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Physical work conditions and disparities in later life functioning: Potential pathways

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ABSTRACT

Research in the US on the social determinants of reduced physical functioning at older ages has typically not considered physical work conditions as contributors to disparities. We briefly describe a model of occupational stratification and segregation, review and synthesize the occupational health literature, and outline the physiological pathways through which physical work exposures may be tied to long-term declines in physical functioning. The literature suggests that posture, force, vibration, and repetition are the primary occupational risk factors implicated in the development of musculoskeletal disorders, through either acute injuries or longer-term wear and tear. Personal risk factors and environmental and structural work characteristics can modify this association. In the long-term, these musculoskeletal disorders can become chronic and ultimately lead to functional limitations and disabilities that interfere with one's quality of life and ability to remain independent. We then use data on occupational characteristics from the Occupational Information Network (O*NET) linked to the 2019 American Community Survey (ACS) to examine disparities among sociodemographic groups in exposure to these risk factors. Occupations with high levels of these physical demands are not limited to those traditionally thought of as manual or blue-collar jobs and include many positions in the service sector. We document a steep education gradient with less educated workers experiencing far greater physical demands at work than more educated workers. There are pronounced racial and ethnic differences in these exposures with Hispanic, Black, and Native American workers experiencing higher risks than White and Asian workers. Occupations with high exposures to these physical risk factors provide lower compensation and are less likely to provide employer-sponsored health insurance, making it more difficult for workers to address injuries or conditions that arise from their jobs. In sum, we argue that physical work exposures are likely an important pathway through which disparities in physical functioning arise.

1. Introduction

Physical functioning is an important component of health and quality of life across the life course. While declines in functioning can affect individuals of all ages, they are most common in older adulthood and are often precursors of disability and loss of independence (Verbrugge & Jette, 1994). Though findings are mixed, several measures suggest that physical functioning has worsened for middle aged and older adults in the US over the past two decades (Case et al., 2020; Crimmins et al., 2016; Zajacova & Montez, 2018; Zimmer & Zajacova, 2020), reversing the trend of improvements (Crimmins, 2004; Seeman et al., 2010). Black and Hispanic Americans have more functional limitations and higher rates of disability than do Whites (Haas & Rohlfsen, 2010; Hayward et al., 2014; Pebley et al., 2021; Zajacova et al., 2014), and lower levels of education are associated with a higher burden of these conditions (Townsend & Mehta, 2021; Zajacova et al., 2014). Women are also more likely to experience functional limitations and disability than men, even when age composition is taken into account (Federal Interagency Forum on Aging-Related Statistics, 2020).

Extensive research on the social determinants of health has delineated the role of macro-social factors in health and health inequalities (Gee and Ford, 2011; Homan, 2021; Krieger, 2021; Marmot and Allen, 2014). Surprisingly little of this research has considered work conditions as mechanisms through which macro-social factors affect health

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(Ahonen et al., 2018; Fujishiro et al., 2021), although this topic has been studied more extensively in Europe (Borg & Kristensen, 2000; Hiesinger & Tophoven, 2019; Jonsson et al., 2021). Ahonen et al. (2018) propose several reasons for this omission, including a focus on education and income as markers of socioeconomic status, the complex and bidirectional relationship between work and health, limited availability of information on work conditions in data sources used to study population health inequities, and a lack of interdisciplinary collaboration between the general health disparities and occupational health fields.

In contrast, the field of occupational health has investigated occupational risk factors for many decades. These studies show that several common physical occupational exposures increase the risk for musculoskeletal conditions that ultimately lead to diminished physical functioning. However, the focus of these studies on the shorter-term consequences of specific exposures in a particular occupation or industry, rather than the accumulation of exposures over the life course in the general population, makes this literature less salient for researchers outside of the field of occupational health.

In this paper, we first briefly outline a model of occupational stratification—i.e., how individuals are sorted into occupations and specific jobs—and how this process is affected by societal issues such as systemic racism. We then review the occupational health literature and outline the physiological pathways through which physical work exposures may produce long-term declines in physical functioning, for use by public health, social science, and gerontology researchers interested in the social determinants of health. We also discuss the gaps in knowledge in occupational health research. We focus on the consequences of physical work exposures for musculoskeletal disorders (MSDs), because they are a frequent cause of functional limitations, the most common diagnosis among older Social Security Disability Insurance (SSDI) recipients (Favreault & Schwabish, 2016), and high prevalence health conditions among older adults. This section of the paper addresses the following questions: 1) What specific physical work activities and exposures are detrimental to musculoskeletal health? 2) Through which physiological mechanisms can these activities typically affect the musculoskeletal system? and 3) How does the accumulation of these exposures over a lifetime of work affect long-term physical functioning?

We then examine variation in detrimental physical work conditions identified in the occupational health literature among social groups. Based on our social determinants framework, we expect to see large disparities in exposure to potentially hazardous work conditions by race, ethnicity, nativity, gender, and socioeconomic status. The goal of this descriptive analysis is to demonstrate that substantial differences among these social groups are, in fact, observed in the population.

2. Social disparities framework

The framework that undergirds this paper is based on literature on social disparities in health, particularly Fujishiro et al. (2021), and the sociological literature on occupational stratification (Asad & Clair, 2018; del Río & Alonso-Villar, 2015; Pager et al., 2009; Rivera, 2020; Wilson, 2017). The framework is shown in Fig. 1 as the left side of an overall schematic diagram of the associations we discuss in this paper. The top-most box in Fig. 1, labeled “Systemic racism, sexism, and anti-immigrant structures and norms”, summarizes Fujishiro et al.’s (2021) macro-sociopolitical model in which they argue that societal level sociopolitical values and priorities (e.g., racism or racial privilege) profoundly influence the distribution of occupations and jobs among members of social groups (e.g., racial, ethnic, and nativity groups).

Within the environment created by the macro-level social institutions and norms described by Fujishiro et al. (2021), we view individual job placements as the product of the interaction between: (1) “job placement factors” and (2) workers’ individual human capital, social background, and personal attributes. Fujishiro et al. (2021) refer to the interplay of these two factors as “sorting systems.” Job placement factors include labor market conditions (demand for and supply of workers with particular skills) and wages, benefits, and working conditions offered by employers. Not shown in Fig. 1, but still important, are social networks, which can also affect job placement and mobility through information about jobs and advice. Individual human capital includes educational attainment, specialized skills, prior work experience, interpersonal skills, etc. and plays a major role in determining individuals’ job opportunities, placement, and mobility (Breen & Jonsson, 2005; Warren et al., 2002).

