing parts within the turbine. Milligan, O'Halloran, and Tipton (2019) report that off-shore wind techs spend about 20% of their work time on torqueing and tensioning which includes applying torque to (un)secure bolts, often in awkward postures, and also while handling heavy equipment including a tension head device that can weight up to 19 kg. Those results overlap with our survey findings, where more than 50% of our wind tech respondents spent more than 30 minutes at a time exposed to awkward posture related MSD hazards including bending wrists up/down frequently and working with arms above the shoulder, most likely while (un)torqueing bolts. As a result, it was not surprising to see many respondents identify tools and equipment as an opportunity for improvement, where many specifically identified the need for lighter tensioning tools. These data provide evidence that wind techs perform torqueing and tensioning tasks that expose them to MSD hazards. It is important to verify if and when those exposures exceed relevant threshold values in order to prioritise and maximise MSD prevention program efforts.

Manual materials handling and specifically lifting has long been associated with MSD. It was surprising that nearly 50% of wind tech respondents lifted objects in excess of 25 kg on their own, although many wind farms have implemented safe lifting policies that require a team approach for lifts greater than 20 kg. However, our results were consistent with Milligan, O'Halloran, and Tipton (2019) who reported that manual handling of loads up to 27 kg in a single person lift was a common physically demanding task. When considering two-handed lifting, under ideal conditions (good grip, symmetrical lift, low frequency, etc.), the National Institute for Occupational Safety and Health (NIOSH) suggests a maximum recommended weight limit of 23 kg (Waters et al. 1993). Given the workspace layout in the turbine, we speculate that wind techs are exposed to conditions that are likely far from ideal, such that recommended weight limits within the turbine would likely be lower. Intervening on manual materials handling exposures, including lifting, likely requires a multi-faceted approach targeting substitution and engineering related controls, since administrative controls in the form of lift education have shown limited efficacy in the prevention of MSD (Denis et al. 2019). Specifically, tool bags/service kits were most frequently identified as the 'heaviest' object moved. This points to a need for interventions and advances that can reduce the weight of tensioning tools. Reducing tool weights would likely benefit both in terms of reducing torqueing and tensioning demands, and also reducing the physical demands of manual materials handling.

Our sample only included data from five females, accounting for less then 5% of our sample, where it is important to consider sex/gender as it can play a critical role in the development of MSD (Côté, 2016). Few identified female responses could suggest that our sample is unrepresentative of the female wind tech experience; however, a report prepared by Electricity Human Resources Canada for Natural Resources Canada suggests that women only make up 20–25% of the clean energy workforce, and only up to 11% of the occupational group defined as technician/technologist (Electricity Human Resources Canada, 2017). Based on the available evidence, our data may modestly underestimate the female experience, but perhaps more importantly, our data reinforce the sex/gender gap within the wind technician workforce. While future work should explore if and how MSD exposures and risks may differ as a function of sex/gender among wind techs, it may also prove useful to probe possible systemic barriers that may be influencing the inclusion of females as wind techs. Issues like the perception of a traditional male-dominated industry and workplace culture (perhaps related to the heavy physical demands) noted by the Electricity Human Resources Canada report (2017), may serve as barriers to address when aiming to create a more inclusive workforce.

These data provide important and necessary evidence about the self-report discomfort and MSD hazard exposures that wind techs face. However, it is important to highlight a few limitations that should inform the interpretation of these findings. As noted above, we were not able to obtain a registry of wind techs, which limited our ability to apply a more rigorous sampling strategy and to calculate a true response rate. However, based on an estimate of 1,200 wind techs in Canada, our response rate was approximately 12%, which is low. We attribute the low response rate, in part, to our recruitment strategy where messaging was circulated from CanWEA, to wind farm operations to be forwarded on to wind techs directly. Despite our efforts to pre-message the survey, and to provide transparency about the intentions of the survey, anecdotally, we understand that some wind farms may have elected not to forward the message on to their wind tech work force. This would have limited both our sample size and the likely number of respondents. Alternatively, it is possible that those without access to appropriate technology (i.e. a laptop or tablet) or those who may be less confident writers (as necessary to respond to open-ended questions) may have passed on the opportunity to participate, which again could be a factor that may partially explain our low sample size. Considering that we did not have a registry, we were unable to identify and follow-up with non-responders to quantify potential non-response bias. It is possible that only those with significant concerns responded to our survey, which would inflate findings related to perceived pain and discomfort. However, in the absence of insights from non-responders, the potential for non-response bias remains as a limitation. It is also important to acknowledge that our results are based on maintenance and operations requirements performed by wind tech in Canada to support on-shore wind turbine operations. While physically demanding tasks are similar between on-shore (our study) and off-shore (Milligan, O'Halloran, and Tipton 2019) wind techs, important situational and environmental factors likely persist that could influence MSD prevention strategy implementation at a system level. As a result, these data should not be used to directly inform MSD prevention strategies for off-shore wind turbine operations.

