Occupational Health Science (2022) 6:73–110
https://doi.org/10.1007/s41542-021-00106-4

ORIGINAL RESEARCH ARTICLE

Musculoskeletal Health and Perceived Work Ability in a Manufacturing Workforce

Alicia G. Dugan[1] · **Rick A. Laguerre**[2] · **Janet L. Barnes-Farrell**[2] · **Jennifer M. Cavallari**[1,3] · **Jennifer L. Garza**[1,3] · **Lindsey A. Graham**[4] · **Gretchen A. Petery**[5] · **Nicholas Warren**[1] · **Martin G. Cherniack**[1]

Received: 2 March 2021 / Revised: 12 October 2021 / Accepted: 13 October 2021 /
Published online: 5 November 2021

Abstract
Aging workers in manufacturing are at greater risk of workforce departure than in other sectors. Workers in manufacturing have a variety of job types. Some jobs require traditional kinds of intensive manual labor, but new technology now requires many workers to operate automated machines from computer workstations, resulting in different physical demands from traditional production jobs that can nonetheless contribute to musculoskeletal strain and decreased functional capacity. Musculoskeletal health (MSH) and perceived work ability (PWA) are relevant to departure decisions, yet studies rarely model these constructs simultaneously. We used the job demands-resources model to evaluate job/personal demands and resources as antecedents of MSH and PWA, and examine both as mediators of departure. Workers from six U.S. manufacturers completed surveys ($N=758$). Most were white, male, married, and middle-aged ($M=47.2$ years). Hypotheses were tested using multiple linear regression and structural equation modeling. MSH and PWA were modeled as latent variables, and all others as observed variables. MSH and PWA were impacted by different demands and resources. Job demands (computer-based) and personal resources (sleep quality, leisure-time walking) predicted MSH, and job resources (supervisor support) and personal resources (sleep surplus) predicted PWA. MSH mediated relations of computer-based job demands, sleep quality, and leisure-time walking with PWA. MSH and PWA were unrelated to departure, likely due to sampling limitations. Identifying upstream causes of MSH and PWA provides primary preventative points of intervention – such as reducing job demands and offering needed resources – that may improve the health and functioning of aging workers.

Keywords Musculoskeletal health · Work ability · Workforce departure · Aging workers · Manufacturing

✉ Alicia G. Dugan
adugan@uchc.edu

Extended author information available on the last page of the article

Introduction

The average age of the American workforce is increasing, as a result of current demographic and social trends, including the aging of the population and the baby boom generation, an increase in life expectancy, and a decline in fertility rates (Ilmarinen, 2001; Loeppke et al., 2013). The proportion of the U.S. workforce aged 55 and older was 22% in 2014, and will increase to an estimated 25% by 2024 (Toossi, 2015). Moreover, the current U.S. trend is toward later retirement (Wheaton & Crimmins, 2012), an expected outcome following the 2008 Great Recession due to reductions in retirement savings and independently from policies that have raised the eligibility age for receiving full social security benefits. This workforce age increase is advantageous to the overall national economy because there are insufficient numbers of younger workers available to replace aging workers when they exit the workforce. Organizations also benefit from retaining older workers because, compared to younger workers, they have greater experience, a stronger work ethic, as well as more autonomy, efficiency, and work-life flexibility, and less work stress and coworker conflict (Loeppke et al., 2013; Shultz & Adams, 2012).

However, on average older workers face more health-related difficulties than younger workers, including decreases in physical capacity, working memory, cognition, vision and hearing acuity, and higher prevalence of musculoskeletal disorders (Loeppke et al., 2013; National Research Council, 2004; Silverstein, 2008). Older workers also experience work-related challenges from excessive job demands (long hours, shift work) and reduced re-employment opportunities. They require longer time for recovery from injury/illness than younger workers, and job-related injuries are more likely to be severe or fatal (Loeppke et al., 2013; Silverstein, 2008).

Musculoskeletal Health in the Manufacturing Sector

The aging of the workforce is of special concern to manufacturers, as the average age of workers in that sector is increasing faster than the workforce in other sectors (Sweet et al., 2010). Manufacturing encompasses a variety of job types with varying demands. Some jobs are characterized by the kinds of manual, labor-intensive job demands traditionally found in heavy industry (e.g., tasks requiring forceful exertion, speed, heavy lifting, vibration, uncomfortable temperatures) that pose obvious risk of injury and poor musculoskeletal health (Segar & Rahman, 2019). Other manufacturing jobs are characterized by demands that are increasingly common in light industry as new technology now requires many workers to staff computer workstations to operate and monitor automated machines (and possibly to load/unload small materials into machines) (Segar & Rahman, 2019). Contemporary computer-aided machining jobs have different physical demands (i.e., static or dynamic sitting/standing postures, disadvantageous upper-extremity positions resulting in forward flexion and shoulder rotation) that are problematic in their own way (Deros et al., 2013), and can pose musculoskeletal risks more common among administrative workers than workers in traditional manual-machining jobs. Administrative workers have their own physical demands including prolonged computer work, combined with excessively static, sedentary work (Crandall et al., 2016; Wærsted et al., 2010).

Workers of all job types within the manufacturing sector have musculoskeletal demands, but they take different forms; examining variation in demands can help elucidate their relation to work ability and musculoskeletal health. Further, combined with long or variable hours (e.g., overtime and shiftwork) with little schedule control and insufficient recovery time, and a challenging psychosocial environment (Gerr et al., 2014; NORA, 2010; Sweet et al., 2010), physical work demands can pose a challenge as workers in manufacturing age because of decreasing physical and adaptive capacity and also cumulative strain from years of work. These same job characteristics also put workers at risk for musculoskeletal disorders (Punnett & Wegman, 2004).

Musculoskeletal disorders (MSDs) include a broad range of inflammatory and degenerative diseases and disorders resulting in pain, primarily in the soft tissues, and impaired function (Buckle & Devereux, 2002). A conceptual framework of contributors to MSDs posits that work-related factors (e.g., demands, resources) and personal factors (physical and psychological demands and resources) potentially contribute to MSDs as they may incite a physiological process that begins with the initial response to a workload (characterized by stress, force, motion, exertion, posture, vibration, temperature, etc.), and may progress to symptoms and/or adaptation, to functional impairment, and finally to disability (National Research Council, 1999).

In contrast to MSDs, musculoskeletal health (MSH) is the maintenance or improvement of the health and functionality of muscles (i.e., mass, strength, power, endurance), joints (i.e., range of motion, flexibility), and bones (i.e., bone strength, mineral density), as well as their integrated functioning (i.e., coordination, balance, speed, agility) (Bouchard et al., 1993; Vuori, 1995). Like MSD, MSH is multidimensional and can best be explained using a biopsychosocial perspective in which environmental and personal factors interact with body structure and function, affecting a person's ability to perform a range of life activities (Bergman, 2007). In the current study, we use the term "MSH-relevant" to refer to work and personal factors that may require exertion of musculoskeletal effort to accomplish (demands), may improve or strengthen musculoskeletal structure and functioning (resources), and have the potential to either strain or support a person's musculoskeletal health.

Older people, and people with high physical demands and psychological distress, generally have a higher prevalence of musculoskeletal pain (McBeth & Jones, 2007). Furthermore, work-related activities can precipitate and/or worsen MSDs (NIOSH, 2015a, b). Aging workers may be especially susceptible to MSDs due to age-related tissue changes and slower tissue healing and remodeling, which require longer rest intervals for tissue repair and for preventing overuse (National Research Council, 2004). In industrialized countries, MSDs are the largest category of all occupational diseases (Punnett & Wegman, 2004; US Department of Labor, 2016), and the leading cause of long-term sick leave among workers (Bergman, 2007). Poor MSH is also associated with increased absenteeism and employee departure due to disability (Silvia Monteiro et al., 2009; Waters, 2004). Moreover, decreased MSH and increased MSD are associated with lower work ability (Eskelinen et al., 1991; Miranda et al., 2010; Nygård et al., 1991; Pohjonen, 2001a; Pohjonen, 2001b; Sjögren-Rönkä et al., 2002; Van den Berg et al., 2009). Notably, workers in the manufacturing sector (both heavy and light) are at high risk for MSDs (Bernard, 1997).

Musculoskeletal Health and Work Ability

Work ability refers to a worker's capacity to carry out the physical, mental, and interpersonal demands of her/his job (Ilmarinen et al., 2008). The concept of work ability was developed by the Finnish Institute of Occupational Health in an effort to empirically determine which workers were most at risk for early departure from the workforce due to disability (Ilmarinen et al., 1991a, b). Work ability was first assessed in the 1980's using the empirically-derived Work Ability Index (WAI), which included clinical measures of health, specifically regarding chronic health conditions and limitations, combined with employee perceptions of work-related functioning (Ilmarinen, 2009). Low levels of work ability are associated with thoughts of retirement and turnover intentions (Camerino et al., 2006; Hopsu et al., 2005) and low WAI scores are associated with increased risk of early retirement, longterm sickness absence, and work disability (van den Berg et al., 2009).

Several of the WAI constituent items measure health status, and as a consequence it has drawn criticism because it has been used to predict health outcomes. It has also been noted that empirical derivations of the WAI have led to post hoc theorizing about work ability, and poor integration with work psychology theory (Ilmarinen & Tuomi, 2004). For this reason, subjectively-appraised work ability, *perceived work ability* (PWA), which does not use any clinical health measures, is increasingly used in work ability studies conducted by organizational psychology researchers. PWA is a robust predictor of employee retirement, absenteeism, and future disability (McGonagle et al., 2015; Miranda et al., 2010), independent of objectively ascertained health conditions and limitations (Ahlstrom et al., 2010; von Bonsdorff et al., 2011). Moreover, it is argued that perceptions of WA are important in and of themselves and sufficient to assess work ability; measures of PWA are psychometrically sound and PWA is a construct that explains unique variance in key correlates of work and health (Brady et al., 2020).

Work ability is an important topic in the study of aging workers (i.e., age 45 or older) as they are in a life phase when they may face major changes in their functional relationship to work (Ilmarinen, 2001). Much of the seminal research on work ability has explicitly focused on aging workers, with interventions emphasizing the maintenance and promotion of work ability to prolong working life (Ilmarinen et al., 1991a, 1991b; Tuomi et al., 1991). However, the direct relation between age and work ability has been in question.

While some studies found that WAI scores decline with increasing age (Fischer et al., 2006; Ilmarinen et al., 1991b; Tuomi et al., 1998), other studies have not. For instance, McGonagle et al. (2015) did not find a relation between PWA and age in two study samples. It may be that work ability is more closely related to health status than age, though age and health status are closely linked. Moreover, PWA reflects an individual's self-assessment of health and functional status, which may be affected by age for some people and not for others (Barnes-Farrell et al., 2004; McGonagle et al., 2014). Recently, evidence for the relation has been strengthened by a meta-analysis of over 100 studies showing that overall, age has a relatively consistent, but small, negative association with work ability (Brady et al., 2020).

Extension of Existing Research

Studies by McGonagle et al. (2015) and Brady et al. (2020) are the most comprehensive recent examinations of work ability, and both are responsive to calls for researchers to further develop the work ability construct and its theoretical underpinnings. These studies together have advanced work ability research by clearly operationalizing the work ability construct, grounding it within accepted organizational theory, and establishing a framework for further investigating the nomological network of the antecedents and outcomes of work ability (Brady et al., 2020). In the current study, we build upon their work and extended it via the specific application of knowledge to the topic of musculoskeletal health among aging workers in the manufacturing sector. Following the recommendation that both the occupational context (e.g., work demands) and personal characteristics (e.g., individual resources) be considered when evaluating antecedents of work ability (Brady et al., 2020), we specifically focused on examining the health/functioning of the musculoskeletal system, as it is an essential determinant of workers' capacity to meet the demands of various types of jobs in the manufacturing sector (Silverstein, 2008). To guide our analysis of work ability's antecedents and enable us to identify various modifiable factors, we applied the job demands–resources (JD-R) model (Bakker & Demerouti, 2007; Demerouti et al., 2001) as did both McGonagle et al. (2015) and Brady et al. (2020).