Labor markets and individual human capital are both affected by macro-social institutions and norms. For example, systemic racism has persistent and insidious effects in multiple stages of the labor market and hiring and promotion practices, despite laws preventing discrimination (Quillian et al., 2017; Pedulla & Pager, 2019; Wilson, 2017). Systemic racism also affects individuals’ human capital through disparities in

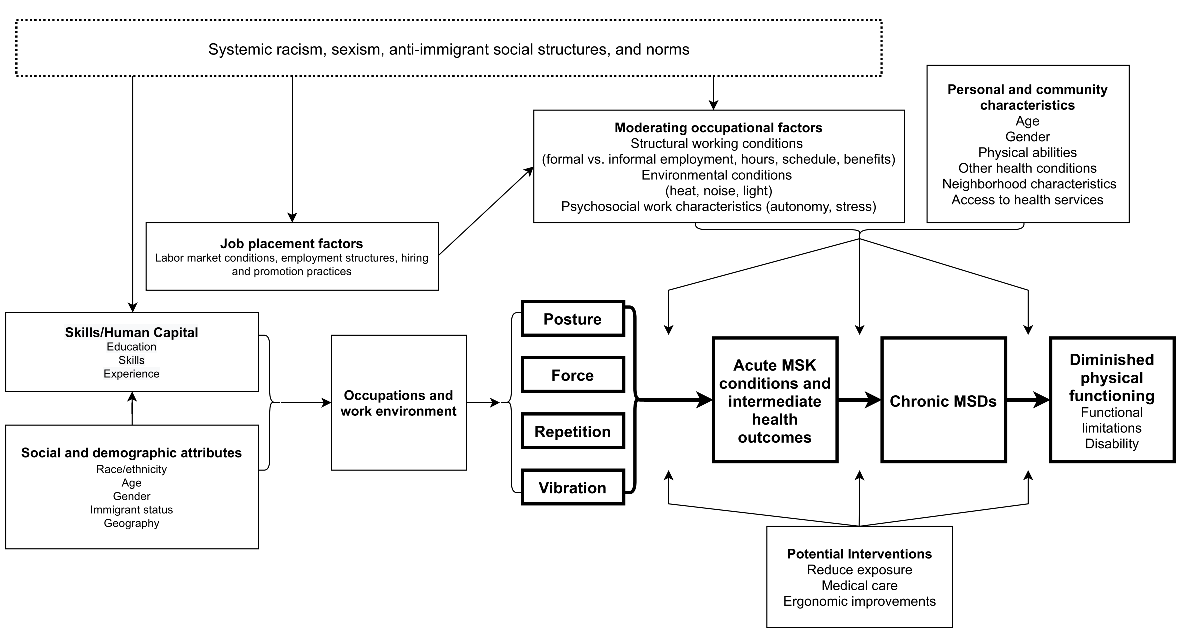

Fig. 1. Proposed pathways between occupational stratification, physical work exposures, and disparities in physical functioning. The bolded boxes and arrows emphasize the part of the pathway that is the focus of this paper.

access to high quality education and skills training (Phillips et al., 2011). Lower educational attainment and a poorer quality education reduces the chances of higher pay and better work conditions for many Black, Hispanic, and immigrant workers. Social background also has important effects: parents who have less experience of higher education themselves and fewer financial resources are less able to help their children get a college education, which limits occupational attainment (Breen & Jonsson, 2005). Residential and educational segregation by race can also narrow social networks that could be useful in job placement and mobility (Pedulla & Pager, 2019).

Macro-social institutions and norms, such as systemic racism and anti-immigrant social structures, can also affect potential moderating factors that can exacerbate or mitigate potential harms due to physically demanding work, as shown in Fig. 1. If workers in a particular occupation are predominantly from less privileged social groups, employers may offer workers fewer benefits, poorer working conditions, and more lax enforcement of occupational safety rules (Fujishiro et al., 2021). For example, because undocumented workers are less likely to report unsafe working conditions for fear of job loss or deportation, employers of undocumented immigrants may have less incentive to reduce workplace hazards (Flynn et al., 2015).

The social disparities framework describes how workers are distributed among jobs and occupations and how this process can be affected by macro-social institutions and norms. In the next section, we turn to the consequences of this sorting process by examining the question of how physically demanding work can affect the development of MSDs.

3. Review of the occupational health literature

In this section, we review the biomechanical pathways through which work conditions can lead to MSDs and ultimately functional limitations and disability (outlined on the right side of Fig. 1). Initial declines in physical functioning are frequently measured as functional limitations, which capture impairments in common movement patterns, such as walking, reaching one's arms overhead, or lifting moderately heavy objects (Verbrugge & Jette, 1994). These impairments can become disabling in later life when they interfere with activities of daily living (ADLs)—activities necessary for personal maintenance, including bathing, personal hygiene, using the toilet, dressing, eating, and moving around one's home (Lawton & Brody, 1969; Verbrugge & Jette, 1994). Physical impairments can also contribute to disability in the domain of instrumental activities of daily living (IADLs), which includes organizational activities such as preparing meals and housekeeping, although these limitations are frequently related to cognitive impairments (Lawton & Brody, 1969; National Academies of Sciences, 2019).

Biomechanics refers to the function of musculoskeletal systems under different conditions. We focus primarily on the potential effects of four biomechanical exposures with sufficient evidence to be considered risk factors for declines in physical functioning: work-related postures, force, vibration, and repetition. We summarize potential pathways between physical work activities and functional limitations at older ages in the bolded section on the right side of Fig. 1. This part of the schematic diagram includes three stages: 1) the effects of specific work activities on acute musculoskeletal (MSK) symptoms, 2) the transition from acute MSK symptoms to chronic musculoskeletal disorders (MSDs), and 3) the association between chronic MSDs and functional limitations and disability. Though we show three distinct stages, this progression is not necessarily linear and individuals need not experience all intermediate stages. Moderating factors can increase the risk of injury and of progression from acute to chronic conditions. These factors include environmental exposures, psychosocial exposures, the duration of exposure, and personal and community characteristics. The diagram also indicates that potential interventions can reverse or slow this progression. We acknowledge that potential interventions and moderating factors certainly play a role in how work activities influence later life health outcomes, but they are not the focus of this literature review.

3.1. Physical risk factors at work and associated adverse outcomes

Physically demanding work may be detrimental to the musculoskeletal system in multiple ways, but the risk factors that have been consistently identified in the occupational health literature are posture, force, repetition, and vibration (Bernard et al., 1997; California Department of Industrial Relations, 1999; Pope et al., 2002). Of these four risk factors, posture and force appear to have a larger effect on the musculoskeletal system than vibration and repetition, which act more as secondary risk factors (Gallagher & Heberger, 2013; Hagberg, 2002). Each of these risk factors and associated MSDs is reviewed below.