Conclusions

These data represent the first comprehensive survey of perceived discomfort and self-reported MSD hazard exposures among wind techs working to service and maintain an ever growing fleet of wind turbines. While evidence indicates that climbing may be the most physically demanding task that wind techs face, the constrained work spaces and layout inside the wind turbine may be the most problematic from an MSD hazard exposure perspective. As a result, these data provide strong evidence that HFE principles should be more robustly considered within the design of wind turbines. Notwithstanding the importance of pro-actively addressing wind turbine design, survey results also indicate opportunities to further investigate and control MSD hazards associated with climbing, torqueing/tensioning and manual materials handling. Future endeavours focussing on the re-design and re-engineering of tools including torque tensioning devices would serve to reduce MSD exposures associated with both torqueing/tensioning and manual materials handling, and were strongly advocated for by responding wind techs. The need for a capable workforce of wind techs continues to grow around the world. It is imperative that we focus our efforts on monitoring and preventing MSD hazard exposures to wind techs to maintain the viability of the workforce over the long term.

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References

Barron, P. J., K. Burgess, K. Cooper, and A. D. Stewart. 2017. "The Physiological Effect of a 'Climb Assist' Device on Vertical Ladder Climbing." *Ergonomics* 60 (7): 1008–1013. doi:10.1080/00140139.2016.1244290.

Cameron, J. A. 1996. "Assessing Work-Related Body-Part Discomfort: Current Strategies and a Behaviorally Oriented Assessment Tool." *International Journal of Industrial Ergonomics* 18 (5–6): 389–398. doi:10.1016/0169-8141(95)00101-8.

Canadian Standards Association. 2012. *CSA Standard Z1004-12, Workplace Ergonomics–A Management and Implementation Standard*. Mississauga, ON: CSA Group.

CanWEA. n.d. "Health and Safety." https://canwea.ca/operations-and-maintenance/health-and-safety/.

CanWEA. n.d. "Operations & Maintenance." https://canwea.ca/operations-and-maintenance/.

Carroll, J., A. McDonald, and D. McMillan. 2016. "Failure Rate, Repair Time and Unscheduled O&M Cost Analysis of Offshore Wind Turbines." *Wind Energy* 19 (6): 1107–1119.

Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD). "Comprehensive Step-by-Step." Accessed 21 May. www.msdprevention.com/Comprehensive-step-by-step.htm.

Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD). 2019. "Worker Discomfort Survey." Accessed 21 May. https://www.msdprevention.com/resource-library/view/worker-discomfort-survey.htm.

Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD). n.d. "Perceived Exertion Survey." CRE-MSD. Accessed 21 May 2019. https://www.msdprevention.com/resource-library/view/perceived-exertion-survey.htm.

Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD). 2019. "Staff Feedback Survey." Accessed 21 May. https://www.msdprevention.com/resource-library/view/staff-feedback-survey.htm.

Collins, D. 2003. "Pretesting Survey Instruments: An Overview of Cognitive Methods." *Quality of Life Research: An International Journal of Quality of Life Aspects of Treatment, Care and Rehabilitation* 12 (3): 229–238. doi:10.1023/a:1023254226592.

Côté, J. 2016. "Can Using a Sex/Gender Lens Provide New Insights into MSD Mechanisms?" Keynote presented at the 9th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders, Toronto, ON.

d'Errico, A., R. Gore, J. E. Gold, J. S. Park, and L. Punnett. 2007. "Medium-and Long-Term Reproducibility of Self-Reported Exposure to Physical Ergonomics Factors at Work." *Applied Ergonomics* 38 (2): 167–175.

Denis, D., M. Gonella, M. Comeau, and M. Lauzier. 2019. *Why Doesn't Training Based on Safe Handling Techniques Work? A Critical Review of the Literature*. Montreal, Quebec: Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRRST).

Descatha, A., Y. Roquelaure, J. F. Chastang, B. Evanoff, M. Melchior, C. Mariot, C. Ha, E. Imbernon, M. Goldberg, and A. Leclerc. 2007. "Validity of Nordic-Style Questionnaires in the Surveillance of Upper-Limb Work-Related Musculoskeletal Disorders." *Scandinavian Journal of Work, Environment & Health* 33 (1): 58–65. doi:10.5271/sjweh.1065.

Dillman, D. A., J. D. Smyth, and L. M. Christian. 2014. *Internet, Phone, Mail, and Mixed-Mode Surveys: The Tailored Design Method*. Hoboken, NJ: John Wiley & Sons.

Donoghue, E. A. 2016. *A17.1 Handbook on Safety Code for Elevators and Escalators*. New York, NY: American Society of Mechanical Engineers.