We first sought to understand whether better MSH among workers in manufacturing is associated with PWA. Work ability has been studied in workers from several occupational groups (i.e., municipal, construction, healthcare, administrative, etc.), but rarely studied in manufacturing (Alavinia et al., 2007; Pohjonen, 2001a; Pohjonen, 2001b; Sjögren-Rönkä et al., 2002; Tuomi et al., 1991; van den Berg et al., 2008). Our aim in conducting this study is to determine whether protecting and promoting MSH in an aging workforce is a key pathway to maintaining work ability and preserving functional status. We thus sought to identify predictors of MSH and PWA among workers in manufacturing, for the purposes of informing the development of targeted preventative interventions that support aging workers' ability to continue working with good health and function, and to have a productive work life that is not curtailed involuntarily.

Demands, Resources, and Perceived Work Ability

We first examined predictors of PWA. According to the JD-R model, job demands are aspects of a person's job that require the expenditure of their physical and psychological effort, and job resources are the needed work-related factors that a person draws from to fulfill their job demands. Job demands related to work ability include five types: quantitative, mental/emotional, physical, environmental conditions, and workplace mistreatment (Brady et al., 2020). Excessive job demands can ignite a health impairment process that, via strain/burnout, leads to poor outcomes (e.g., health problems). Having abundant job resources sparks a motivational process which, via well-being/engagement, leads to positive outcomes (e.g., good performance) (Schaufeli & Taris, 2014). Job resources related to work ability include seven types: coworker support, supervisor support, job control, task resources, rewards, justice perceptions, and organizational climate (Brady et al., 2020). The JD-R model also posits that job resources can attenuate the negative effects of job demands, resulting in decreased worker strain, and reduced adverse health outcomes.

In their meta-analysis of work ability studies, Brady and colleagues (2020) used the JD-R model as a framework and found consistent negative associations between job demands and work ability, and consistent positive associations between resources (both job and personal) and work ability. McGonagle et al. (2015) also used the JD-R model to assess job demands and resources (both job and personal), as well as their interactions, as predictors of PWA. Findings suggested that personal and job resources are more strongly associated with PWA in the short term, while job demands seem to accumulate over time, having a lagged effect on PWA. Although McGonagle et al. (2015) did not find supportive evidence for an association of job demands/resources interactions with PWA; other studies have found support for these interactive associations (Bakker et al., 2005; Xanthopoulou et al., 2007).

Over time, the originators of the JD-R model recognized that the inclusion of personal resources was an important extension of their model (Demerouti & Bakker, 2011) and defined personal resources as beneficial aspects of self, linked to feelings of resiliency and mastery that people can draw from in conducting their daily life activities (Bakker et al., 2014). Further development of the concept within work ability research has differentiated two types of personal resources: psychosocial and health-based (Brady et al., 2020). Psychosocial personal resources (e.g., self-efficacy, optimism) and health-based personal resources (e.g., general health indicators such as sleep, health behaviors such as physical activity) can both influence daily functioning and a worker's ability to successfully fulfill their work role.

McGonagle et al. (2015) incorporated both types of personal resources (e.g., general health status, positive affectivity) into their model, and found that resources were the strongest predictors of PWA, relative to demands. In their meta-analysis, Brady et al. (2020) likewise found that resources were stronger predictors of work ability than demands. Both McGonagle et al. (2015) and Brady et al. (2020) found particularly strong associations between health-related personal resources and work ability. These findings suggest that in addition to job demands and resources, it is critical to take into consideration workers' personal resources; and in this current study on musculoskeletal health, health-related personal resources are particularly relevant.

Demands from work are not the only sort that prompt the expenditure of physical and psychological effort, and thus we propose that in models examining variance in PWA, it is also necessary to consider a worker's *personal demands*. The JD-R model recently evolved to include personal demands, however research is in its early stages (Bakker & Demerouti, 2017). Personal demands have primarily been operationalized as self-imposed expectations for work performance and behavior which compel workers to invest effort and thus incur physical and psychological costs (Barbier et al., 2013). In existing studies, these have taken the form of personality traits (perfectionism, emotional instability; Lorente Prieto et al., 2008) and workaholism (working excessively and compulsively; Guglielmi et al., 2012; Schaufeli et al., 2009).

Barbier et al. (2013) called for further research to clarify the concept, opening up the possibility of alternative interpretations and other variables being operationalized as personal demands. For instance, Zeijen et al. (2021) suggested that in addition to personal demands that compel workers to invest extra effort into work, attention should be paid to personal demands (e.g., maladaptive beliefs, awfulizing, need for control) that cause workers to withhold effort, deplete energy, and risk strain. One factor identified as a hindrance to effort is work-life conflict, operationalized as a personal demand in a study that applied the JD-R model to nurses, and found to be strongly associated with burnout (Moloney et al., 2018).

This suggests that responsibilities outside of work may represent personal demands, which is in keeping with *Total Worker Health*®, an approach that explicitly posits that worker health is affected by what takes place both at work and outside of work (NIOSH, 2015a, b). Childcare and eldercare responsibilities can require effort analogous to that of paid work and drain personal resources (Himmelweit, 1995; Hochschild, 1997); they also have a negative association with work ability (Cadiz et al., 2019; Fischer et al., 2006; Vedovato & Monteiro, 2014). Routine household chores/maintenance and household management have similar effects (Dugan & Barnes-Farrell, 2020). As such, we use the term *personal demands* in our study to refer to unpaid home/family work, and posit that the cumulative impact of demands and resources at play in a person's life, both in paid work and private life, must be accounted for to fully understand how they contribute to PWA. Thus, we propose the following hypotheses:

Hypothesis 1: MSH-relevant job demands are negatively associated with PWA
Hypothesis 2: MSH-relevant job resources are positively associated with PWA
Hypothesis 3: MSH-relevant personal demands are negatively associated with PWA
Hypothesis 4: MSH-relevant personal resources are positively associated with PWA
Hypothesis 5: MSH-relevant job resources will moderate (buffer) relations between MSH-relevant job demands and PWA
Hypothesis 6: MSH-relevant personal resources will moderate (buffer) relations between MSH-relevant personal demands and PWA

Demands, Resources, and Musculoskeletal Health

According to the JD-R model, job demands and resources, independently and in interaction with one another, can impact health, including MSH (Schaufeli & Taris, 2014). For instance, Joling et al. (2008) found that job demands (i.e., high physical workload) were associated with an increased risk of MSDs, and that job resources (i.e., quality of communication) independently predicted reduced risk and also buffered the effect of demands on MSDs. Similarly, Pekkarinen et al. (2013) found that among nurses working in geriatric units, job demands (i.e., heavy mental workload) were associated with increases in musculoskeletal symptoms, and that job resources (i.e., distributive justice) buffered against this effect.

Past research shows that personal demands and resources are also linked to MSH. This is in keeping with a landmark report explicitly stating that MSD problems are caused by both work and non-work activities, and that research fails to fully assess MSH due to its prioritization of work-related factors over non-work-related factors (National Research Council, 1999). Strazdins and Bammer (2004) found that in addition to job demands (i.e., repetitive work, poor ergonomic equipment), lack of resources due to home/family demands (i.e., fewer opportunities for relaxation and exercise during non-work time) were linked to upper-body musculoskeletal symptoms among women. Another study revealed that the physical demands of providing informal care to dependent adults increased physical strain and musculoskeletal discomfort (Darragh et al., 2015). Other research suggests the physical demands of child care (e.g., lifting, carrying, bending, and sitting on the floor) are associated with poorer MSH in day care workers (Gratz et al., 2002) and mothers of young children (Vincent & Hocking, 2013). On the other hand, personal resources, such as the muscular strength and functioning provided by leisure time physical activity and exercise, are associated with improved MSH (Garber et al., 2011; Vuori, 1995). Thus, we propose the following hypotheses:

Hypothesis 7: MSH-relevant job demands are negatively associated with MSH
Hypothesis 8: MSH-relevant job resources are positively associated with MSH
Hypothesis 9: MSH-relevant personal demands are negatively associated with MSH
Hypothesis 10: MSH-relevant personal resources are positively associated with MSH
Hypothesis 11: MSH-relevant job resources will moderate (buffer) relations between MSH-relevant job demands and MSH
Hypothesis 12: MSH-relevant personal resources will moderate (buffer) relations between MSH-relevant personal demands and MSH

Finally, because the relation between demands and resources and PWA may partially be explained by a worker's MSH, we propose the following:

Hypothesis 13: MSH is positively associated with PWA

Hypothesis 14: MSH partially mediates relations between job demands, job resources, personal demands, personal resources and PWA

Work Ability, Musculoskeletal Health, and Employee Departure

Empirically, work ability predicts employee departure (e.g., disability retirement) and is associated with turnover intentions (Ilmarinen, 2009). WAI scores have been associated with increased risk of early retirement, long-term sickness absence, and work disability (van den Berg et al., 2009), and PWA has been associated with retirement, absenteeism, and future disability (McGonagle et al., 2015; Miranda et al., 2010). Recently, a meta-analysis showed that work ability (using both WAI and PWA measures) was associated with exit intentions and behaviors, and a variety of related work outcomes including job attitudes and performance, motivation, and strain (Brady et al., 2020).

Poor MSH is also linked to absenteeism and employee departure due to disability (Silvia Monteiro et al., 2009; Waters, 2004). However, the way in which MSH and PWA, when examined together, affect employee departure has not been empirically examined. To determine the best possible point of intervention, we investigated the relation between the MSH and PWA, as well as the roles of these variables in predicting employee departure. We define organizational departure as workers who left the workplace for various (health and non-health) reasons, including voluntary and involuntary work cessation, work disability, and planned retirement. Thus, we propose that:

Hypothesis 15: PWA is negatively associated with employee departure

Hypothesis 16: MSH is negatively associated with employee departure

Hypothesis 17: PWA partially mediates the relation between MSH and employee departure

The Current Study

We build on the most detailed recent examinations of work ability by McGonagle et al., (2015) and Brady et al., (2020) by expanding their applications of the JD-R model to examine PWA and employee departure in two new ways. First, our model is relevant to the health of the musculoskeletal system in particular, rather than to health in general. Second, in response to a call from Barbier et al. (2013) to further investigate the concept of personal demands in the context of the JD-R framework, we include personal demands as predictors in our model, because unpaid home/family labor places physical and psychological demands on workers that potentially affect their MSH and PWA. Figure 1 shows our conceptual model.

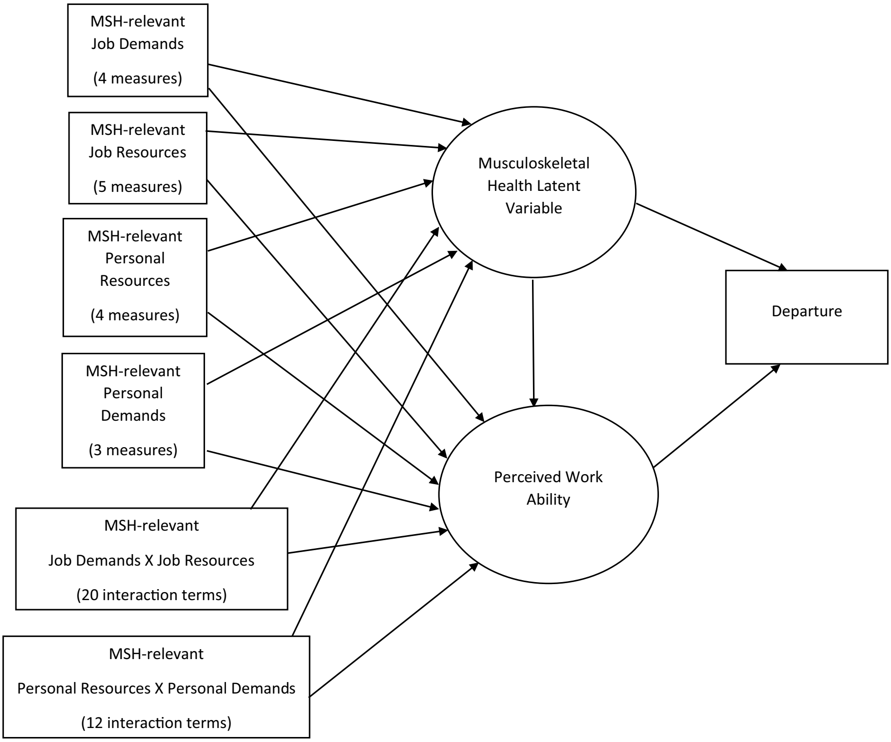

Fig. 1 Conceptual Model of Perceived Work Ability and Musculoskeletal Health

Method

Participants

This study is part of a longitudinal cohort study, conducted in six medium-sized (175–525 employees) skilled light manufacturing companies in the Northeast U.S. Light industry is the manufacturing of relatively high-value items per unit of weight (e.g., consumer goods such as furniture, clothes, home appliances); it uses moderate amounts of partially-processed materials to produce goods that are relatively low cost and easily transportable, with production usually taking place in relatively small manufacturing units on industrial estates; see Cherniack et al., 2015; Li & Lin, 2017). Four of the companies were unionized.