3.1.1. Posture

3.1.1.1. Prolonged standing. Prolonged standing is associated with pain, discomfort, and muscle fatigue, especially in the low back and lower extremities, as well as adverse cardiovascular and pregnancy-related outcomes (Coenen et al., 2017; Halim & Omar, 2011; McCulloch, 2002; Waters & Dick, 2015). The definition of "prolonged" varies in the literature, but adverse effects of standing have been documented after relatively short periods. Coenen et al. (2017) found that people began to demonstrate low back symptoms after 71 min of standing, while others found that workers can experience fatigue and discomfort at shorter durations depending on floor surface and the tasks done by the upper extremities (Halim et al., 2012; Lin et al., 2012).

Of health outcomes associated with prolonged standing, low back pain and muscle fatigue are most pertinent to the development of MSDs. Low back pain is a musculoskeletal complaint with several biomechanical causes (Coenen et al., 2017). Standing in suboptimal postures can place pressure on the facet joints, which connect the vertebrae and allow for spinal movement, leading to joint degeneration and potentially osteoarthritis; standing can also exacerbate pain in individuals already experiencing facet joint-related pain (Kalichman & Hunter, 2007). The inability to take sitting or walking breaks is associated with low back pain, potentially due to muscular fatigue from maintaining upright posture (Tissot et al., 2009). Discomfort and muscle fatigue experienced in the lower extremities during prolonged standing is more likely to involve vascular, rather than biomechanical, pathways. Blood and metabolic byproducts can pool in the legs during long periods of standing upright, leading to swelling and inflammation (Balasubramanian et al., 2009; Coenen et al., 2017). As with low back pain, the ability to move during work and adjust postures reduces lower extremity MSK complaints (Reid et al., 2010; Waters & Dick, 2015).

3.1.1.2. Prolonged sitting. Prolonged sitting is often defined as sitting for longer than 30 min, though the exact time period varies, and workers may spend far longer periods sitting depending on their occupation (Healy et al., 2013; Parry & Straker, 2013). Prolonged static postures, such as sitting, can lead to muscle fatigue and imbalance, pain, increased compressive forces in the spine and deformation of intervertebral discs, eventually culminating in MSDs (Todd et al., 2007). These adverse effects are exacerbated by non-neutral postures of the spine. For example, the slumped position adopted by many workers can lead to excessive flexion of the spine, and a rotated spinal posture that may be required when operating some equipment or working at a non-ergonomic workstation can lead to imbalances in the muscles stabilizing the spine (Burdorf et al., 1993; Pope et al., 2002; Szeto & Lam, 2007; Todd et al., 2007). These adverse effects of sitting may be ameliorated with ergonomic improvements to workstations to promote neutral postures as well as with intermittent breaks from sitting (Szeto & Lam, 2007; Tissot et al., 2009; Todd et al., 2007). In addition to the direct biomechanical relationships between sitting and MSDs, sedentary work may also be considered a risk factor for MSDs through its relationship with overweight/obesity (Choi et al., 2010).

3.1.1.3. Awkward postures. In the ergonomics literature, awkward postures are defined as joint positions that are significant deviations from neutral (Kittusamy & Buchholz, 2004; Pope et al., 2002). This definition includes most postures that are not sitting or standing—crouching, kneeling, squatting, and twisting. Awkward postures may be especially detrimental to musculoskeletal health when adopted frequently in occupational settings (Marras & Karwowski, 2006; Pope et al., 2002). Awkward postures put workers at risk for musculoskeletal problems due to the disruption of muscle synergy (Gallagher, 2005). According to the *differential fatigue theory*, asymmetric motions overload certain muscles and joints more than others, which can cause muscles to fatigue at different rates, resulting in the disruption of natural movement patterns (Kumar, 2001). Asymmetric motions can lead to chronic nerve compression, the increased use and shortening of some muscles and the underuse and weakening of other muscles (Mackinnon & Novak, 1994). The body then recruits other muscles to compensate for the imbalances, ultimately establishing a cycle of muscular imbalance that disrupts natural movement patterns, and further strains the body (Mackinnon & Novak, 1994).

Awkward postures, such as tiptoeing, stooping, squatting, kneeling, and sitting on the floor, have been associated with acute discomfort in the lower extremities (Reid et al., 2010), while bending and twisting have been associated with low back pain (Das, 2015; Plouvier et al., 2009). Osteoarthritis (OA)—a non-inflammatory, degenerative joint disease that occurs through the degeneration of cartilage, bone, and soft tissues that are important for joint function—is one of the most common long-term ailments associated with work involving kneeling and squatting (Coggon et al., 2000; Holte et al., 2000; Jensen, 2008b; McDonough & Jette, 2010).

3.1.2. Force

In the occupational health literature, force refers to the mechanical effort needed to overcome friction or gravity to accomplish a task (National Research Council and Institute of Medicine, 2001). Force can be broadly divided into three categories: lifting, carrying, and pushing/-pulling. These activities are most often associated with jobs that involve manual material handling, but also affect workers in other contexts, such as patient lifting and moving in healthcare settings. Force produces torque on the joints as well as tension, compression, and shearing forces on the tissues; when this force exceeds the body's tolerance, it becomes potentially injurious (National Research Council and Institute of Medicine, 2001).

Previous research has found dose-dependent connections between manual material handling or patient lifting and discomfort in the lower extremities, low back, and hip (Bern et al., 2013; Deros et al., 2010; Lee et al., 2013; Reid et al., 2010), and between pushing and pulling and low back pain, neck pain, knee pain, sciatica, and shoulder complaints (Hoozemans et al., 2002, 2014; Landsbergis et al., 2020; Reid et al., 2010). Heavy lifting, especially in combination with awkward postures, has been associated with long-term ailments, including osteoarthritis of the knee and hip (Bern et al., 2013; Coggon et al., 2000; Gallagher, 2005; Jensen, 2008a, 2008b), degeneration of the intervertebral discs, and osteoarthritis of the facet joints in the spine (Urits et al., 2019). In addition to these conditions due to gradual wear and tear, force can also lead to immediate musculoskeletal symptoms or conditions through acute injuries caused by a single traumatic event, such as a fracture (Courtney & Webster, 1999; National Research Council and Institute of Medicine, 2001).

