The Paradoxical Health Effects of Occupational Versus Leisure-Time Physical Activity

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Abstract

Generally, physical activity (PA) is conceived as among the best investments for a long healthy life and is therefore widely encouraged for the general population.

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For example, recent PA guidelines for adults recommend at least 150 min a week of moderate-intensity PA or at least 75 min a week of vigorous-intensity PA, without specifying the domain of PA. However, the epidemiological evidence for beneficial health effects and lower mortality associated with higher levels of PA is mostly limited to PA occurring during leisure time (LTPA). In contrast, emerging evidence has shown that high levels of occupational PA (OPA) increase the risk for adverse health outcomes and mortality from cardiovascular diseases and all causes. The observation of differential health effects of OPA and LTPA is referred to as the "PA health paradox." Up to now, all PA public health guidelines have ignored this paradox, not distinguishing OPA and LTPA. This is unfortunate as OPA of various types and intensities is a fundamental requirement for working people. Most adults spend more than half of their time awake at work, and lower socioeconomic groups are predominantly physically active as part of their work. In-depth knowledge of the PA paradox is therefore fundamental for understanding the physical determinants of the socioeconomic health inequalities in working populations. In this chapter, we give an introduction and historical perspective to the PA health paradox, provide an overview of the current epidemiological evidence for the PA paradox, and reflect on the implications of the PA health paradox for future research, health promotion, and disease prevention.

Keywords

Physical activity at work · Physical work demands · Ergonomics · Physical workload · Sedentary work · Cardiovascular disease · Mortality

Introduction to the PA Health Paradox

Physical activity (PA) comprises a wide variety of movements, postures, and activities. In the PA continuum, PA can range from activities requiring small amounts of energy expenditure and effort, such as sitting, to strenuous activities increasing the energy expenditure many times beyond resting levels – such as stair climbing, running, or lifting of heavy objects.

PA is known to improve health and prevent noncommunicable diseases, such as hypertension, obesity, diabetes, cancer, cardiovascular disease, and mortality (U.S. Department of Health and Human Services 2018). More recently, also documentation for the beneficial effects of PA on mental health and well-being has emerged (White et al. 2017). The strongest evidence is for the beneficial health effect of moderate-to-vigorous intensity PA (e.g., activities like brisk walking, running, team sports, and cycling), but more recent studies have also shown positive health effects of PA of light intensity like slow walking (Ekelund et al. 2019). In other words, physical inactivity can inflict harmful effects on several noncommunicable diseases (U.S. Department of Health and Human Services 2018), while even small increments in daily PA can have beneficial health effects.

The most recent US PA guideline for adults recommends at least 150 min a week of moderate-intensity PA or at least 75 min a week of vigorous-intensity PA (U.S. Department of Health and Human Services 2018). Moreover, the WHO recently announced a global action plan for promoting PA, “More active people for a healthier world,” with the main message of a need for promoting any kind of PA to people worldwide, with a systemic approach including stakeholders, city planners, policy makers, and others (World Health Organization 2018). In a recent publication in Lancet Global Health, initiated by the WHO (Guthold et al. 2018), the proportion not fulfilling the PA guideline (based on total PA at work, home, transport, and leisure time) is twice as high in high-income countries as in low-income countries. Thus, by not differentiating between OPA and LTPA, low-income countries are found to have the highest proportion fulfilling the PA guidelines (Guthold et al. 2018), while failure to meet the PA guidelines appears to be predominantly a problem for high-income countries. Considering the evident contrast in health and life expectancy of high-income and low-income countries, there seems to be a flawed logic that low-income countries should have the least problems with fulfilling the supposedly health-promoting PA guidelines.

This flaw in logic can be explained by the basic common assumption across current PA guidelines and action plans that “the more PA, the better,” no matter the domain, environment, or context in which the PA occurs. Despite the fact that empirical evidence for beneficial effects of PA is mostly restricted to LTPA (U.S. Department of Health and Human Services 2018), this common assumption dominates. For the majority of people, however, the most prevalent domain of PA is OPA (Lear et al. 2017). This is particularly the case for lower socioeconomic groups and in low-income countries, where hardly any PA is recreational (Lear et al. 2017).