The parent study focuses on aging in the manufacturing sector, measuring changes over a five-year time period in musculoskeletal, psychosocial, and work-related variables (see Cherniack et al., 2015). All workers at selected sites were eligible to participate in the study, regardless of age. We sampled both production and administrative workers who have different types and combinations of physical demands related to their jobs (i.e., jobs may require intensive manual labor, operation of automated machines from computer workstations in dynamic sitting/standing postures, or sedentary computer work in static postures). We included a diverse group of workers to obtain variability in job demands in order to fully assess relations with musculoskeletal health. The study was reviewed and approved by the University's Institutional Review Board, and each study participant signed the approved written consent prior to study participation.

Consenting workers completed paper questionnaires at three time points (12–18 months apart), administered on-site by research staff during work hours. Surveys assessed a variety of health, work and non-work, and psychosocial variables using established measures that the research team has a history of extensive use with (Morse et al., 1998, 2004). Participants received a small incentive for completion. The cross-sectional survey data used in this paper were collected at Time 1 (2008) when there was a true inception cohort. The employee departure data was assessed at Time 3 (2013).

Measures

Predictors of MSH and PWA

MSH-Relevant Job Demands To evaluate the variety of job demands that workers within this cohort have, we assessed four MSH-relevant job demands. Psychological job demands, a subscale of the Job Content Questionnaire (JCQ; Karasek, 1985; Karasek et al., 1998) consists of four items (e.g., "My job requires working very fast") with a 4-point scale from 1 (*strongly disagree*) to 4 (*strongly agree*), and an average score was calculated from these items.

We assessed physical job demands relevant to manual work with six items from the Occupational Safety and Health Administration (OSHA) 1995 checklist (OSHA, 1995; n.d.) by asking respondents how many hours on an average day they spend in six activities: (a) twisting of torso; (b) kneeling/squatting; (c) grasping an object hard with your whole hand; (d) repeatedly bending the neck in any direction; (e) moderate forward or side bending of torso; and (f) severe forward bending of torso more than 45 degrees. The six items were rated with a 5-point scale ranging from 0 (*0 h*) to 4 (*more than 8 h*) with in-between values in 2-h increments. Responses to the six items were averaged.

We assessed computer-based physical demands with two OSHA checklist items (OSHA, 1995; n.d.) by asking respondents how many hours on an average day they spend in two activities: (a) sitting stationary; and (b) holding the neck, shoulder, arms, or hands in one position for a long time. The two items were rated with a 5-point scale ranging from 0 (*0 h*) to 4 (*more than 8 h*) with in-between values in 2-h increments. Responses to the two items were averaged.

Standing or walking at work was assessed with a one-item measure from the EPIC Physical Activity Questionnaire (Wareham et al., 2002) that asked what proportion of time (in 10% increments) on the job was spent standing or walking, with a 11-point scale ranging from 0 (*always sitting*) to 10 (*always standing/walking*).

MSH-Relevant Job Resources We assessed five MSH-relevant job resources. Coworker support and supervisor support were each measured with JCQ subscales (Karasek, 1985; Karasek et al., 1998). Each subscale includes two items (e.g., coworker: "People I work with are helpful in getting the job done"; supervisor: "My supervisor pays attention to what I am saying") rated on a 4-point scale from 1 (*strongly disagree*) to 4 (*strongly agree*); averages were computed for each.

A single question created for this survey considered an aspect of postural control, the ability to decide when to stand or sit at work ("Depending on the needs of the job, can you decide when to sit, stand, or move around?"), using a 4-point scale from 1 (*never*) to 4 (*always*). Another aspect of control, schedule control, was assessed by asking participants to indicate their level of agreement with the statement "I have control over my work schedule" on a 4-point scale from 1 (*strongly disagree*) to 4 (*strongly agree*) (Breaugh, 1985). How work hours fit with non-work commitments was evaluated with the question "In general, do your working hours fit in with your family or social commitments outside work?" which was rated on a 4-point scale from 1 (*very well*) to 4 (*not at all well*); this scale was reverse coded so that high values indicated better fit (European Foundation, 2007).

MSH-Relevant Personal Demands We assessed three MSH-relevant personal demands. Child care was assessed with a single item that asked how much personal responsibility the worker had for any children under the age of 18 in the household on a 4-point scale, with response options that included 0 (*no children under 18 in household*), 1 (*another adult has primary responsibility*), 2 (*I share responsibility with another adult*), and 3 (*I have primary responsibility*). Adult care was assessed with two items that asked how many adults (a) under age 65, and (b) aged 65 and older, were dependent on the individual for help in any way due to disability or chronic illness, with response options ranging from 0 (*none*) to 5 (*five or more adults*). We summed responses to the two items to create an adult care composite with a range from 0 to 10.

House and garden work was assessed with two items that asked respondents to estimate the number of hours in an average week that they spent doing household chores (e.g., cleaning, washing, cooking) and outdoor chores (e.g., gardening, yard work, do-it-yourself activities). Both items used a six-point response scale in three-hour increments including 0 (*0 h*), 1 (*1–3 h*), 2 (*4–6 h*), 3 (*7–9 h*), 4 (*10–12 h*), and 5 (*13 or more hours*) (Wareham et al., 2002). We summed responses to the two items to create a house and garden work composite with a range from 0 to 10, with higher scores reflecting more time spent working on housework and outdoor chores.

MSH-relevant personal resources We assessed four health-based personal resources relevant to MSH. Sleep quality was assessed using an item from the Pittsburgh sleep quality index (Buysse et al., 1989) that asked respondents to answer "How would you describe the quality of your sleep on a typical night?" using a 5-point rating scale from 0 (*can't say*) to 4 (*good*). Two questions assessed sleep duration, asking respondents to indicate (a) the typical number of hours they slept within a 24-h period and (b) the number of sleep hours they needed for good functioning. Both items used an eight-point response scale ranging from 1 (*less than 4 h*) to 8 (*greater than 10 h*) with in-between values in 1-h increments. We used these two items to calculate a sleep discrepancy variable (i.e., actual sleep hours minus needed sleep hours), with negative values indicating a sleep deficit and positive values indicating a sleep surplus.

We used single-item measures to assess the number of hours respondents spent in an average week doing two forms of leisure-time physical activity: vigorous physical exercise (e.g., fitness, aerobics, swimming, jogging, cycling) and walking (e.g., walking to work, shopping, leisure time). Both items used a six-point response scale in three-hour increments including 0 (*0 h*), 1 (*1–3 h*), 2 (*4–6 h*), 3 (*7–9 h*), 4 (*10–12 h*), and 5 (*13 or more hours*) (Wareham et al., 2002).

Mediators/Outcomes

Musculoskeletal Health Several scales were used to create a MSH latent variable, in which we modeled MSH as a factor with four indicators including overall physical health, absence of pain and limited motion, absence of MSH-related work and activity limitations, and absence of MSH-related sleep limitations. Overall physical health was assessed using the Short-Form Health Survey's (SF-12) physical health component scale and computed per its guidelines (Ware et al., 1998). This instrument features 12 questions and response weights to generate valid and reliable, norm-based, standardized scores (e.g., cross-sectional U.S. sample: Ware et al., 1996; cross-cultural sample: Gandek et al., 1998; longitudinal sample: Jenkinson et al., 1997: for scoring instructions see Ware et al., 1998). Standardized scores have a mean of 50, with possible scores ranging from 0 to 100. Higher scores indicate better physical health.

Work and activity limitation due to musculoskeletal problems (Miranda et al., 2014) was measured by asking respondents to indicate whether they were limited in their work or regular activities during the past week because of any: (a) back problem; (b) knee problem; (c) hand, arm, or shoulder problem. The three items were rated with a 5-point scale ranging from 1 (*not at all limited*) to 5 (*unable to work or do regular activities*) and were reverse coded before being averaged (European Foundation, 2007). Higher scores indicate an absence of work and activity limitations.

Sleep limitation due to musculoskeletal problems (Miranda et al., 2014) used a similar scale. Participants were asked to indicate whether they had any difficulty sleeping during the past week because of any: (a) back problem; (b) knee problem; (c) hand, arm, or shoulder problem. The three items were rated with a 5-point scale ranging from 1 (*no difficulty*) to 5 (*so much difficulty that I can't sleep*), and were reverse coded before being averaged (European Foundation, 2007). Higher scores indicate an absence of sleep limitations.

Pain and limited motion (Miranda et al., 2014) were assessed by asking participants to look at an anatomical diagram of the human body and indicate how much pain, aching, or stiffness/limited motion they had during the past 3 months in the various bodily areas shown: (a) neck; (b) shoulder; (c) wrist or forearm; (d) hands; (e) low back; (f) knee; and (g) foot. The seven items were rated with a 5-point scale ranging from 0 (*none*) to 4 (*extreme*). Responses were reverse coded and summed so that higher values indicated absence of pain. This meant that scores potentially ranged from 0 (indicating extreme pain in all bodily areas) to 28 (indicating no pain). The observed range in the present study was 11 to 28.

Perceived Work Ability Perceived work ability was measured using four items from the Health and Retirement Survey of 2008 (Smith et al., 2013) which have been used in previous research (McGonagle et al., 2015). The measure included an item that assessed respondents' current overall work ability relative to their best ever and three items that assessed respondents' work ability pertaining to the physical, mental and interpersonal demands of their job. For all four items, the response scale ranged from (0) *cannot currently work at all* to (10) *best work ability of lifetime*. Our analyses used perceived work ability as a latent variable with the four WAI items as indicators. Standardized factor loadings ranged from 0.79 to 0.84.

Employee Departure Employee departure is a 5-year cumulative outcomes measure assessed at Time 3 with administrative data provided by Human Resources departments (when available) and informally on-site (when necessary). To create the dichotomous departure variable, we coded employees who were still currently employed in the organization as a 1 (*employee did not depart*), and we coded employees who had departed from the organization for any reason (i.e., voluntary and involuntary termination, voluntary retirement, long-term disability, and death) as a 2 (*employee departed*).

Control Variables *Control variables* were age (continuous, measured in years), gender (categorical, female or male), household income (categorical, $10,000-$24,999, $25,000-49,999, $50,000-$74,999, $75,000-$99,999, $100,000 or more), and job type (categorical, production or administrative).

Analytical Strategy

The hypotheses were tested using multiple linear regression and structural equation modeling (SEM) in Mplus 8.1 (Muthén, & Muthén, 1998–2017). Job demands, job resources, personal demands, personal resources, and employee departure were modeled as observed variables. MSH and PWA were modeled as latent variables. Standardized factor loadings for MSH ranged from 0.68 (pain and limited motion) to 0.83 (work and activity limitation), while the work ability loadings ranged from 0.79 (overall work ability) to 0.84 (mental work ability). After mean-centering, we created two sets of interactions terms. The first set comprised 20 interactions that represented all possible pairings of job demands and job resources. The second set consisted of 12 interactions which accounted for every pair of personal resources and personal demands. Because work ability is a negatively skewed construct, we used robust maximum likelihood (MLR) estimation, which is robust to non-normality. All variables, including controls, were modeled simultaneously.

Results

Descriptive statistics are shown in Table 1. A total of 758 employees completed the survey. Response rates were low and ranged from 29 to 52%, likely due to worker concerns about employers having access to their personal information, in spite of assurances about confidentiality by research staff. Other barriers included the lengthy nature of the paper surveys, difficulty recruiting people on the second and third shifts (although researchers recruited on-site on all shifts), and lower education levels and lack of English-language proficiency (although researchers offered assistance in filling out surveys). The population was 71% male, 83% white, and 71% married/partnered. The mean age was 47.2 years old ($SD = 10.9$). Fifty-two percent had production jobs (rather than administrative jobs). For all scales, Cronbach alphas showed an acceptable level of internal consistency (ranging from 0.50 to 0.88). Bivariate correlations are shown in Tables 2, 3, and 4.