3.1.3. Vibration

Occupational tasks that involve vibrating tools or machinery have been associated with several MSDs (Bernard et al., 1997; Hagberg, 2002). Vibration can stimulate muscle contraction and increase the force required to hold an object, increasing the risk of force-related injury to the tendons and nerves (National Research Council and Institute of Medicine, 2001). Evidence from animal experiments suggests that vibration causes peripheral nerve damage, which could account for the loss of hand mobility experienced by humans following prolonged exposure to vibration (Zimmerman et al., 2017, 2020).

There is extensive evidence of an association between occupational exposure to vibration and the eponymous hand-arm vibration syndrome, an occupational disease characterized by musculoskeletal, vascular, and neurologic symptoms. These symptoms involve pain, reduced grip strength, numbness, tingling, and low blood flow in the fingers (also called Raynaud's phenomenon or white finger) (Bernard et al., 1997; Shen & House, 2017). Exposure to whole-body vibration has been linked to sciatica and pain in the low back, neck, and knees, but evidence supporting this link has been mixed (Bernard et al., 1997; da Costa & Vieira, 2010; Landsbergis et al., 2020; Urits et al., 2019).

3.1.4. Repetition

Repetition is considered a risk factor for work-related MSDs through inflammatory and fibrotic (scarring) pathways (Al-Shatti et al., 2005; Barbe et al., 2003; Barr et al., 2003, 2004). Research in animals has revealed that repetitive motions can cause microtrauma to tissues, which activates the inflammatory system, leading to swelling and attraction of immune cells (Abdelmagid et al., 2012; Al-Shatti et al., 2005; Barbe et al., 2003; Barr et al., 2003, 2004).

Chronic activation of this immune response, which can occur without adequate breaks from the repetitive motions, can lead to nerve compression and replacement of the injured tissue with fibrotic (scar) tissue, which can be painful and interfere with mobility (Abdelmagid et al., 2012; Barbe et al., 2003; Barr, 2006; Barr et al., 2004). In humans, repetitive hand motions can cause inflammation and swelling that compress the median nerve and lead to carpal tunnel syndrome (Yassi, 1997). Carpal tunnel syndrome is a prevalent work-related MSD, characterized by pain, numbness, and tingling in the arm and hand (da Costa & Vieira, 2010; Dale et al., 2015; Yassi, 1997). Repetitive work has also been linked to knee, arm, and back pain (Andersen et al., 2007; da Costa & Vieira, 2010; Urits et al., 2019). Though these adverse effects of repetition are present even with tasks requiring negligible force, higher risks are observed with repetition of high-force activities (Abdelmagid et al., 2012; Barbe et al., 2013; Gallagher & Heberger, 2013).

3.2. Mechanisms linking acute complaints and injuries to chronic conditions

While some MSDs are permanent and require only a single exposure, many become chronic only after repeated exposures. There appears to be a dose-response relationship between biomechanical risk factors and several MSDs (Bern et al., 2013; Plouvier et al., 2015). Studies of long-term exposure in retired populations have found that greater exposure to occupational biomechanical risk factors during the working years is associated with greater risk of MSDs in later life (Berg et al., 1988; Calmels et al., 1998; Dong et al., 2011; Plouvier et al., 2015). In other words, damage can accumulate across the life course and eventually lead to more serious and permanent problems.

Acute pain can become chronic as part of a maladaptive neurologic process through which the body's pain receptors become more sensitive and the brain perceives the same stimuli to be more painful (Baliki & Apkarian, 2015; Basbaum et al., 2009). An emerging body of evidence suggests that opioids commonly prescribed to manage pain may actually increase sensitivity to pain in the long-term (Ballantyne, 2017; Feehan & Zadina, 2019; Green-Fulgham et al., 2019).

In contrast to the more gradual wear and tear process described previously, acute workplace injuries can also lead to chronic conditions. At one extreme, a worker who experiences a severed spinal cord as a result of a fall can be paralyzed and thus functionally impaired for the rest of life (Chen et al., 2016). Less serious injuries can increase susceptibility to future injury, especially if occupational modifications are not made (Handford et al., 2017; Krause and Lund, 2004; Sears et al., 2021). In the absence of adequate treatment or recovery, individuals experiencing pain or recovering from an injury often develop dysfunctional movement patterns to avoid further pain in the affected area; these patterns can overload other tissues and lead to secondary musculoskeletal damage (Merkle et al., 2020; Ro et al., 2019).

3.3. Linking work-related musculoskeletal conditions to declines in physical functioning

Ultimately, these musculoskeletal conditions can lead to declines in physical functioning, impeding one's ability to engage in activities necessary for continued employment or independent living. For many of these conditions, diminished functioning is part of the natural history of disease in the absence of treatment. By its nature, arthritis limits joint mobility and has been associated with several functional limitations, including stair climbing and walking, as well as difficulty with instrumental activities such as housekeeping. Hand-arm vibration syndrome can cause permanent damage after progressing to advanced stages (Handford et al., 2017; Shen & House, 2017). Affected individuals frequently have problems with the fine motor tasks associated with dressing, personal hygiene, and using the phone, and they have difficulty with gripping activities, including cooking, washing dishes, and driving (Budd et al., 2018; Handford et al., 2017).

In other cases, the pain that results from these disorders can itself be limiting, even if there is no biomechanical loss of mobility in the joints or tissues. Individuals in pain are more likely to develop functional limitations and disability, often at younger ages (Covinsky et al., 2009; Leveille et al., 2007; Zimmer & Rubin, 2020). Pain in specific sites tends to be associated with reduced functioning involving these sites. For example, back pain has been associated with limitations involving the lower body, such as bending and walking (Ensrud et al., 1994; Ettinger et al., 1994; Guccione et al., 1994; Lyons et al., 1994; Mäkelä et al., 1993), shoulder pain appears to make lifting and carrying objects more difficult (Smith-Forbes et al., 2015), and carpal tunnel pain has been associated with reduced strength and mobility in the hand and wrist (Atroshi et al., 1999; Katz et al., 1998).

Although functional limitations and disability often result from MSDs, these outcomes are not inevitable. Characteristics of the local built and home environment can affect whether a given level of musculoskeletal impairment impedes normal activities and progresses to disability (Clarke et al., 2008; Verbrugge & Jette, 1994). Medical interventions, including physical therapy or joint replacement surgery, can slow or reverse the progression from acute injuries or MSDs to diminished physical functioning (Carvalho et al., 2017; Verbrugge & Jette, 1994). Leaving physically demanding occupations, either through early retirement or receipt of disability benefits, can help improve or stabilize health (Börsch-Supan et al., 2017; Mazzonna and Peracchi, 2017).