Does it matter if the PA occurs during working hours or leisure time? In contrast to the established benefits of LTPA, recent reviews suggest that OPA may actually be detrimental for health and longevity (Coenen et al. 2018a; Li et al. 2013). These differential health effects can be explained by the type, duration, intensity, and activity-rest patterns of PA that differ characteristically during work and leisure (Holtermann et al. 2017).

LTPA is characterized by dynamic movements at conditioning intensity levels mostly performed voluntarily over short time periods with enough recovery time afterward (Holtermann et al. 2017). In contrast, OPA often involves static work and is typically of much longer duration, and its purpose, design, and social context differ from LTPA (Holtermann et al. 2017). At work, demands of being productive dominate, and the environment and social organization of work are designed to maximize efficiency or profit, often with disregard for workers’ health. Consequently, OPA may be rather constrained to either predominantly sitting for an office worker, standing still for a manufacturing worker in a production line, walking for a cleaner, or heavy lifting and manual handling for a construction worker. These activities often require maintenance of awkward and static postures and monotonous and repetitive movements and, in general, constitute nonconditioning activities that are performed over long periods of time, often exceeding standard 8 h per day, 5 days per week, and may include overtime and weekend work or even exposure to multiple jobs frequently held by workers of low socioeconomic position. Such work schedules typically do not provide sufficient recovery time.

Historical Perspective of the PA Health Paradox

While beneficial cardiovascular health effects of LTPA are well established, the literature about the respective effects of OPA remains inconsistent. Research in the 1950s and 1960s, comparing PA and health of different occupational groups, identified sedentary work as a potential cardiovascular risk factor (Morris et al. 1966). This research has been the starting point of a large amount of epidemiological research on the health effects of PA. Surprisingly, however, while these first studies were based on OPA, much of that later work focused on LTPA.

These classic studies were vulnerable to alternative explanations because of selection bias (the health status influences which job and level of OPA the person choses or is capable to remain employed in) and socioeconomic confounding (because of the relatively high correlation between socioeconomic status and OPA, it is difficult to differentiate OPA from health behaviors, access to healthcare, and other psychosocial factors which may impact the health outcomes). In their pioneering work, Morris and colleagues were probably one of the firsts being able to control for socioeconomic position. They attributed the lower risk of coronary heart disease among London bus conductors to their relatively high level of movement at work compared to the more sedentary work of their colleagues, the bus drivers (Morris et al. 1966). However, since then, research has shown that the excess risk of cardiovascular disease among urban bus drivers is not experienced by rural bus drivers, and, for urban bus drivers, it has shown to be independent of both LTPA and OPA (Rosengren et al. 1991; Gustavsson et al. 1996). Instead, the excess risk among urban bus drivers is now thought to be attributable to the high levels of job stress experienced by those drivers (Belkic et al. 1994), a psychosocial job factor that may have confounded the reported association with sedentary work. It is also questionable if driving a more than 7-ton heavy bus loaded with people on two decks and without power steering or power braking at the time of Morris' study should be considered sedentary work.

Another influential study of San Francisco Longshore men published in 1975 by Paffenbarger and colleagues used a more accurate three-level OPA measure that was based on energy expenditure estimates derived from earlier ergonomic studies among Los Angeles dockworkers (Paffenbarger and Hale 1975). While Paffenbarger found no substantial differences between light and moderate levels of OPA, those performing high OPA with repeated bursts of high-level energy expenditure had a reduced risk of dying from coronary heart disease. It should be noted that at that time, the union contracts regulated recovery time by limiting each work hour to 55% PA and 45% rest for the workers with high OPA. Also, after a minimum of 5 years (average 13 years), these workers moved from jobs with high OPA to jobs with lower OPA, which may very well explain the lower risks in the high OPA subgroup of workers.