Direct Effect of MSH-relevant Demands and Resources on Perceived Work Ability

Table 5 summarizes the predictors of work ability, as assessed in Hypotheses 1 – 4. As shown in Table 5 (step 5), job demands did not influence PWA (H1). For job resources, supervisor support ($\beta = 0.14$, $p < 0.01$) had a positive effect on PWA (H2). All effects of MSH-relevant personal demands were non-significant (H3). However, one personal resource—sleep surplus ($\beta = 0.14$, $p < 0.01$)—had a significant positive effect on PWA (H4). There were no other significant direct effects observed between MSH-relevant demands and resources on PWA. Overall, we found partial support for Hypotheses 2 and 4, but there was no support for Hypotheses 1 and 3.

Interactive Effects of Demands and Resources on Perceived Work Ability

There was one significant interaction term in each set of job demands-by-resources, and personal demands-by-resources interactions. See Appendices B, C, and D for the full results of the PWA interaction tests. Unfortunately, these moderations were inconsistent; job and personal resources did not consistently buffer the relations between MSH-relevant job and personal demands and PWA. Thus, we infer partial support for H5 and H6.

Direct Effect of MSH-relevant Demands and Resources on Musculoskeletal Health

Table 6 summarizes the predictors of MSH, as explored in Hypotheses 7 through 10. Table 6 (step 5) shows that for job demands, computer-based physical demands

Table 1 Descriptive statistics for all study variables ($N = 758$)

Demographics (scale)	*Mean or %*	*SD*	Predictors (scale)	*Mean or %*	*SD*	Outcomes (scale)	*Mean or %*	*SD*
Demographics			Job Demands			Musculoskeletal Health Indicators		
Age (continuous)	47.2	10.9	Psychological demands (1–4)	2.6	0.47	Physical component score (0–100)	50.3	7.27
Gender			Physical demands: manual (0–4)	0.9	0.85	Work limitations due to MSH (1–5)	4.7	0.44
1 = Male	70.6%		Physical demands: computer (0–4)	1.6	1.07	Sleep limitations due to MSH (1–5)	4.8	0.39
2 = Female	29.4%		Time standing/walking (0–9)	5.2	2.83	Pain and limited motion (0–28)	24.4	3.19
Race			Job Resources			Work Ability Indicators		
1 = White	82.3%		Coworker support (1–4)	2.9	0.50	Overall Work Ability (0–10)	9.5	1.02
0 = Non-white	17.2%		Supervisor support (1–4)	2.9	0.63	Physical Work Ability (0–10)	9.5	1.05
Marital Status			Sit/stand decision (1–4)	3.0	0.88	Mental Work Ability (0–10)	9.2	1.36
1 = Married/partnered	70.7%		Schedule control (1–4)	2.5	0.76	Interpersonal Work Ability (0–10)	9.2	1.35
0 = Not married/partnered	28.9%		Work/non-work fit (1–4)	3.1	0.78	Outcome		
Missing	0.4%		Personal Demands			Employee departure		
Income			Child care (0–3)			1 = no	85.2%	
1 = $10,000—24,999	1.7%		0 = No children under 18 in household	55.8%		2 = yes	14.8%	
2 = $25,000—49,999	13.2%		1 = Another adult has primary responsibility	3.0%				
3 = $50,000—74,999	23.0%		2 = Share responsibility with another adult(s)	33.4%				
4 = $75,000—99,999	27.7%		3 = Have primary responsibility	7.1%				
5 = > $100,000	32.7%		Missing	0.7%				
Missing	1.7%		Adult care (number of adults; 0–10)	0.5	0.96			

Table 1 (continued)

Demographics (scale)	*Mean or %*	*SD*	Predictors (scale)	*Mean or %*	*SD*	Outcomes (scale)	*Mean or %*	*SD*
Job type (admin or production)			House & garden work hours per week (0–10)	4.4	2.33			
1 = admin	42.0%		Personal Resources					
2 = production	51.8%		Sleep quality (0–4)	3.1	0.90			
Missing	6.2%		Sleep hour discrepancy (actual – needed sleep)	-0.3	1.18			
			Exercise hours (0–5)	1.4	1.34			
			Walking hours (0–5)	2.2	1.36			

Table 2 Correlation Matrix of Demographics and Demand/Resource Variables

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	Age	-																					
2	Gender	.09*	-																				
3	Race	.06	.03	-																			
4	Marital Status	.25**	-.12**	-.03	-																		
5	Income	.08*	-.22**	.11**	.43**	-																	
6	Job type	-.17**	-.27**	-.10**	-.04	-.09*	-																
7	JD psych dem	-.11**	.03	.02	.02	.08*	-.14**	(.67)															
8	JD manual work	.08*	.03	-.08*	-.05	-.34**	.14**	.03	(.88)														
9	JD comp work	-.02	.35**	.05	.01	.07	-.24**	.19**	-.10**	(.63)													
10	JD stand/walk	.08*	-.19**	-.07	-.01	-.20**	.25**	-.06	.45**	-.53**	-												
11	JR coworker sup	-.04	.08*	.15**	.01	.09*	-.09*	-.04	-.14**	.11**	-.19**	(.69)											
12	JR supervisor sup	.07*	.10**	-.03	.00	.01	-.17**	-.09*	-.10**	.06	-.14**	.44**	(.85)										
13	JR sit/stand	.04	.06	-.03	.01	.11**	-.13**	-.04	-.18**	.10**	-.17**	.09**	.07	-									
14	JR sched ctrl	.10**	.09*	.05	.06	.18**	-.24**	.01	-.22**	.19**	-.23**	.19**	.18**	.19**	-								
15	JR fit	.18**	.12**	-.02	.06	.07*	-.22**	-.12**	-.13**	.10**	-.16**	.18**	.23**	.20**	.32**	-							
16	PD child care	-.27**	-.11**	-.07*	.13**	.06	.06	.14**	.00	.02	.00	-.03	-.05	-.01	-.02	-.17**	-						
17	PD adult care	.13**	-.04	.03	.09*	.05	.02	.07	.10**	.06	.07*	-.09*	-.11**	-.06	.00	-.02	.04	-					
18	PD house/ garden	-.04	.07*	.03	.05	.03	.06	-.02	.10**	-.02	.12**	.01	.04	-.01	-.13**	-.07	.22**	.04	(.50)				

Table 2 Continued

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
19	PR sleep quality	-.03	-.02	.03	.03	.12**	-.10**	-.06	-.12**	.07	-.11**	.16**	.09*	.02	.16**	.23**	-.07	-.05	.01	-			
20	PR sleep discrep	.10**	-.03	.02	.07	.06	-.06	-.12**	.00	-.03	.03	.12**	.08*	-.01	.10**	.20**	-.11**	-.08*	.02	.37**	-		
21	PR exercise	-.15**	-.16**	-.02	-.07*	.11**	.06	.01	-.06	.03	-.03	.05	.05	.07	.04	.10**	.01	-.04	.16**	.10**	.09*	-	
22	PR walking	-.01	.01	.00	-.06	-.04	.03	-.04	.13**	-.04	.15**	-.01	.03	.04	-.05	.03	-.03	.03	.41**	.00	.07	.30**	-

Alphas are in parentheses, where applicable

JD psych dem = job demands psychological demands; JD manual work = job demands manual work; JD comp work = job demands computer work; JR coworker sup = job resource coworker support; JR supervisor sup = job resource supervisor support; JR sit/stand = job resource sit/stand decision; JR sched ctrl = job resource schedule control; JR fit = job resource work/non-work fit; PD child care = personal demand child care; PD adult care = personal demand adult care; PD house/garden = personal demand house and garden work; PR sleep quality = personal resource sleep quality; PR sleep discrep = personal resource sleep discrepancy (high values = sleep surplus; low values = sleep deficit); PR exercise = personal resource exercise hours; PR walking = personal resource walking hours

$^{*} = p < .05$; $^{**} = p < .01$

Table 3 Correlation Matrix of Demographics and Outcome Variables

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Age	-														
2	Gender	.09*	-													
3	Race	.06	.03	-												
4	Marital Status	.25**	-.12**	-.03	-											
5	Income	.08*	-.22**	.11**	.43**	-										
6	Job Type	-.17**	-.27**	-.10**	-.04	-.09*	-									
7	MSH Physical component	-.17**	-.07	.04	-.01	.13**	-.02	-								
8	MSH Work limitation	-.14**	-.07*	.09*	.00	.15**	.04	.56**	(.63)							
9	MSH Sleep limitation	-.12**	-.12**	.02	.00	.16**	.07	.47**	.64**	(.65)						
10	MSH Pain and limited motion	-.06	-.14**	.01	.02	.13**	.05	.52**	.52**	.47**	(.68)					
11	Overall Work Ability	-.14**	-.07*	.09*	.00	.15**	.04	.56**	.29**	.24**	.27**	-				
12	Physical Work Ability	-.11**	.04	.04	.01	.13**	-.11**	.27**	.27**	.22**	.29**	.74**	-			
13	Mental Work Ability	-.02	.02	-.01	.02	.09*	-.02	.14**	.18**	.23**	.25**	.61**	.64**	-		
14	Interpersonal Work Ability	.00	.07	.02	.01	.07	-.08*	.11**	.16**	.18**	.22**	.56**	.59**	.77**	-	
15	Employee Departure	-.03	.06	-.07	-.12**	-.14**	-.04	-.05	-.02	-.02	-.03	-.05	-.05	-.04	-.01	-

Alphas are in parentheses, where applicable
MSH = musculoskeletal health

* = $p < .05$; ** = $p < .01$

Table 4 Correlation Matrix of Demands/Resources and Outcome Variables

Variable	Musculoskeletal Health				Work Ability				Departure
	Physical component	Work limitation	Sleep limitation	Pain and limited motion	Overall	Physical	Mental	Interpersonal	Employee Departure
JD psych dem	.02	-.06	-.09*	-.13**	-.04	-.03	-.18**	-.11**	-.12**
JD manual work	-.19**	-.14**	-.16**	-.21**	-.15**	-.18**	-.12**	-.13**	-.01
JD comp work	-.03	-.04	-.06	-.17**	.00	.05	-.07	.00	.00
JD stand/walk	-.08*	-.06	-.06	-.05	-.08*	-.14**	-.03	-.09*	-.01
JR coworker sup	.12**	.11**	.09*	.12**	.12**	.12**	.06	.16**	.04
JR supervisor sup	.01	.04	.05	.07	.11**	.13**	.13**	.20**	.11**
JR sit/stand	.08*	.04	.07	.07	.03	.04	.05	.07	.02
JR sched ctrl	.12**	.05	.02	.07	.13**	.14**	.09*	.11**	.01
JR fit	.07	.08*	.04	.10**	.05	.07*	.10**	.13**	.03
PD child care	.02	.06	.04	-.02	.08*	.03	-.03	-.02	-.09*
PD adult care	-.11**	-.08*	-.11**	-.10**	-.03	-.06	-.02	-.01	.03
PD house/garden	.01	.00	.00	-.02	.04	.04	.03	.09*	-.05
PR sleep quality	.24**	.24**	.26**	.29**	.16**	.18**	.14**	.16**	-.01
PR sleep discrep	.13**	.12**	.12**	.15**	.15**	.18**	.16**	.20**	-.01
PR exercise	.18**	.09*	.10**	.14**	.08*	.10**	.07	.05	.00
PR walking	.06	.08*	.03	.05	-.02	-.04	-.01	.03	.09*

JD psych dem = job demands psychological demands; JD manual work = job demands manual work; JD comp work = job demands computer work; JR coworker sup = job resource coworker support; JR supervisor sup = job resource supervisor support; JR sit/stand = job resource sit/stand decision; JR sched ctrl = job resource schedule control; JR fit = job resource work/non-work fit; PD child care = personal demand child care; PD adult care = personal demand adult care; PD house/garden = personal demand house and garden work; PR sleep quality = personal resource sleep quality; PR sleep discrep = personal resource sleep discrepancy (high values = sleep surplus; low values = sleep deficit); PR exercise = personal resource exercise hours; PR walking = personal resource walking hours

* = $p < .05$; ** = $p < .01$

Table 5 Multiple Regression Results for Perceived Work Ability as Outcome Variable