However, not all workers have access to these interventions or opportunities to slow declines in physical functioning. Workers employed in informal arrangements are less likely to receive health insurance, sick leave, workers' compensation, or disability insurance benefits, which would allow them to receive medical care and take adequate time off to recover from acute injuries, and because they are less likely to be protected by OSHA regulations, they may have even greater physical demands and hazards at work (Hall & Greenman, 2015; Lipscomb et al., 2006; Siqueira et al., 2014). Non-metropolitan areas are often underserved by the healthcare system (Douthit et al., 2015), and because they have a higher proportion of jobs in the physically demanding agricultural and extraction industries, they provide fewer alternative job opportunities to move into less-demanding work (Akashi-Ronquest et al., 2011; Fayer and Watson, 2020). Proximity to SSDI offices and availability of physicians can reduce barriers to application for disability benefits, which can help workers exit jobs detrimental to their health and make up for lost income (Akashi-Ronquest et al., 2011; Deshpande and Li, 2019).

3.4. Other factors

Though the four risk factors discussed above (posture, force, vibration, and repetition) are the primary risk factors identified in the literature, several moderating factors can influence the relationship between physically strenuous work and subsequent MSDs. Many physiological problems could be reversible or less detrimental with shorter durations and with adequate rest between shifts, but long working hours, overnight shifts, and back-to-back shifts can prevent workers from fully recovering from the strains they experience on the job (Burgard & Lin, 2013; Holterman et al., 2020; Landsbergis et al., 2014; National Research Council and Institute of Medicine, 2001).

Environmental conditions are also important. Under hot environmental conditions, workers have reduced physical capacity and an increased risk of accidents, both of which can lead to occupational injuries (Kjellstrom et al., 2016; Lucas et al., 2014; Park et al., 2021). Noise can increase the risk of injury by making it harder for workers to concentrate or hear warnings (Cantley et al., 2015). Inadequate lighting can cause workers to adopt awkward postures to improve vision and can increase the risk for injury (California Department of Industrial Relations, 1999).

Personal risk factors such as age, gender, and other health conditions, can modify the association between physically demanding work and MSDs (Schulte et al., 2012). Evidence suggests that the same physical job characteristics are more detrimental to the health and wellbeing of older workers and women than their respective counterparts (Brussig & Drescher, 2021; Fletcher et al., 2011; Oakman et al., 2017; Rogers & Wiatrowksi, 2005; Schulte et al., 2012; Steege et al., 2014) and that workers already experiencing physical limitations are at increased risk for work-related injuries (Fraade-Blanar et al., 2017).

Workplace interventions have the potential to reduce the chances that physical risk factors at work lead to long-term declines in physical functioning. Many of these interventions can serve the dual purpose of accommodating employees with existing MSK complaints or MSDs while simultaneously preventing the development of these disorders in other employees. Effective interventions often include both engineering controls, which involve (re)designing workstations, tools, and equipment used by workers to reduce ergonomic strain, and administrative controls, which involve the organization and assignment of job tasks (California Department of Industrial Relations, 1999; National Research Council and Institute of Medicine 2002). Although the specific modifications vary according to the type of work, a common component of successful workplace interventions is employee involvement in their design and implementation (National Research Council and Institute of Medicine 2002, Yazdani & Wells, 2018).

4. Unequal burden of occupational risk factors in the population

We now examine whether work conditions associated with MSDs are more frequent among the disadvantaged social groups suggested by our social determinants framework. For this descriptive analysis, we use reports of occupational content and context from the Occupational Information Network (O*NET) linked by occupational codes to jobs reported by employed respondents in the American Community Survey (ACS). We use O*NET to infer exposure to strenuous physical work because previous research has found that the physical work characteristics measured in O*NET are significantly associated with several adverse outcomes reported in surveys, including workplace injury, arthritis, and functional limitations (Andrasfay et al., 2021; Dembe et al., 2014; Fraade-Blanar et al., 2017).

O*NET data are derived from ongoing surveys of workers (incumbents) in formal employment, and ratings by occupational experts, about a variety of occupational characteristics. O*NET is sponsored by the US Department of Labor Employment and Training Administration and developed by the National Center for O*NET Development (O*NET OnLine, n.d.). We use data from O*NET version 25.0, which was released in August 2020. From the dozens of questions asked of workers about their background and activities and work conditions on the job, we selected the six that most closely correspond to the risk factors identified in the previous section. For postural risk factors, we include three questions about how frequently a worker's job requires: (a) standing, (b) sitting, and (c) kneeling, crouching, stooping, or crawling. Our measure of force is taken from occupational analyst ratings of the "importance of the ability to exert maximum muscle force to lift, push, pull, or carry objects." Repetition and vibration are assessed through incumbent reports of how much the job requires making repetitive motions and how often the job requires exposure to whole body vibration.

In Table 1 we provide examples of occupations that have the highest levels of each of these risk factors in O*NET. This table shows that exposure to these risk factors occurs in a broad range of occupations. While some of these high-exposure occupations are niche jobs, such as foundry mold and coremakers and tree fellers, many are fairly common, such as restaurant cooks, maids, housekeepers, construction-related occupations, and firefighters.

Data on the demographic and socioeconomic characteristics of workers are obtained from the 2019 American Community Survey (ACS) (Ruggles et al., 2020). The ACS is administered by the US Census Bureau to supplement the decennial census with more detailed information about the American population. We investigate variations in key working conditions among more and less advantaged social groups in American society—i.e., by gender, age, race/ethnicity and foreign-born status, educational attainment, metropolitan residence, personal income quartile, and health insurance status (Ahonen et al., 2018; Burgard & Lin, 2013; Landsbergis et al., 2014; Lipscomb et al., 2006). The analysis includes individuals aged 16 and over who were currently employed at the time of the survey, except for those in legislative and military occupations, which are not included in O*NET. To link individuals in the ACS to O*NET job characteristics, we crosswalked the 2010 Census occupation codes available in the ACS to the 2010 Standard Occupation Classification Codes (SOC) provided in O*NET. After these restrictions and linkage to O*NET, there are 1,514,811 employed individuals with occupational characteristics in our sample.

Table 2 demonstrates that, as anticipated, there are huge disparities in the prevalence of occupational exposures among social groups. The estimates are the percentage of civilian workers employed in 2019 whose occupational exposures are in the top quartile for each of the identified risk factors, by selected demographic and socioeconomic characteristics. These quartiles are estimated from the full sample of workers using weights provided by the ACS. If there were no differences among social groups in occupational exposure, about 25% of each subgroup would be in the highest quartile; deviations from this value indicate over or underrepresentation in physically demanding work. We also present the average number of risk factors for which workers in each group fall into the top quartile to investigate high exposure to multiple risk factors.