The simultaneous assessment of OPA, LTPA, and application of modern multivariate analyses controlling for potential confounders began with the seminal prospective Western Collaborative Group Study of 3525 men employed in 10 Californian companies (Rosenman et al. 1975). The study found that high levels of LTPA had a protective effect on coronary heart disease (Rosenman et al. 1975). However, in contrast to earlier studies, this study did not find any protective effect for high levels of OPA regarding coronary heart disease. In fact, it is the first prospective cohort study adjusting for potential confounding factors that documented differential effects for OPA and LTPA on risk for cardiovascular disease. Several population-based prospective Scandinavian studies published since the 1980s observed similar patterns, starting with the Oslo Men's study, in which the authors for the first time explicitly called attention to this pattern as a "paradoxical" finding (Holme et al. 1981).

The literature on OPA and cardiovascular health has remained inconsistent for more than three decades. In 2010, an editorial calling on researchers to disentangle the effects of OPA and LTPA summarized the accumulated evidence as follows: "with regard to PA and cardiovascular disease (CVD), the epidemiological literature is actually more inconsistent than is often recognized. Most epidemiological studies to date either failed to differentiate between LTPA and OPA, or excluded OPA from their analyses altogether. While the beneficial effects of LTPA on the circulatory system appear well established (U.S. Department of Health and Human Services 2018), the health effects of OPA have remained inconsistent (Kristal-Boneh and Silber 1998). In high quality prospective population-based observational studies, higher levels of OPA were associated with a reduced risk of CVD in some studies (Salonen et al. 1982; Hu et al. 2007), showed no association in others (Kannel et al. 1986; Haapanen et al. 1996), or were associated with an increased CVD risk (Eaton et al. 1995; Krause et al. 2015; Krause et al. 2000). A few studies showed differential effects, with LTPA being protective and OPA having no effect (Haapanen et al. 1996), LTPA having no effect and OPA constituting a CVD risk (Krause et al. 2015), LTPA having a protective effect only among persons with low levels of OPA (Hu et al. 2007) or LTPA constituting a CVD risk (Eaton et al. 1995). One case–control study reported an inverse relationship of LTPA with acute myocardial infarction, but a u-shaped association with OPA" (Krause 2010).

In 2010, Holtermann and colleagues referred for the first time to the PA health paradox in the title of a paper that reported on the differential health effects of OPA and LTPA in a prospective study of Danish workers (Holtermann et al. 2012). Following this paper, there has been an increasing number of publications on the PA health paradox. Reviews of prospective studies that simultaneously analyzed both LTPA and OPA in multivariate models, adjusting for key potential confounders, report about 25% increased cardiovascular and all-cause mortality risks for high OPA compared to low OPA (often defined as having a predominantly sedentary job) (Coenen et al. 2018a; Li et al. 2013). It is the newer studies with better exposure assessments of OPA that tend to confirm the PA health paradox (Coenen et al. 2018a). There is less evidence for women and for stroke, potentially because women engage to a lesser extent in high-intensity OPA and because stroke incidence is a relatively rare disease requiring large study samples. A recent 2019 US cohort study of over 30,000 working women addressed both evidence gaps and showed that higher intensity levels of OPA increased the risk for stroke and transient ischemic attack, while LTPA decreased these risks (Hall et al. 2019). These latest findings corroborate the PA health paradox for women and cerebrovascular disease.

Empirical Evidence for the PA Health Paradox

During the last decade, epidemiological evidence indicating a PA health paradox has been rapidly accumulating, with studies showing differential health effects of OPA and LTPA on disease and mortality outcomes.