Electricity Human Resources Canada. 2017. "Profile of women working in the clean energy sector in Canada." https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/energy-resources/Profile_of_Women_Working_in_the_Clean_Energy_Sector_in_Canada_compressed.pdf.

Evanoff, B. A., M. Yung, S. Buckner-Petty, J. H. Andersen, Y. Roquelaure, A. Descatha, and A. M. Dale. 2019. "The CONSTANCES Job Exposure Matrix Based on Self-Reported Exposure to Physical Risk Factors: Development and Evaluation." *Occupational & Environmental Medicine* 76 (6): 398–406.

Freiberg, A., C. Schefter, M. Girbig, V. C. Murta, and A. Seidler. 2018. "Health Effects of Wind Turbines in Working environments – a scoping review." *Scandinavian Journal of Work, Environment & Health* 44 (4): 351–369. doi:10.5271/sjweh.3711.

Hamberg-van Reenen, H. H., A. J. Van Der Beek, B. M. Blatter, M. P. Van Der Grinten, W. Van Mechelen, and P. M. Bongers. 2008. "Does Musculoskeletal Discomfort at Work Predict Future Musculoskeletal Pain?" *Ergonomics* 51 (5): 637–648. doi:10.1080/00140130701743433.

Hanson, M. A. 2013. "Green Ergonomics: Challenges and Opportunities." *Ergonomics* 56 (3): 399–408. doi:10.1080/00140139.2012.751457.

Hanson, M. A., and A. Thatcher. 2019. "Identifying Human Factors and Ergonomics Issues in Green Jobs: Facilitating Sustainable Green Jobs." In *Human Factors for Sustainability: Theoretical Perspectives and Global Applications*, edited by A. Thatcher, K.J. Zink & K. Fischer, Chapter 8, 171–192. Boca Raton: CRC Press.

Jia, N., T. Li, S, Hu, X. Zhu, K. Sun, L. Yi, Q. Zhang, G. Luo, Y. Li, X. Zhang, Y. Gu, and Z. Wang. 2016. "Prevalence and Its Risk Factors for Low Back Pain among Operation and Maintenance Personnel in Wind Farms." *BMC Musculoskeletal Disorders* 17 (1): 314. doi:10.1186/s12891-016-1180-y.

Kuorinka, I., B. Jonsson, A. Kilbom, H. Vinterberg, F. Biering-Sørensen, G. Andersson, and K. Jørgensen. 1987. "Standardised Nordic Questionnaires for the Analysis of

Musculoskeletal symptoms." *Applied Ergonomics* 18 (3): 233–237. doi:10.1016/0003-6870(87)90010-x.

Messing, K. 2014. *Pain and Prejudice: what Science Can Learn about Work from the People Who Do It. Between the Lines*. Toronto, ON.

Messing, K., N. Vézina, M. Ève, S. Ouellet, F. Tissot, V. Couture, and J. Riel. 2008. "Body Maps: An Indicator of Physical Pain for Worker-Oriented Ergonomic Interventions." *Policy and Practice in Health and Safety* 6 (2): 31–49. doi:10.1080/14774003.2008.11667722.

Milligan, G. S., J. P. O'Halloran, and M. J. Tipton. 2019. "A Job Task Analysis for Technicians in the Offshore Wind Industry." *Work* 63 (4): 537–545. doi:10.3233/WOR-192961.

Milligan, G. S., J. O'Halloran, and M. J. Tipton. 2020. "An Ergonomics Assessment of Three Simulated 120 m Ladder Ascents: A Comparison of Novice and Experienced Climbers." *Applied Ergonomics* 85: 103043. doi:10.1016/j.apergo.2019.103043.

van der Beek, A. J., J. T. Dennerlein, M. A. Huysmans, S. E. Mathiassen, A. Burdorf, W. van Mechelen, J. H. van Dieën, M. H. Frings-Dresen, A. Holtermann, P. Janwantanakul, H. F. van der Molen, D. Rempel, L. Straker, K. Walker-Bone, and P. Coenen. 2017. "A Research Framework for the Development and Implementation of Interventions Preventing Work-Related Musculoskeletal Disorders." *Scandinavian Journal of Work, Environment & Health* 43 (6): 526–539. doi:10.5271/sjweh.3671.

Waters, T. R., V. Putz-Anderson, A. Garg, and L. J. Fine. 1993. "Revised NIOSH Equation for the Design and Evaluation of Manual Lifting Tasks." *Ergonomics* 36 (7): 749–776. doi:10.1080/00140139308967940.

Werner, R. A., A. Franzblau, N. Gell, S. S. Ulin, and T. J. Armstrong. 2005. "Predictors of Upper Extremity Discomfort: A Longitudinal Study of Industrial and Clerical Workers." *Journal of Occupational Rehabilitation* 15 (1): 27–35. doi:10.1007/s10926-005-0871-2.