Consistent with the gendered nature of work, men are more likely than women to be employed in jobs requiring frequent standing, frequent kneeling or stooping, exertion of force, and exposure to whole body vibration. Women are more commonly employed in jobs requiring frequent sitting and repetitive motions. On average, men have a higher count of risk factors than women (1.7 vs. 1.2).

Although young workers (ages 16–19 and 20–24) are disproportionately employed in jobs requiring frequent standing and repetitive motions, age differences in exposure to these risk factors beyond age 25 are quite modest. Notably, high exposure to these risk factors is fairly common among workers older than 55.

Differences in exposure to these risk factors by race, ethnicity, and foreign-born status are striking and are highlighted in Fig. 2. Because foreign-born individuals constitute a substantial share of the Asian and Hispanic populations and because immigrants have different occupational profiles than US-born workers (Orrenius & Zavodny, 2009; del Río & Alonso-Villar 2015), we disaggregate the Asian and Hispanic populations into US-born and foreign-born. Foreign-born Hispanic workers have the highest exposure to all risk factors (with the exception of sitting), but US-born Hispanic, Black, and Native American workers also experience relatively high exposure. In contrast, both US-born and foreign-born Asian/Pacific Islander workers are overrepresented only for jobs requiring frequent sitting and have the lowest exposure to the

Table 1
O*NET occupations with high levels of exposure to physical occupational risk factors.

Risk factor	10 highest scoring O*NET occupations	
Posture-standing	Cooks, restaurant	Foundry mold and coremakers
	Meat, poultry, and fish cutters and trimmers	Roof bolters, mining
	Tire builders	Pharmacy aides
	Combined food preparation and serving workers, including fast food	Dishwashers
	Fiberglass laminators and fabricators	Cooks, private household
Posture-sitting	Software developers	Insurance underwriters
	Securities and commodities traders	Insurance claims clerks
	Loan counselors	Regulatory affairs specialists
	Telephone operators	Customs brokers
	Administrative law judges, adjudicators, and hearing officers	Telemarketers
Posture-kneeling, crouching, stooping, or crawling	Manufactured building and mobile home installers	Automotive body and related repairers
	Tile and marble setters	Tire repairers and changers
	Carpet installers	Electrical and electronics installers and repairers, transportation equipment
	Floor layers	Stonemasons
	Helpers-roofers	Cement masons and concrete finishers
Exerting force to lift, push, pull or carry objects	Municipal firefighters	Tree trimmers and pruners
	Structural iron and steel workers	Nursery workers
	Athletes and sports competitors	Brickmasons and blockmasons
	Forest firefighters	Stonemasons
	Reinforcing iron and rebar workers	Construction laborers
Repetitive motions	Roof bolters, mining	Dental hygienists
	Shoe machine operators and tenders	Diagnostic medical sonographers
	Maids and housekeeping cleaners	Hairdressers, hairstylists, and cosmetologists
	Meat, poultry, and fish cutters and trimmers	Tire builders
	Coating, painting, and spraying machine setters and tenders	Coil winders, tapers, and finishers
Whole body vibration	Locomotive firers	Mine shuttle car operators
	Excavating and loading machine and dragline operators	Fallers (tree fellers, loggers)
	Pipelayers	Roof bolters, mining
	Loading and moving machine operators, underground mining	Earth drillers, except oil and gas
	Paving, surfacing, and tamping equipment operators	Highway maintenance workers

Note: Data are from O*NET Version 25.0

Table 2
Percent of employed individuals with high exposure to physical occupational risk factors.

	N	Standing	Sitting	Awkward Postures	Force	Repetition	Vibration	Count of risk factors
Gender								
Men	787,487	28.2	20.2	30.1	33.6	22.6	39.6	1.7
Women	727,324	21.5	30.3	19.4	13.0	27.5	8.3	1.2
Age								
16-19	55,432	62.6	8.9	24.0	23.6	51.5	20.7	1.9
20-24	122,714	38.8	17.9	26.8	26.0	35.9	24.9	1.7
25-34	300,131	24.0	25.5	23.6 ns	23.2 ns	25.0	23.1	1.4
35-44	295,784	21.7	26.3	24.4 ns	23.7 ns	22.7	24.6	1.4
45-54	312,611	21.0	26.7	25.6	24.3 ns	21.6	26.0	1.5
55-64	305,369	21.3	27.1	26.2	24.2 ns	21.5	26.8	1.5
65+	122,770	20.0	28.0	24.6 ns	20.4	19.7	23.9	1.4
Race/ethnicity								
White	1,045,180	21.4	26.8	22.7	20.8	22.1	23.3	1.4
Black	123,352	26.5	22.4	29.0	27.7	26.8	23.6 ns	1.6
Hispanic US-born	119,637	31.1	22.4	27.1	26.4	29.8	26.4	1.6
Hispanic foreign-born	92,224	45.3	12.4	40.8	47.3	37.2	44.1	2.3
Asian/Pacific IslanderUS-born	22,963	19.3	33.0	13.8	11.9	23.2 ns	13.6	1.1
Asian/Pacific Islander foreign-born	71,266	20.3	33.2	16.5	12.6	24.9	14.0	1.2
Native American	9,790	30.7	18.4	30.8	30.6	30.8	29.8	1.7
Other race	30,399	26.2	24.8	23.1ns	20.3 ns	25.9	21.2	1.4
Educational attainment								
Less than high school	95,116	55.4	6.0	43.3	50.1	44.7	46.0	2.5
High school or equivalent	486,260	37.7	16.3	36.9	37.1	34.4	37.0	2.0
Some college	362,854	24.9	24.6	26.7	23.5	27.9	23.6	1.5
College	570,581	7.1	37.2	9.2	6.3	10.1	10.0	0.8
Metropolitan residence								
Metropolitan or mixed	1,311,163	24.6	25.8	24.3	23.0	24.6	24.0	1.5
Non-metropolitan area	203,648	28.2	18.7	30.4	30.3	27.7	31.0	1.7
Personal income quartile								
Lowest income quartile	380,987	43.4	14.6	31.3	28.3	38.6	24.1	1.8
Top income quartile	364,532	8.1	38.1	12.9	10.9	9.0	19.7	1.0
Health insurance status								
No health insurance	131,196	45.3	12.5	38.9	41.6	38.7	39.5	2.2
Not insured through employer	299,298	32.7	19.8	29.9	26.0	30.7	25.4	1.6
Insured through employer/union[a]	1,084.317	19.7	28.4	21.5	20.5	21.2	22.3	1.3

Numbers are unweighted but percentages are weighted using weights provided by the ACS. Data on the occupational risk factors are taken from O*NET Version 25.0; high exposure is defined as the highest quartile among all employed individuals. Count refers to the number of risk factors on which an individual falls into the top quartile. Unless indicated as non-significant (ns), all values are significantly different at the 5% level from the first listed category after Bonferroni adjustment for multiple testing (Bland & Altman, 1995).