Model	Step 1: Controls & MSH	Step 2: Job Demands (JD)	Step 3: Job Resources (JR)	Step 4: Personal Demands (PD)	Step 5: Personal Resources (PR)
	β (SE)	*β (SE)*	*β (SE)*	*β (SE)*	*β (SE)*
Perceived Work Ability predicted by:					
Age	-.06 (.04)	-.04 (.04)	-.06 (.04)	-.06 (.01)	-.07 (.04)
Gender (male = 1, female = 2)	-.08 (.04)*	.09 (.04)*	.10 (.04)*	.09 (.04)*	.11 (.04)**
Income	.07 (.04)	.05 (.04)	.05 (.04)	.04 (.04)	.03 (.04)
Job type	.06 (.04)	-.07 (.04)	-.05 (.04)	-.05 (.04)	-.05 (.04)
Musculoskeletal Health (MSH)	.36 (.07)***	.33 (.07)***	.32 (.07)***	.32 (.07)***	.29 (.07)***
JD psych dem		-.11 (.05)*	-.07 (.04)	-.08 (.04)	-.07 (.05)
JD manual work		-.08 (.05)	-.06 (.05)	-.08 (.05)	-.07 (.05)
JD comp work		-.06 (.05)	-.08 (.05)	-.08 (.05)	-.10 (.05)
JD stand/walk		-.02 (.06)	-.01 (.05)	-.03 (.05)	-.02 (.05)
JR coworker sup			.02 (.06)	.02 (.06)	.01 (.06)
JR supervisor sup			.14 (.05)**	.13 (.05)**	.14 (.05)**
JR sit/stand			-.01 (.05)	-.01 (.05)	.00 (.05)
JR sched ctrl			.06 (.05)	.07 (.05)	.06 (.05)
JR fit			.00 (.05)	.01 (.05)	-.01 (.05)
PD child				.02 (.04)	.02 (.04)
PD adult care				.05 (.04)	.06 (.04)
PD house/garden				.07 (.04)	.09 (.06)
PR sleep quality					.01 (.05)
PR sleep discrep					.14 (.05)**
PR exercise					.04 (.05)
PR walking					-.10 (.06)
Total R^2	**.15****	**.17*****	**.19*****	**.20*****	**.22*****

JD psych dem = job demands psychological demands; JD manual work = job demands manual work; JD comp work = job demands computer work; JR coworker sup = job resource coworker support; JR supervisor sup = job resource supervisor support; JR sit/stand = job resource sit/stand decision; JR sched ctrl = job resource schedule control; JR fit = job resource work/non-work fit; PD child = personal demand child care; PD adult care = personal demand adult care; PD house/garden = personal demand house and garden work; PR sleep quality = personal resource sleep quality; PR sleep discrep = personal resource sleep discrepancy (high values = sleep surplus; low values = sleep deficit); PR exercise = personal resource exercise hours; PR walking = personal resource walking hours. Parameters are standardized beta coefficients (β). For parsimony, only significant interactions are shown

*$p < .05$; **$p < .01$; ***$p < .001$

had a significant negative effect (β = -0.15, $p < 0.05$) on MSH (H7). With respect to the personal resources, sleep quality (β = 0.30, $p < 0.001$) and walking (β = 0.10, $p < 0.05$) had positive effects on MSH (H10). Like PWA, personal demands had no significant influence on MSH (H9). Moreover, no significant direct effects were observed for job resources on MSH (H8). Based on these results, we inferred partial support for Hypotheses 7 and 10, and no support for Hypotheses 8 and 9.

Interactive Effects of Demands and Resources on Musculoskeletal Health

Interactive effects were more prevalent for MSH than for PWA. For MSH, we observed three significant interaction terms within the set of job demands-by-resources interactions and three significant interaction terms for personal demands-by-resources. See Appendices B, E, and F for the full results of the MSH interaction tests. Similar to the results of the interactive effects on PWA, the interaction terms inconsistently represented the buffering effects of job and personal resources. As a result, this poses challenges in making inferences about the interaction plots. Therefore, we conclude that there is partial support for Hypotheses 11 and 12.

Influence of Perceived Work Ability and Musculoskeletal Health on Employee Departure

As seen in Table 5 (step 5), MSH had a positive direct effect (β = 0.29, $p < 0.001$) on PWA (H13). We tested whether the significant predictors of MSH—*computer-based physical demands, sleep quality, and hours spent walking*—had an indirect effect on PWA, via MSH. Using Selig and Preacher's (2008) bootstrapping procedure, we utilized the parameter estimates of the aforementioned predictors of MSH (a′-paths), and the MSH-PWA linkage (b′-path), along with their respective standard errors. Based on 20,000 iterations, we determined the 95% confidence intervals for computer-based physical demands, sleep quality, and hours walking.

As seen in Table 7, the confidence intervals for these estimates do not include zero, which is evidence consistent with mediation. Therefore, we inferred that MSH partially mediates the effects of job/personal demands and resources on PWA (H14). Table 8 shows that there was no significant association between PWA (H15) or MSH (H16) and employee departure. Consequently, it was unnecessary to test for the indirect effect of MSH on employee departure, via PWA (H17). To summarize, there was full support Hypothesis 13 and partial support for Hypothesis 14. However, we found no support for Hypotheses 15, 16, and 17. Table 9 provides an overview of all study hypotheses and associated results.

Discussion

The present study examined predictors of MSH and PWA, as well as their effects on departure, in a population particularly susceptible to steeper declines in health—aging workers in the manufacturing sector. Our goal was to expand the literature

Table 6 Multiple Regression Results for Musculoskeletal Health as Outcome Variable

Model	Step 1: Controls	Step 2: Job Demands (JD)	Step 3: Job Resources (JR)	Step 4: Personal Demands (PD)	Step 5: Personal Resources (PR)
	β (SE)	*β (SE)*	*β (SE)*	*β (SE)*	*β (SE)*
Musculoskeletal Health predicted by:					
Age	-.19 (.04)***	-.20 (.04)***	-.21(.04)***	-.20 (.04)***	-.16 (.04)***
Gender (male = 1, female = 2)	-.03 (.05)	-.01 (.05)	-.03 (.05)	-.03 (.05)	.00 (.05)
Income	.20 (.04)***	.17 (.05)***	.16 (.05)**	.17 (.05)**	.14 (.05)**
Job type	.02 (.05)	.01 (.05)	.05 (.05)	.05 (.05)	.07 (.05)
JD psych dem		-.11 (.04)**	-.07 (.04)	-.07 (04)	-.04 (.04)
JD manual work		-.12 (.06)*	-.09 (.06)	-.09 (.06)	-.08 (.06)
JD comp work		-.13 (.06)*	-.13 (.06)*	-.12 (.06)*	-.15 (.06)*
JD stand/walk		-.06 (.06)	-.04 (.06)	-.02 (.06)	-.04 (.06)
JR coworker sup			.10 (.05)	.09 (.05)	.07 (.05)
JR supervisor sup			-.03 (.05)	-.04 (.04)	-.03 (.04)
JR sit/stand			.04 (.04)	.04 (.04)	.05 (.04)
JR sched ctrl			.04 (.05)	.04 (.05)	.01 (.05)
JR fit			.10 (.05)*	.10 (.05)*	.04 (.05)
PD child				.01 (.04)	.05 (.04)
PD adult care				-.07 (.05)	-.06 (.05)
PD house/garden				.00 (.04)	-.06 (.04)
PR sleep quality					.30 (.05)***
PR sleep discrep					.05 (.05)
PR exercise					.04 (.04)
PR walking					.10 (.04)*
Total R^2	**.08****	**.12*****	**.14*****	**.15*****	**.26*****

JD psych dem = job demands psychological demands; JD manual work = job demands manual work; JD comp work = job demands computer work; JR coworker sup = job resource coworker support; JR supervisor sup = job resource supervisor support; JR sit/stand = job resource sit/stand decision; JR sched ctrl = job resource schedule control; JR fit = job resource work/non-work fit; PD child = personal demand child care; PD adult care = personal demand adult care; PD house/garden = personal demand house and garden work; PR sleep quality = personal resource sleep quality; PR sleep discrep = personal resource sleep discrepancy (high values = sleep surplus; low values = sleep deficit); PR exercise = personal resource exercise hours; PR walking = personal resource walking hours. Parameters are standardized beta coefficients (β). For parsimony, only significant interactions are shown

$^*p < .05$; $^{**}p < .01$; $^{***}p < .001$

by modifying McGonagle et al.'s (2015) and Brady et al.'s (2020) recent and comprehensive examinations of work ability which apply the JD-R model. In doing so, we made two contributions above and beyond their work. First, we incorporated a multidisciplinary operationalization of MSH into the model and narrowed the scope of predictors to those that held a greater theoretical importance for MSH and PWA. Second, we delivered a fuller account of the JD-R model by adding personal demands as predictors of MSH and PWA, responding to a call from other researchers to further investigate the concept of personal demands (Barbier et al., 2013).

Direct Effects

Our findings for PWA showed that one job resource (i.e., supervisor support) and one personal resource (i.e., sleep surplus) were associated with PWA, although several of the other job and personal resources that we examined were not. McGonagle et al. (2015) found that three job resources were related to PWA (including supervisor support, as we found), and that many personal resources (i.e., five psychosocial, two health-based) were also linked to PWA. The incongruence between our and McGonagle et al.'s (2015) findings may be that they included different personal resources (i.e., mostly psychosocial, such as sense of control, beneficial personality traits) and job resources (i.e., autonomy) than those used in our investigation. Our findings were somewhat more congruent with Brady et al. (2020), who found in their meta-analysis that seven job resources (i.e., coworker support, supervisor support, job control, task resources, rewards, justice perceptions, positive organizational climate) were consistently, positively related to work ability. They also found that four types of health-based personal resources were positively related to work ability: general health (including sleep), physical health, mental health, and health behaviors (including physical activity) as well as ten types of psychosocial personal resources. A future study of PWA and MSH should assess the role of psychosocial personal resources, which were not included in our study.

We used measures to evaluate the variety of MSH-relevant job demands that workers in the manufacturing sector have, none of which were related to work ability. These findings differ from McGonagle et al. (2015) who examined a different set of job demand measures and found several (i.e., role overload, physical demands,

Table 7 Indirect Effects of Computer-based demands, Sleep Quality, and Walking on Perceived Work Ability as Outcome Variable, via Musculoskeletal Health (Mediator)

Dependent Variable: Perceived Work Ability	Bootstrapped Confidence Interval
Predictor	
Computer-based physical demands	95% CI
	[-.07, -.01]
Sleep quality	95% CI
	[.03, .13]
Walking hours	95% CI
	[.003, .04]

Table 8 Multiple Regression Results for Employee Departure as Outcome Variable

Model	Step 1: Controls	Step 2: Musculoskeletal Health	Step 3: Perceived Work Ability
	β (SE)	*β (SE)*	*β (SE)*
c. Employee Departure predicted by:			
Age	-.02 (.05)	-.02 (.05)	-.02 (.05)
Gender (male = 1, female = 2)	.04 (.04)	.04 (.04)	.04 (.04)
Income	-.14 (.04)**	-.14 (.04)**	-.13 (.04)**
Job type	-.04 (.04)	-.04 (.04)	-.04 (.04)
Musculoskeletal Health		-.01 (.05)	.01 (.05)
Perceived Work Ability			-.05 (.06)
Total R^2	**0.03**	**0.03**	**.03***

Employee departure (1 = stayed; 2 = left); *$p < .05$; **$p < .01$

unfavorable body positions, negative environmental conditions) to be related to PWA. Brady et al. (2020) also found five types of job demands to be consistently, negatively related to work ability: quantitative, mental/emotional, physical, environmental conditions, and workplace mistreatment. Importantly, our finding that resources (rather than demands) relate to PWA aligns with the JD-R model, which generally posits that engagement-related positive outcomes such as PWA partially result from abundant job resources (Schaufeli & Taris, 2014).

Overall, the MSH direct effects observed in this study were in line with previous research and support Schaufeli and Taris' (2014) assertion that strain-related outcomes tend to result from both available resources and excessive job demands due to their impairment of health. Our reported association between MSH and computer work contributes to growing research based on the problematic nature of computer work for MSH, combined with the broader set of risks associated with sedentary jobs (Crandall et al., 2016; Wærsted et al., 2010). Future studies in light manufacturing should consider assessing mental/cognitive job demands, as the operation of automated machines increasingly requires workers to have technical ability and critical-thinking skills, which have been linked to MSH (Aas et al., 2011).