Regarding the effect of OPA on *all-cause mortality*, evidence from 17 prospective cohort studies published before 2017 are summarized in a systematic review with meta-analysis of data from 193,696 participants (Coenen et al. 2018a). Men with high levels of OPA had an 18% increased risk of all-cause mortality compared to men engaging in low levels of OPA (hazard ratio (HR) 1.18, 95% CI 1.05–1.34). The same effect was not seen among women (hazard ratio 0.90, 95% CI 0.80–1.01). This gender difference may be due to the fact that most physically demanding jobs are being performed by male blue-collar workers, and when women and men share the same job, the heaviest work tasks may more often be performed by the male co-workers. Apart from gender differences, the adverse health effect of OPA appears to be much stronger if measured as relative aerobic strain taking cardiorespiratory fitness into account compared to OPA measured as energy expenditure only. (Krause et al. 2015). Since the publication of this review, additional evidence has been published on the effect of OPA on all-cause mortality.

Regarding *cardiovascular disease mortality*, a systematic review of 19 prospective cohort studies showed no overall effect of OPA on CVD mortality (hazard ratio 0.98, 95% CI 0.88–1.09) and no differences by sex or between various CVD mortality outcomes (coronary heart disease mortality, stroke, and unspecified CVD) (Coenen et al. 2019). Although this review does not confirm adverse health effects of OPA with regard to CVD mortality, the lack of a beneficial health effect of OPA still indicates a differential health effect compared to LTPA, thus supporting a PA health paradox. In addition, one needs to consider that CVD outcomes such as coronary heart disease or heart failure with activity-related symptoms such as angina pectoris or dyspnea are prone to healthy worker selection effects that bias health risk estimates downward.

As we will describe in the following section, explanations for the PA health paradox mainly focus on cardiovascular mechanisms. It is therefore logical that a fair share of the evidence on the PA health paradox is based on CVD outcomes. In 2013, a systematic review on the effects of OPA and LTPA on CVD outcomes was published (Li et al. 2013). In this review, based on a meta-analysis, it was shown that high levels of LTPA were associated with reduced risks of CVD, with effect sizes of 0.66 for coronary heart disease, 0.72 for stroke, and 0.61 for unspecified CVDs. These findings were in contrast to those for OPA consistently showing increased risk of CVD incidence with high levels of OPA, with relative risk effect sizes of 1.25 for coronary heart disease, 1.07 for stroke, and 1.47 for unspecified CVDs.

Additional evidence for differential effects of OPA and LTPA on CVD is provided by studies using *cardiovascular biomarkers* as outcomes. In a group of blue-collar workers, it was shown that accelerometer measured PA (i.e., sitting, standing, walking, and stair climbing) resulted in a significantly higher heart rate when conducted during work than during leisure time, leading to higher relative aerobic strain during work (Coenen et al. 2018b). In the same group of workers, accelerometer measured LTPA was found to be associated with lower resting heart rate, while, on the contrary, accelerometer measured OPA was associated with a higher resting heart rate (Hallman et al. 2017). A Belgian study found that high self-reported OPA was associated with an increased ambulatory blood pressure (Clays et al. 2012). In a study of Finnish workers, those with high OPA were found to be more prone to future increased progression of atherosclerosis compared with those with low OPA, and those effects were strongest among workers with pre-existing cardiovascular disease (Krause et al. 2007).

Although most of the evidence on the PA paradox relates to CVD outcomes, there is also evidence for other health-related outcomes, including cancer, musculoskeletal disorders, long-term sickness absence, and mental health.

Regarding *cancer* outcomes, studies have reported on comparable beneficial health effects for cancer mortality (Autenrieth et al. 2011) and prostate cancer (Hrafnkelsdóttir et al. 2015) for OPA and LTPA. Another study, however, supported the PA paradox by showing reduced risks for breast cancer for those engaging in high-level LTPA but increased risks for those with high-level OPA (Friedenreich et al. 2009).