[a] The wording of the ACS question on health insurance includes insurance through a spouse's employer, in addition to one's own.

other risk factors.

Educational attainment is characterized by the strongest differentials in occupational exposures among the factors considered in this analysis. Except for sitting, the proportion of workers in the highest risk quartile for each of the occupational characteristics is at least four times as large among those with less than high school education compared to those with college education, as shown in Fig. 3. The count of risk factors for those with less than high school education is over three times that for those with at least a college degree (2.5 vs. 0.8).

Finally, we examine risk factors by metropolitan status, income, and health insurance coverage, variables which can hamper workers' ability to treat and manage workplace injuries and MSDs. Workers in non-metropolitan areas are exposed to these risk factors more frequently than those in metropolitan or mixed metropolitan/non-metropolitan areas. Workers in the lowest income quartile are frequently in the highest quartiles of exposure to standing (43%), kneeling/stooping (31%), force (28%), and repetitive motions (39%). These occupational exposures are also more common among workers without health insurance or without employer-sponsored health insurance. Uninsured workers are especially vulnerable to long term complications from untreated or poorly treated work-related MSDs, but workers with non-employer-based health insurance, such as public insurance or individually purchased plans with high deductibles, may also avoid seeking timely care due to cost and/or access (Carvalho et al., 2017).

5. Discussion

In the US, research on the social determinants of health has generally paid little attention to physical work conditions and demands as pathways through which social status may produce health disparities (Ahonen et al., 2018), with some exceptions (Andrasfay & Goldman, 2020; Burgard & Sonnega, 2018; Clougherty et al., 2010; Landsbergis, 2010; Landsbergis et al., 2014; Mueller & Bartlett, 2019; Pebley et al., 2021; Townsend & Mehta, 2021). Yet research on the social determinants of health strongly suggests that societal level processes shape the type of workplace environments to which individuals are exposed and the occupational health literature shows that these exposures have important effects on health. In this paper, we summarized this literature on the main pathways through which these effects may occur to assist public health, social science, and gerontology researchers in conceptualizing potential associations. We also examined the unequal burden of occupational risk in social groups in the US, showing that there are huge disparities in the prevalence of occupational exposures across demographic and socioeconomic groups.

There are several limitations to our O*NET-ACS analysis. First, O*NET measures are not ideal proxies for the underlying risk factors we want to measure. For example, with the sitting and standing measures, we cannot determine whether workers have the ability to take frequent breaks, which is important for determining the potential effects of prolonged sitting and standing. The O*NET vibration measure is full-body vibration, for which the evidence as a risk factor is more mixed compared to the evidence for the use of vibrating tools. It is also

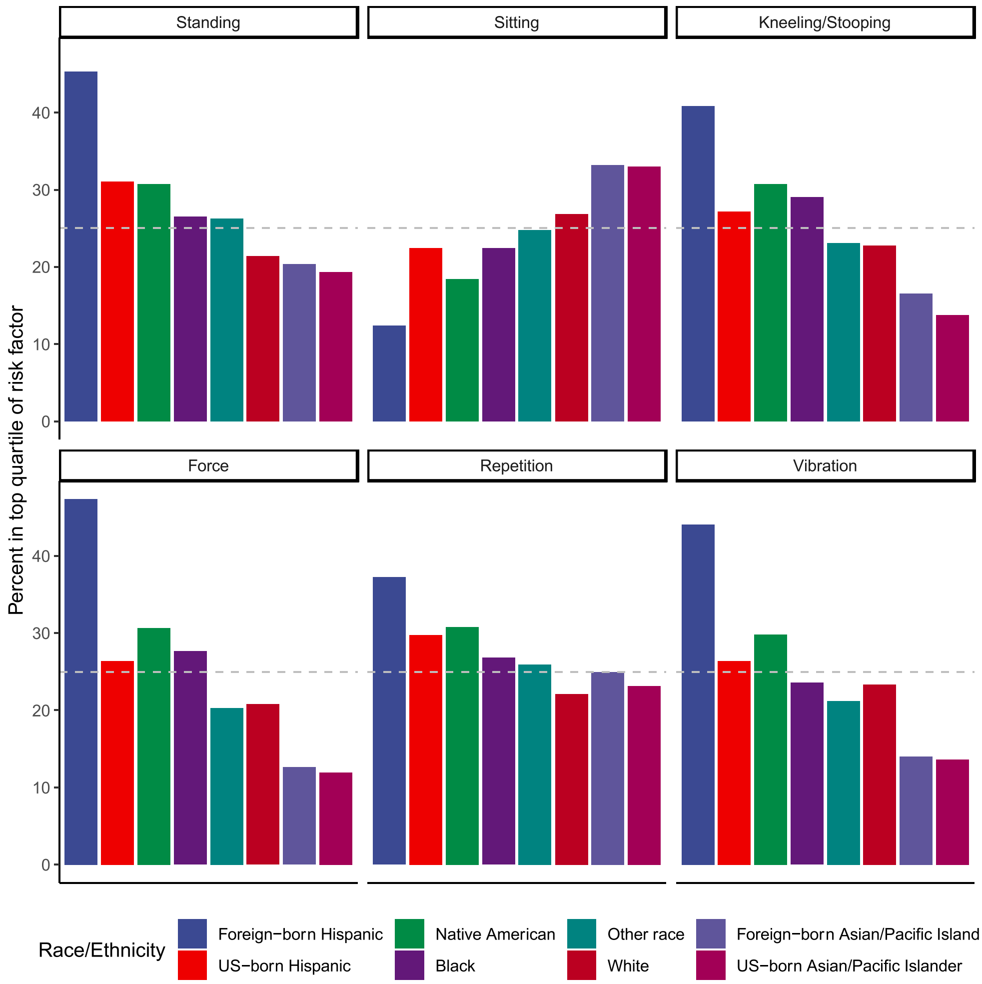

Fig. 2. Percent of workers in the highest quartile of physical occupational risk factors by race/ethnicity and foreign-born status. Demographic data are from the 2019 American Community Survey (ACS), restricted to employed individuals. Percentages are weighted using weights provided by the ACS. Data on the occupational risk factors are taken from O*NET Version 25.0. High exposure is defined as the highest quartile among all employed individuals. The dotted line indicates 25%, which would be expected if work exposures were distributed equally by race/ethnicity and foreign-born status.

important to note that O*NET includes only formal sector workers (i.e., those working for an employer who is recognized as such by the US Department of Labor). Informal work (e.g., day labor, domestic work, gig work) may be more physically strenuous and hazardous than work done by workers in the formal sector (Flynn et al., 2015; Hall & Greenman, 2015; Mueller & Bartlett, 2019). Because informal workers are more likely to have low income and education, be foreign-born, and be Hispanic or Black (Abraham & Houseman, 2019; Raijman, 2019), the consequence of this omission of informal workers from O*NET data may lead us to underestimate the associated disparities in occupational risk. In other words, if the O*NET data included reports on physical work activities and contexts separately for formal and informal workers, the social and demographic disparities shown in Table 2 would likely be even greater.