Our finding of a positive association between leisure-time walking and MSH is consistent with prior studies indicating the effectiveness of walking interventions for improving pain and function outcomes (O'Connor et al., 2015). The association between sleep quality and MSH has been observed in several recent studies (de Souza et al., 2020; Marklund et al., 2020; Roizenblatt et al., 2015; Vinstrup et al., 2018).

Overall, we did not find significant associations of any personal demands and either PWA or MSH, but this may be attributed to the small proportion of participants affected by child care, adult care, and domestic home/garden responsibilities. Moreover, eldercare is periodic and never affected more than ~ 15% of the parent study's population at any cross-sectional point. Therefore, conclusions are guarded.

Table 9 Overview of Study Hypotheses and Results

	Hypothesis	Results
Predictors of Perceived Work Ability (PWA)	Hypothesis 1: MSH-relevant job demands are negatively associated with PWA	[N.S.] MSH-relevant job demands were not associated with PWA
	Hypothesis 2: MSH-relevant job resources are positively associated with PWA	**Supervisor support** is positively associated with PWA
	Hypothesis 3: MSH-relevant personal demands are negatively associated with PWA	[N.S.] MSH-relevant personal demands were not associated with PWA
	Hypothesis 4: MSH-relevant personal resources are positively associated with PWA	**Sleep discrepancy**, in the form of a sleep surplus, was positively associated with PWA
Demand and Resource Interactions and PWA	Hypothesis 5: MSH-relevant job resources will moderate (buffer) relationships between MSH-relevant job demands and PWA	**1 Significant interaction.** Time Standing/Walking X Coworker Support
	Hypothesis 6: MSH-relevant personal resources will moderate (buffer) relationships between MSH-relevant personal demands and PWA	**1 Significant interaction.** House/garden work X Avg hours spent walking
Predictors of Musculoskeletal Health (MSH)	Hypothesis 7: MSH-relevant job demands are negatively associated with MSH	**Computer-based physical job demands** were negatively associated with MSH
	Hypothesis 8: MSH-relevant job resources are positively associated with MSH	[N.S.] MSH-relevant job resources were not associated with MSH
	Hypothesis 9: MSH-relevant personal demands are negatively associated with MSH	[N.S.] MSH-relevant personal demands were not associated with MSH
	Hypothesis 10: MSH-relevant personal resources are positively associated with MSH	**Sleep quality** and **Walking** was positively associated with MSH
Demand and Resource Interactions and MSH	Hypothesis 11: MSH-relevant job resources will moderate (buffer) relationships between MSH-relevant job demands and MSH	**3 Significant interactions.** Time spent standing/walking X supervisor support. Computer-based physical job demands X work hours fit with life. Computer-based physical job demands X supervisor support
	Hypothesis 12: MSH-relevant personal resources will moderate (buffer) relationships between MSH-relevant personal demands and MSH	**3 Significant interactions.** Child care X sleep quality. Child care X sleep discrepancy. Adult care X sleep quality

Table 9 (continued)

	Hypothesis	Results
MSH & Mediation	Hypothesis 13: MSH is positively associated with PWA	MSH was positively associated with PWA
	Hypothesis 14: MSH partially mediates relationships between job demands, job resources, personal demands, and personal resources and PWA	MSH mediated relationship between **computer-based physical job demands, sleep quality, and walking** with PWA
PWA & Employee Departure	Hypothesis 15: PWA is negatively associated with employee departure	[N.S.] PWA was not associated with employee departure
	Hypothesis 16: MSH is negatively associated with employee departure	[N.S.] MSH was not associated with employee departure
	Hypothesis 17: PWA partially mediates the relationship between MSH and employee departure	[N.S.] PWA did not mediate the relationship between MSH and employee departure

Further work is needed to examine and clarify the concept of personal demands within the context of work ability and MSH.

Interactions

We systematically examined the interactive and buffering effects of the JD-R variables. In line with prior research (e.g., Mansell & Brough, 2005), the interactive effects did not consistently buffer against adverse work- and health-related outcomes. This has been a limitation of the JD-R model for quite some time (Kain & Jex, 2010; Tucker et al., 2008), which is why a growing proportion of occupational health scholars opt for the use of direct effects (Luchman & González-Morales, 2013). Detailed interpretations of our counterintuitive results are hindered by the large number of interaction terms evaluated. Ostensibly, this increases the family-wise error rate.

Nevertheless, our interaction results broadly support the need for future studies to integrate qualitative approaches to JD-R and MSH research. For instance, semi-structured interviews (see Lundh & Rydstedt, 2016) with a subsample of workers in manufacturing may contextualize instances where counterintuitive findings are discovered. Another possible explanation may be found through psychological contract theory (Rousseau & Schalk, 2000), which suggests that certain job resources (e.g., supervisor support) lend themselves to yielding mixed results due to their dependence on employee perceptions of trust and reciprocity. The expectations workers have of their employers, co-workers, and work environment influence whether a demand or resource has its hypothesized impact; therefore, we urge future researchers to include assessments of employee expectations when designing studies that seek to evaluate interactive effects of the JD-R.

Limitations

As does the most recent iteration of the JD-R model, we included personal demands in our study in the form of home/family work (i.e., caregiving and home/garden responsibilities), for which we found no direct effects. This may be attributed to the small portion of the sample reporting such demands, possibly due to those demands affecting people at limited time periods in their life span. Personal demands that were conceptualized as being MSH-relevant may actually have been less relevant to MSH and PWA than other types of personal demands. Our measures may also have been insufficient, as although child care and adult care responsibilities were reported as low, anecdotally in focus groups, many older workers told us that they had adult children move back home during a period of financial uncertainty (the study period coincided with the Great Recession of 2008). Moreover, our creation of a composite variable of housework and garden work is a methodological weakness because we are unable to clearly make a connection between the score and hours spent working in the house and garden. This may be an epidemiological issue of misclassification. Further, there may be more salient constructs for assessing the personal demands which could be examined in future studies; for example, prolonged use of computers and mobile devices is associated with musculoskeletal symptoms, yet studies rarely examine computer/device use in personal life in combination with their use at work (Borhany et al., 2018). Finally, although we use the term "*personal demand*" because of our theoretical framing using a resources-based perspective (i.e., job demand-resources model), this has the drawback of eclipsing the positive associations (i.e., enjoyment, restoration) of home/family work that may be relevant to MSH and work ability.

Although an underlying assumption of this study was that employees would leave work due to health and work demand factors, the reality was that due to the recession of 2008 and its associated enduring economic hardships, expected retirements did not occur and disability retirement was virtually absent (Cherniack et al., 2015). Thus, despite associations of MSH and PWA, it is possible that exceptional conditions and period effects may negate application of these constructs to employee departure. A major limitation of this study was the imprecision of our employee departure measure. Although the goal of these analyses was to identify contributors to employee departure, the results, while in the expected direction, were not statistically significant. We chose to create an inclusive measure, capturing all types of employee departure that might be associated with MSH and PWA decrements: voluntary and involuntary termination, retirement, long-term disability, and death. An unknown percentage of these departures may not be due to decreased PWA or MSH (random misclassification), and thus necessarily dilute any associations between these predictors and employee departure outcomes and bias results towards the null hypothesis. This, combined with the relatively small number of participants who left employment in this study, made statistical significance difficult to achieve. Future research should examine the association of PWA and MSH and other factors known to be related to exit intentions and behaviors, including job attitudes (e.g., satisfaction, commitment), job performance, motivation (e.g., engagement), and strain (Brady et al., 2020).

Other limitations of this study should be considered. This was a cross-sectional study (apart from the employee departure variable), so we are unable to make any statement on causation. The self-reported nature of all measures may also have led to imprecision or bias. For instance, the measure of MSH we used may be limited. It may be that chronic MSH problems, rather than intermittent, matter most in terms of perceptions of PWA. In addition, more younger workers departed (compared to older workers), which may reflect a healthy worker effect or show that younger employees were able to find work elsewhere. However, our data did not provide that contextual information.

Implications for Prevention and Intervention

This study, in combination with existing studies, adds to the growing body of literature demonstrating the connection between poorly designed work, reduced work ability and MSH, and outcomes of disability and employment departure. To the list of work predictors, this study also adds non-work factors—accounting for personal demands and decrements in personal resources. These findings strengthen the rationale for a *Total Worker Health*® (TWH) approach to interventions which addresses exposures in both the work and non-work domains as well as their interactions, and are more effective in improving worker health (NIOSH, 2015a, b). One non-work factor that emerged as noteworthy in this study, the recession of 2008, speaks to the importance of considering broader impacts on worker health from the larger social-ecological environment.

In our sample from the industrial sector, MSH was predicted by job demands (computer-based) and personal resources (sleep quality, leisure-time walking), and PWA was predicted by job resources (supervisor support) and personal resources (sleep surplus). These results suggest changes in work organization that reduce job demands and increase personal resources, particularly by allowing employees more time for recovery activities such as sleep and health-enhancing activities such as physical exercise, would be beneficial. Schedule flexibility and control are the most obvious targets, but the importance of supervisor support in our model suggests that improving this workplace resource might also improve personal circumstances and well-being.

The constructs and predictors of MSH and PWA thus have potential for improving work organization, work design, and work/life balance. On the individual level, they have implications for screening and clinical treatment of disability, as well. Study results suggest that brief measures of both constructs could have a dual purpose. Decrements in either or both could flag the need for a more detailed analysis of the patient's work and non-work demands and resources, with suggestions for personal and organizational changes designed to improve function. These decrements could also serve as a diagnostic screening tool to quickly identify patients who might be in need of treatment and rehabilitation. Ideally, a simple battery of MSH and PWA indicators could be administered longitudinally, with sudden changes in measure magnitude or slope over time serving to identify patients in need of more concerted attention.

Conclusion

This study makes several important contributions to this field of research. Work ability research is not common in the U.S., and our study expands the research on work ability in the American workforce. Moreover, we focus on the manufacturing sector, a sector that is largely overlooked in work ability research, but one that is appropriate for a study focused on MSH, work ability, and employee departure (Sweet et al., 2010), particularly given its aging workforce. We observed new associations between both job and personal resources and work ability, job demands and personal resources and MSH, and MSH and work ability. Identifying antecedents of MSH and PWA can provide points of intervention to improve the health and functioning of aging workers. Our study indicates that reducing job demands and offering resources that increase psychosocial support at work and engagement in health behaviors may be effective interventions for promoting MSH and work ability.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s41542-021-00106-4.

Acknowledgements The authors would like to thank the workers and leaders at the manufacturing companies who contributed to this study for their effort and dedication to worker well-being. We also appreciate the contributions of Dr. Anne Kenny to early versions of this paper including participation in study conception and generation of study hypotheses.

Authors' Contributions AGD, JLB, JMC, LG, and NW contributed to the conception of the scientific questions and design of the work. RAL, LG, and GAP contributed to data analysis approach and performed data analysis. AGD, RAL, JLB, JMC, JLG, NW, and MGC contributed to interpretation of results. All authors contributed to manuscript preparation and revisions.

Funding This publication was supported by Grant Number R01OH008929 from the U.S. National Institute for Occupational Safety and Health. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of NIOSH.

Availability of Data and Material The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Code Availability The data that support the findings of this study are available on request from the corresponding author.

Declarations

Ethics Approval The Institutional Review Board at the University of Connecticut's School of Medicine approved the study protocol and written informed consent was obtained. Protocol number: 18-072S-2.

Consent to Participate Written informed consent was obtained by all study participants.

Consent for Publication Obtained.

Conflicts of Interest/Competing Interests The authors declare no conflicts of interest.

Disclaimer The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

References

Aas, R. W., Holte, K. A., Lie, K., & Lode, I. A. (2011). On long term sick leave due to musculoskeletal diseases and disorders: Experiences of work demands. *Work, 39*(3), 233–242.

Alavinia, S. M., van Duivenbooden, C., & Burdorf, A. (2007). Influence of work-related factors and individual characteristics on work ability among Dutch construction workers. *Scandinavian Journal of Work, Environment & Health, 33*, 351–357.

Ahlstrom, L., Grimby-Ekman, A., Hagberg, M., & Dellve, L. (2010). The work ability index and single-item question: Associations with sick leave, symptoms, and health—A prospective study of women on long-term sick leave. *Scandinavian Journal of Work, Environment, and Health, 36*(5), 404–412.

Bakker, A. B., & Demerouti, E. (2007). The job demands-resources model: State of the art. *Journal of Managerial Psychology, 22*, 309–328.

Bakker, A. B., & Demerouti, E. (2017). Job demands–resources theory: Taking stock and looking forward. *Journal of Occupational Health Psychology, 22*(3), 273.

Bakker, A. B., Demerouti, E., & Euwema, M. C. (2005). Job resources buffer the impact of job demands on burnout. *Journal of Occupational Health Psychology, 10*, 170–180.
Bakker, A. B., Demerouti, E., & Sanz-Vergel, A. I. (2014). Burnout and work engagement: The JD–R approach. *Annual Review of Organizational Psychology and Organizational Behavior, 1*, 389–411.
Barbier, M., Hansez, I., Chmiel, N., & Demerouti, E. (2013). Performance expectations, personal resources, and job resources: How do they predict work engagement? *European Journal of Work and Organizational Psychology, 22*(6), 750–762.
Barnes-Farrell, J. L., Bobko, N., Fischer, F., Iskra-Golec, I., Kaliterna, L., & Tepas, D. (2004). Comparisons of work ability for health care workers in five nations. In J. Ilmarinen & S. Lehtinen (Eds.), Past, present and future of work ability: Proceedings of the 1st international symposium on Work Ability (People and Work Research Reports No. 65; pp. 76–82). Finnish Institute of Occupational Health.
Bergman, S. (2007). Public health perspective–how to improve the musculoskeletal health of the population. *Best Practice & Research Clinical Rheumatology, 21*(1), 191–204.
Bernard, B. P. (1997). *Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back*. Department of Health and Human Services, National Institute for Occupational Safety and Health.
Borhany, T., Shahid, E., Siddique, W. A., & Ali, H. (2018). Musculoskeletal problems in frequent computer and internet users. *Journal of Family Medicine and Primary Care, 7*(2), 337.
Bouchard, C., Shephard, R. J., & Stephens, T. (1993). *Physical activity, fitness, and health*. Human Kinetics Publishers.
Brady, G. M., Truxillo, D. M., Cadiz, D. M., Rineer, J. R., Caughlin, D. E., & Bodner, T. (2020). Opening the black box: Examining the nomological network of work ability and its role in organizational research. *Journal of Applied Psychology, 105*(6), 637.
Breaugh, J. A. (1985). The measurement of work autonomy. *Human Relations, 38*, 551–570.
Buckle, P. W., & Devereux, J. J. (2002). The nature of work-related neck and upper limb musculoskeletal disorders. *Applied Ergonomics, 33*(3), 207–217.
Buysse, D. J., Reynolds, C. F., III., Monk, T. F., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh sleep quality index: A new instrument for psychiatric practice and research. *Psychiatry Research, 28*, 193–213.
Cadiz, D. M., Brady, G., Rineer, J. R., & Truxillo, D. M. (2019). A review and synthesis of the work ability literature. *Work, Aging and Retirement, 5*(1), 114–138.
Camerino, D., Conway, P. M., Van der Heijden, B. I. J. M., Estryn-Behar, M., Consonni, D., Gould, D., … Hasselhorn, H. (2006). Low perceived work ability, ageing and intention to leave nursing: A comparison among 10 European countries. *Journal of Advanced Nursing, 56*, 542–552.
Cherniack, M., Dussetschleger, J., Farr, D., & Dugan, A. (2015). Workplace cohort studies in times of economic instability. *American Journal of Industrial Medicine, 58*, 138–151.
Crandall, K. J., Zagdsuren, B., Schafer, M. A., & Lyons, T. S. (2016). Static and active workstations for improving workplace physical activity and sitting time. *International Journal of Human Movement and Sports Sciences, 4*(2), 20–25.
Darragh, A. R., Sommerich, C. M., Lavender, S. A., Tanner, K. J., Vogel, K., & Campo, M. (2015). Musculoskeletal discomfort, physical demand, and caregiving activities in informal caregivers. *Journal of Applied Gerontology, 34*(6), 734–760.
de Souza, J. M., de A Pinto, R. Z., Tebar, W. R., Gil, F., Delfino, L. D., Morelhão, P. K., ... & Christofaro, D. G. (2020). Association of musculoskeletal pain with poor sleep quality in public school teachers. *Work*, (Preprint), 1–8.
Demerouti, E., & Bakker, A. B. (2011). The job demands-resources model: Challenges for future research. *SA Journal of Industrial Psychology, 37*(2), 01–09.
Demerouti, E., Bakker, A. B., Nachreiner, F., & Schaufeli, W. B. (2001). The job demands-resources model of burnout. *Journal of Applied Psychology, 86*, 499–512.
Deros, B. M., Khamis, N. K., Ghani, J. A., Yusoff, A. R. M., & Salleh, C. (2013). A study on common risks and body parts complaints by standing workstation female operators in an electronics product manufacturing company. *Applied Science and Engineering Progress, 6*(2), 71–78.
Dugan, A. G., & Barnes-Farrell, J. L. (2020). Working mothers' second shift, personal resources, and self-care. *Community, Work & Family, 23*(1), 62–79.

Eskelinen, L., Kohvakka, A., Merisalo, T., Hurri, H., & Wägar, G. (1991). Relationship between the self-assessment and clinical assessment of health status and work ability. *Scandinavian Journal of Work, Environment & Health, 17*(1), 40–47.

European Foundation. (2007). *Fourth European working conditions survey*. European Foundation for the Improvement of Living and Working Conditions.

Fischer, F. M., Borges, F. D. S., Rotenberg, L., Latorre, M. R. D. O., Soares, N. S., Rosa, P. F. L. S., & Landsbergis, P. (2006). Work ability of health care shift workers: What matters? *Chronobiology Journal, 23*, 1165–1179.

Gandek, B., Ware, J. E., Aaronson, N. K., Apolone, G., Bjorner, J. B., Brazier, J. E., Bullinger, M., Kaasa, S., Leplege, A., Prieto, L., & Sullivan, M. (1998). Cross-validation of item selection and scoring for the SF-12 health survey in nine countries: Results from the IQOLA project. *Journal of Clinical Epidemiology, 51*, 1171–1178.

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I. M., ... & Swain, D. P. (2011). American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and Science in Sports and Exercise*, *43*(7), 1334–1359.

Gerr, F., Fethke, N. B., Anton, D., Merlino, L., Rosecrance, J., Marcus, M., & Jones, M. P. (2014). A prospective study of musculoskeletal outcomes among manufacturing workers: II. Effects of psychosocial stress and work organization factors. *Human Factors, 56*(1), 178–190.

Gratz, R. R., Claffey, A., King, P., & Scheuer, G. (2002). The physical demands and ergonomics of working with young children. *Early Child Development and Care, 172*(6), 531–537.

Guglielmi, D., Simbula, S., Schaufeli, W. B., & Depolo, M. (2012). Self-efficacy and workaholism as initiators of the job demands-resources model. *Career Development International, 17*, 375–389.

Himmelweit, S. (1995). The discovery of "unpaid work": The social consequences of the expansion of "work." *Feminist Economics, 1*(2), 1–19.

Hochschild, A. R. (1997). *The time bind: When work becomes home and home becomes work*. Metropolitan Books.

Hopsu, L., Leppänen, A., Tanta, R., & Louhevaara, V. (2005). Perceived work ability and individual characteristics as predictors for early exit from working life in professional cleaners. *International Congress Series, 1280*, 84–88.

Ilmarinen, J. (2009). Work ability: A comprehensive concept for occupational health research and prevention. *Scandinavian Journal of Work, Environment & Health, 35*(1), 1–5.

Ilmarinen, J. E. (2001). Aging workers. *Occupational and Environmental Medicine, 58*(8), 546–546.

Ilmarinen, J., & Tuomi, K. (2004). Past, present and future of work ability. *People and Work Research Reports, 65*, 1–25.

Ilmarinen, J., Tuomi, K., Eskelinen, L., Nygård, C. H., Huuhtanen, P., & Klockars, M. (1991a). Background and objectives of the Finnish research project on aging workers in municipal occupations. *Scandinavian Journal of Work, Environment and Health, 17*(Suppl 1), 7–11.

Ilmarinen, J., Tuomi, K., Eskelinen, L., Nygård, C. H., Huuhtanen, P., & Klockars, M. (1991b). Summary and recommendations of a project involving cross-sectional and follow-up studies on the aging worker in Finnish municipal occupations (1981–1985). *Scandinavian Journal of Work, Environment & Health, 17*(Suppl. 1), 135–141.

Ilmarinen, J., Gould, R., Järvikoski, A., & Järvisalo, J. (2008). Diversity of work ability. In R. Gould, J. Ilmarinen, J. Järvisalo, & S. Koskinen (Eds.), *Dimensions of work ability: Results of the Health 2000 survey* (pp. 13–24). Helsinki: Finnish Institute of Occupational Health.

Jenkinson, C., Layte, R., Jenkinson, D., Lawrence, K., Petersen, S., Paice, C., & Stradling, J. (1997). A shorter form health survey: Can the SF-12 replicate results from the SF-36 in longitudinal studies? *Journal of Public Health Medicine, 19*, 179–186.

Joling, C. I., Blatter, B. M., Ybema, J. F., & Bongers, P. M. (2008). Can favorable psychosocial work conditions and high work dedication protect against the occurrence of work-related musculoskeletal disorders? *Scandinavian Journal of Work, Environment & Health, 34*(5), 345–355.

Kain, J. & Jex, S. (2010). Karasek's (1979) job demands-control model: A summary of current issues and recommendations for future research, Perrewé, P.L. and Ganster, D.C. (Ed.) *New Developments in Theoretical and Conceptual Approaches to Job Stress (Research in Occupational Stress and Well Being, Vol. 8)*, Emerald Group Publishing Limited, pp. 237–268.

Karasek, R. A. (1985). *Job content questionnaire and user's guide*. University of Massachusetts Lowell, Department of Work Environment.

Karasek, R. A., Brisson, C., Kawakami, N., Houtman, I., Bongers, P., & Amick, B. (1998). Job Content Questionnaire (JCQ): An instrument for internationally comparative assessments of psychosocial job characteristics. *Journal of Occupational Health Psychology, 3*(4), 322–355.

Li, J., & Lin, B. (2017). Rebound effect by incorporating endogenous energy efficiency: A comparison between heavy industry and light industry. *Applied Energy, 200*, 347–357.

Loeppke, R. R., Schill, A. L., Chosewood, L. C., Grosch, J. W., Allweiss, P., Burton, W. N., ... & Hymel, P. (2013). Advancing workplace health protection and promotion for an aging workforce. *Journal of Occupational and Environmental Medicine*, *55*(5), 500–506.

Lorente Prieto, L., Salanova Soria, M., Martínez Martínez, I., & Schaufeli, W. (2008). Extension of the job demands-resources model in the prediction of burnout and engagement among teachers over time. *Psicothema, 20*, 354–360.

Luchman, J. N., & González-Morales, M. G. (2013). Demands, control, and support: A meta-analytic review of work characteristics interrelationships. *Journal of Occupational Health Psychology, 18*(1), 37–52.

Lundh, M., & Rydstedt, L. W. (2016). A static organization in a dynamic context: A qualitative study of changes in working conditions for Swedish engine officers. *Applied Ergonomics, 55*, 1–7.

Mansell, A., & Brough, P. (2005). A comprehensive test of the job demands-control interaction: Comparing two measures of job characteristics. *Australian Journal of Psychology, 57*(2), 103–114.

Marklund, S., Mienna, C. S., Wahlström, J., Englund, E., & Wiesinger, B. (2020). Work ability and productivity among dentists: Associations with musculoskeletal pain, stress, and sleep. *International Archives of Occupational and Environmental Health, 93*(2), 271–278.

McBeth, J., & Jones, K. (2007). Epidemiology of chronic musculoskeletal pain: Best practice & research. *Clinical Rheumatology, 21*(3), 403–425.

McGonagle, A. K., Barnes-Farrell, J. L., Di Milia, L., Fischer, F. M., Hobbs, B. B., Iskra-Golec, I., ... & Smith, L. (2014). Demands, resources, and work ability: A cross-national examination of health care workers. *European Journal of Work and Organizational Psychology, 23*(6), 830–846.

McGonagle, A. K., Fisher, G. G., Barnes-Farrell, J. L., & Grosch, J. W. (2015). Individual and work factors related to perceived work ability and labor force outcomes. *Journal of Applied Psychology, 100*(2), 376.