Despite these limitations, the large disparities in exposures to MSD-related physical occupational risks among socioeconomic and demographic groups, combined with clear evidence from the occupational health literature on the physiological links between risk exposures and MSDs, suggest that work conditions are likely to be an important pathway through which social disadvantage may lead to decreased physical functioning at older ages, as well as other types of health problems (Wanner et al., 2019).

In the US, there are many laws, programs, and regulatory agencies to protect workers, which could in theory help reduce occupational health disparities (Siqueira et al., 2014). In practice, many vulnerable workers are not protected from harmful workplace exposures.

Certain industries, such as agriculture, and employee classifications, such as independent contractors, are not covered by many regulations and protections (Siqueira et al., 2014). Some have argued that the relatively low fines on employers combined with low probability of inspection by an under-resourced OSHA may not effectively deter employers from violating safety regulations (Siqueira et al., 2014). Moreover, many of these existing federal laws and regulations are focused on preventing severe and fatal occupational injuries rather than lessening the cumulative impact of the types of exposures reviewed in this paper. Policies that would help prevent occupational exposures from progressing to long-term declines in physical functioning, such as paid sick leave or minimum rest breaks, are not mandated at the federal level (Siqueira et al., 2014). Individual workplaces could implement tailored ergonomic prevention measures, but employers frequently underestimate the benefits relative to the costs of interventions to prevent injuries or MSDs (Melhorn & Gardner, 2004; Yazdani & Wells, 2018). The absence of federal requirements for these protections places the burden on states or individual employers to protect workers and paves the way for inequalities to emerge. While disadvantaged individuals have constrained opportunities and protections in this context, advantaged individuals can "avoid risks and adopt protective strategies using flexible resources: knowledge, money, power, prestige, and beneficial social connections" (Clouston et al., 2021; Link & Phelan, 1995). Avoiding the risks associated with physically demanding work by pursuing certain types of employment may be an important pathway through which socioeconomic advantage affects health, particularly in the longer term. Future research should consider the role of working conditions across the life course in order to better understand the social

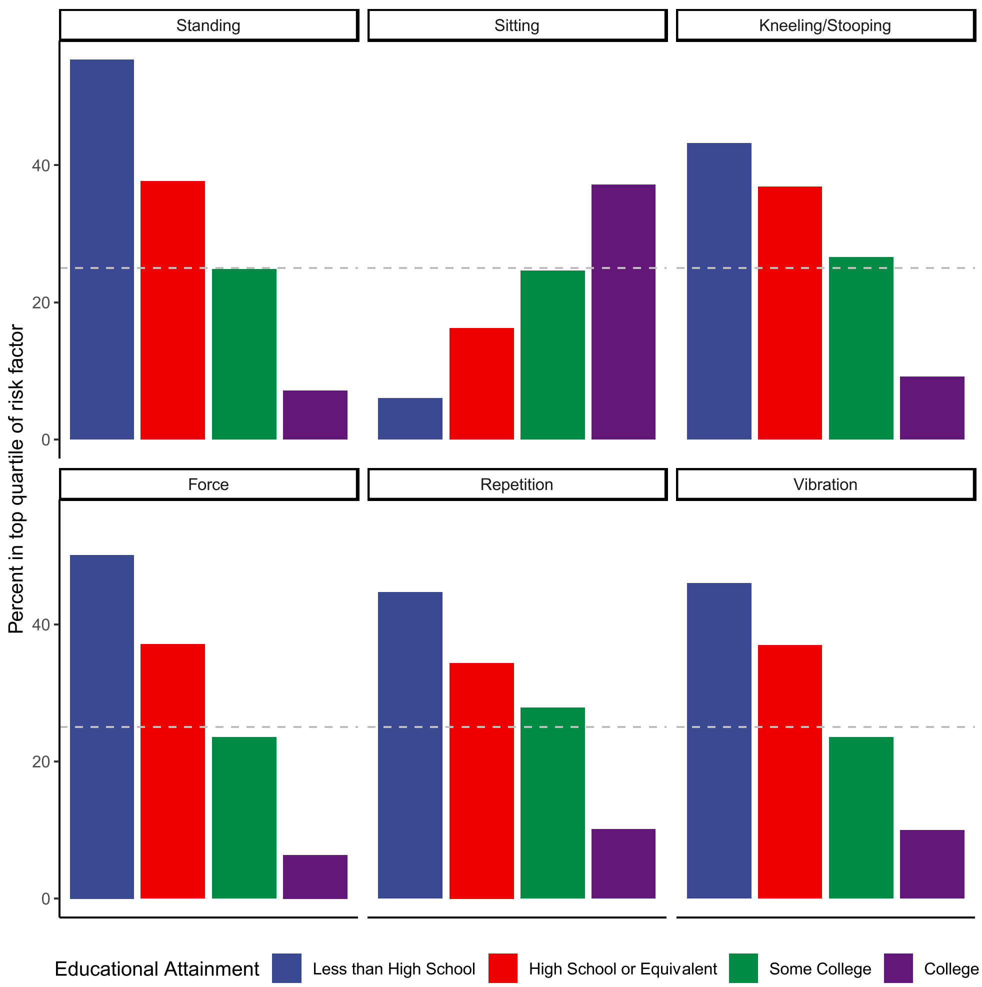

Fig. 3. Percent of workers in the highest quartile of physical occupational risk factors by educational attainment. Demographic data are from the 2019 American Community Survey (ACS), restricted to employed individuals. Percentages are weighted using weights provided by the ACS. Data on the occupational risk factors are taken from O*NET Version 25.0; high exposure is defined as the highest quartile among all employed individuals. The dotted line indicates 25%, which would be expected if work exposures were distributed equally by educational attainment.

determinants of inequalities in physical functioning in later life.

Declaration of competing interest

None.

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