Miranda, H., Kaila-Kangas, L., Heliövaara, M., Leino-Arjas, P., Haukka, E., Liira, J., & Viikari-Juntura, E. (2010). Musculoskeletal pain at multiple sites and its effects on work ability in a general working population. *Occupational and Environmental Medicine, 67*(7), 449–455.

Miranda, H., Punnett, L., & Gore, R. J. (2014). Musculoskeletal pain and reported workplace assault: A prospective study of clinical staff in nursing homes. *Human Factors, 56*(1), 215–227.

Moloney, W., Boxall, P., Parsons, M., & Cheung, G. (2018). Factors predicting registered nurses' intentions to leave their organization and profession: A job demands-resources framework. *Journal of Advanced Nursing, 74*(4), 864–875.

Morse, T. F., Dillon, C., Warren, N., Levenstein, C., & Warren, A. (1998). The economic and social consequences of work-related musculoskeletal disorders: The Connecticut Upper-Extremity Surveillance Project (CUSP). *International Journal of Occupational and Environmental Health, 4*(4), 209–216.

Morse, T., Dillon, C., Weber, J., Warren, N., Bruneau, H., & Fu, R. (2004). Prevalence and reporting of occupational illness by company size: Population trends and regulatory implications. *American Journal of Industrial Medicine, 45*(4), 361–370.

Muthén, L.K. & Muthén, B.O. (1998–2017). Mplus user's guide. Eighth Edition. Muthén & Muthén.

National Institute for Occupational Safety and Health (2015a). *Musculoskeletal disorders. NIOSH Program Portfolio.* Retrieved from http://www.cdc.gov/niosh/programs/msd/

National Institute for Occupational Safety and Health (2015b). *Total Worker Health*™. Retrieved from http://www.cdc.gov/niosh/twh/

National Research Council. (1999). *Work-related musculoskeletal disorders: Report, workshop summary, and workshop papers*. The National Academies Press.

National Research Council. (2004). *Committee on the health and safety needs of older workers. Health and safety needs of older workers*. The National Academies Press.

NORA Manufacturing Sector Council. (2010, June). *National occupational research agenda (NORA): National manufacturing agenda*. Retrieved from http://www.cdc.gov/niosh/nora/comment/agendas/manuf/pdfs/ManufJune2010.pdf

Nygård, C. H., Eskelinen, L., Suvanto, S., Tuomi, K., & Ilmarinen, J. (1991). Associations between functional capacity and work ability among elderly municipal employees. *Scandinavian Journal of Work, Environment & Health, 17*(Suppl 1), 122–127.

O'Connor, S. R., Tully, M. A., Ryan, B., Bleakley, C. M., Baxter, G. D., Bradley, J. M., & McDonough, S. M. (2015). Walking exercise for chronic musculoskeletal pain: Systematic review and meta-analysis. *Archives of Physical Medicine and Rehabilitation, 96*(4), 724–734.

Occupational Safety and Health Administration. (n.d.). Computer Workstations eTool Checklist. https://www.osha.gov/SLTC/etools/computerworkstations/checklist.html

Occupational Safety and Health Administration. (1995). Draft proposed ergonomic protection standard: Summaries, explanations, regulatory text, appendices A and B. *Special Supplement, Occupational Safety and Health Reporter, 24.*

Pekkarinen, L., Elovainio, M., Sinervo, T., Heponiemi, T., Aalto, A. M., Noro, A., & Finne-Soveri, H. (2013). Job demands and musculoskeletal symptoms among female geriatric nurses: The moderating role of psychosocial resources. *Journal of Occupational Health Psychology, 18*(2), 211.

Pohjonen, T. (2001a). Age-related physical fitness and the predictive values of fitness tests for work ability in home care work. *Journal of Occupational and Environmental Medicine, 43*(8), 723–730.

Pohjonen, T. (2001b). Perceived work ability of home care workers in relation to individual and work-related factors in different age groups. *Occupational Medicine, 51*(3), 209–217.

Punnett, L., & Wegman, D. H. (2004). Work-related musculoskeletal disorders: The epidemiologic evidence and the debate. *Journal of Electromyography and Kinesiology, 14*(1), 13–23.

Roizenblatt, S., Souza, A. L., Palombini, L., Godoy, L. M., Tufik, S., & Bittencourt, L. R. A. (2015). Musculoskeletal pain as a marker of health quality. Findings from the epidemiological sleep study among the adult population of Sao Paulo city. *PLoS One, 10*(11), e0142726.

Rousseau, D., & Schalk, R. (2000). *Psychological contracts in employment: Cross-national perspectives*. Sage Publications.

Schaufeli, W. B., & Taris, T. W. (2014). A critical review of the job demands-resources model: Implications for improving work and health. In *Bridging occupational, organizational and public health* (pp. 43–68). Springer.

Schaufeli, W. B., Bakker, A. B., Van der Heijden, F. M. M. A., & Prins, J. T. (2009). Workaholism, burnout and well-being among junior doctors: The mediating role of role conflict. *Work & Stress, 16*, 249–272.

Segar, G., & Rahman, M. N. A. (2019). Musculoskeletal symptoms and ergonomic risk assessment among production operators at manufacturing industries: A review. In *IOP Conference Series: Materials Science and Engineering* (Vol. 607, No. 1, p. 012009). IOP Publishing.

Selig, J. P., & Preacher, K. J. (2008, June). Monte Carlo method for assessing mediation: An interactive tool for creating confidence intervals for indirect effects [Computer software]. Available from http://quantpsy.org/

Shultz, K. S., & Adams, G. A. (2012). *Aging and work in the 21st century*. Psychology Press.

Silverstein, M. (2008). Meeting the challenges of an aging workforce. *American Journal of Industrial Medicine, 51*(4), 269–280.

Silvia Monteiro, M., Maria Costa Alexandre, N., Ilmarinen, J., & Mendes Rodrigues, C. (2009). Work ability and musculoskeletal disorders among workers from a public health institution. *International Journal of Occupational Safety and Ergonomics, 15*(3), 319–324.

Sjögren-Rönkä, T., Ojanen, M. T., Leskinen, E. K., Mustalampi, S. T., & Mälkiä, E. A. (2002). Physical and psychosocial prerequisites of functioning in relation to work ability and general subjective well-being among office workers. *Scandinavian Journal of Work, Environment & Health, 28*, 184–190.

Smith, J., Fisher, G., Ryan, L., Clarke, P., House, J., & Weir, D. (2013). *Psychosocial and Lifestyle Questionnaire: 2006 – 2010*. Ann Arbor, MI: Survey Research Center, Institute for Social Research, University of Michigan. Retrieved from http://hrsonline.isr.umich.edu/sitedocs/userg/HRS2006-2010SAQdoc.pdf

Strazdins, L., & Bammer, G. (2004). Women, work and musculoskeletal health. *Social Science & Medicine, 58*(6), 997–1005.

Sweet, S., Pitt-Catsouphes, M., Besen, E., Hovhannisyan, S., & Pasha, F. (2010). Talent pressures and the aging workforce: Responsive action steps for the health care and social assistance sector (No. 2.1, p. 0). Industry Sector Report.

Toossi, M. (2015). Labor force projections to 2024: The labor force is growing, but slowly. *Monthly Labor Review, Rev.*, *138*, 1. U.S. Bureau of Labor Statistics.

Tucker, J. S., Sinclair, R. R., Mohr, C. D., Adler, A. B., Thomas, J. L., & Salvi, A. D. (2008). A temporal investigation of the direct, interactive, and reverse relations between demand and control and affective strain. *Work & Stress, 22*(2), 81–95.
Tuomi, K., Eskelinen, L., Toikkanen, J., Jarvinen, E., Ilmarinen, J., & Klockars, M. (1991). Work load and individual factors affecting work ability among aging municipal employees. *Scandinavian Journal of Work, Environment & Health, 17*(Suppl. 1), 128–134.
Tuomi, K., Ilmarinen, J. A., Jahkola, A., Katajarinne, L., & Tulkki, A. (1998). *Work ability index* (2nd ed.). Finnish Institute of Occupational Health.
US Department of Labor - Bureau of Labor Statistics. (2016). Nonfatal Occupational Injuries and Illnesses Requiring Days Away From Work, 2015.
van den Berg, T. I., Alavinia, S. M., Bredt, F. J., Lindeboom, D., Elders, L. A., & Burdorf, A. (2008). The influence of psychosocial factors at work and life style on health and work ability among professional workers. *International Archives of Occupational and Environmental Health, 81*(8), 1029–1036.
van den Berg, T. I., Elders, L. A., de Zwart, B. C., & Burdorf, A. (2009). The effects of work-related and individual factors on the Work Ability Index: A systematic review. *Occupational and Environmental Medicine, 66*(4), 211–220.
Vedovato, T. G., & Monteiro, I. (2014). Health conditions and factors related to the work ability of teachers. *Industrial Health, 52*, 121–128.
Vincent, R., & Hocking, C. (2013). Factors that might give rise to musculoskeletal disorders when mothers lift children in the home. *Physiotherapy Research International, 18*(2), 81–90.
Vinstrup, J., Jakobsen, M. D., Calatayud, J., Jay, K., & Andersen, L. L. (2018). Association of stress and musculoskeletal pain with poor sleep: Cross-sectional study among 3,600 hospital workers. *Frontiers in Neurology, 9*, 968.
von Bonsdorff, M. B., Seitsamo, J., Ilmarinen, J., Nygård, C. H., von Bonsdorff, M. E., & Rantanen, T. (2011). Work ability in midlife as a predictor of mortality and disability in later life: A 28-year prospective follow-up study. *Canadian Medical Association Journal, 183*(4), E235–E242.
Vuori, I. (1995). Exercise and physical health: Musculoskeletal health and functional capabilities. *Research Quarterly for Exercise and Sport, 66*(4), 276–285.
Wærsted, M., Hanvold, T. N., & Veiersted, K. B. (2010). Computer work and musculoskeletal disorders of the neck and upper extremity: A systematic review. *BMC Musculoskeletal Disorders, 11*(1), 79.
Ware, J. E., Kosinski, M., & Keller, S. D. (1996). A 12-item short-form health survey: Construction of scales and preliminary tests of reliability and validity. *Medical Care, 34*, 220–233.
Ware, J. E., Kosinkski, M., & Keller, S. D. (1998). *How to score the SF-12 physical and mental health summary scales*. Quality Metric.
Wareham, N. J., Jakes, R. W., Rennie, K. L., Mitchell, J., Henning, S., & Day, N. E. (2002). Validity and repeatability of the EPIC-Norfolk physical activity questionnaire. *International Journal of Epidemiology, 31*, 168–174.
Waters, T. R. (2004). National efforts to identify research issues related to prevention of work-related musculoskeletal disorders. *Journal of Electromyography and Kinesiology, 14*(1), 7–12.
Wheaton, F., & Crimmins, E. M. (2012). The demography of aging and retirement. In M. Wang (Ed.), *Handbook of Retirement.* Oxford University Press.
Xanthopoulou, D., Bakker, A. B., Demerouti, E., & Schaufeli, W. B. (2007). The role of personal resources in the job demands-resources model. *International Journal of Stress Management, 14*(2), 121.
Zeijen, M. E., Brenninkmeijer, V., Peeters, M. C., & Mastenbroek, N. J. (2021). Exploring the role of personal demands in the health-impairment process of the job demands-resources model: A study among master students. *International Journal of Environmental Research and Public Health, 18*(2), 632.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Authors and Affiliations

Alicia G. Dugan[1] · Rick A. Laguerre[2] · Janet L. Barnes-Farrell[2] · Jennifer M. Cavallari[1,3] · Jennifer L. Garza[1,3] · Lindsey A. Graham[4] · Gretchen A. Petery[5] · Nicholas Warren[1] · Martin G. Cherniack[1]

1 Department of Medicine, Division of Occupational and Environmental Medicine, University of Connecticut School of Medicine, 263 Farmington Avenue, Farmington, CT 06030, USA

2 Department of Psychological Sciences, University of Connecticut, 406 Babbidge Road, Unit 1020, Storrs, CT 06269, USA

3 Department of Public Health Sciences, University of Connecticut School of Medicine, 195 Farmington Avenue, Farmington, CT 06030, USA

4 Dunlap and Associates, Inc., 110 Lenox Avenue, Stamford, CT 06906-2300, USA

5 National Center for Productive Aging and Work, National Institute for Occupational Safety and Health (NIOSH), 4676 Columbia Parkway, MS C-2, Cincinnati, OH 45226-1998, USA