Research on *musculoskeletal diseases* provides limited evidence on the association between metabolic equivalents of PA and musculoskeletal symptoms. However, there is a substantial body of evidence that OPA, when measured as body postures and movements, increases the risk for musculoskeletal symptoms. For example, studies have found an increased risk for low back pain from occupational heavy lifting (Coenen et al. 2014), prolonged occupational standing (Coenen et al. 2016), and other occupational demands such as carrying, pushing/pulling, awkward trunk postures, and whole body vibrations (Griffith et al. 2012). Occupational tasks such as repetitive handling, upper arm and neck flexion, and high manual forces were associated with neck and upper limb pain (van Rijn et al. 2010). There is some scientific evidence for LTPA being protective for musculoskeletal symptoms such as low back pain (Shiri and Falah-Hassani 2017). However, the evidence is not consistent, and the proverbial “tennis elbow” is a well-known example for LTPA-related musculoskeletal disorders. Still, there is some evidence for the PA health paradox regarding musculoskeletal outcomes. Similarly, high OPA increases the risk for *long-term sickness absence*, while high LTPA reduces this risk (Andersen et al. 2018). Moreover, a recent meta-analysis based on 98 studies and almost 650,000 participants showed that high LTPA was associated with high levels of mental health, while high OPA was associated with poor *mental health* (White et al. 2017). In conclusion, the PA health paradox is not limited to physical health outcomes but also is relevant for work disability and mental health outcomes.

Mechanisms for the PA Health Paradox

A plausible explanation of the PA health paradox requires an overview of the potential underlying physiological mechanisms. Knowledge about both the acute and long-term physiological responses to PA provides a fundament for understanding the differential health effects of OPA and LTPA. Below, we describe ways in which similar PA can have different effects on health if performed at work compared to during leisure time.

PA of larger muscle groups over short time (from few minutes to an hour) at high intensity (e.g., stair climbing, cross-fit, and running) is known to lead to a concurrent increase in ventilation, heart rate, blood pressure, metabolism, energy expenditure, and inflammation markers. In the hours (24 or more) following PA, the autonomous and hormonal systems downregulate heart rate and blood pressure, called post-exercise hypotension (de Brito et al. 2019). However, this phenomenon is documented following high-intensity short-time exercise or LTPA only. Even though heart rate and blood pressure are elevated during the short duration of LTPA, the downregulation of heart rate and blood pressure lasting for several hours after the activity results in overall lower 24-h average levels (Pimenta et al. 2019). Since both heart rate and blood pressure are strong independent predictors of CVD and mortality (Korshøj et al. 2015a; Banegas et al. 2018), lowered 24-h average levels of heart rate and blood pressure are considered beneficial for the cardiovascular system and longevity.

Inflammation markers also initially increase during exercise, reach a peak up to 48 h after the exercise, and then return to baseline levels after 2–6 days of recovery time (Kasapis and Thompson 2005). Current evidence suggests that regular moderate PA may reduce inflammation markers over time, and this in turn reduces chronic disease and mortality risks. However, large controlled trials show conflicting results on PA and inflammation markers, and it is not yet clear what persons may benefit from what type of activity and if PA-induced long-term changes in inflammation markers actually result in lower morbidity and mortality (Ertek and Cicero 2012). Nevertheless, it is well established that regular intensity PA of short duration (predominantly occurring during leisure and exercise) can increase cardiorespiratory fitness and that higher levels of cardiorespiratory fitness are associated with lower resting heart rate and blood pressure and lower cardiovascular disease and mortality risks (Bahls et al. 2018).

In contrast, the opposite is happening when the PA is performed with similar or, more typically, lower intensity over several hours during work. This will lead to many hours of increased heart rate, blood pressure, and inflammation markers during work and without downregulation of these physiological factors, in the hours following OPA (Ertek and Cicero 2012). This results in overall increased 24-h levels of heart rate, blood pressure, and inflammation markers, all known to be harmful for the cardiovascular system through mechanical stress and injury of the endothelium and deeper layers of the arterial wall, followed by inflammatory wall repair processes that lead to atherosclerotic changes, such as plaques and aneurysms (Thubrikar 2007). In the long term, this type of PA performed at work for several days per week and over several years can increase the risk for CVD and mortality. The long-term health effects of OPA can differ substantially depending on its intensity, duration, and recovery time. Long duration of OPA and high cumulative aerobic workloads, long working hours and weekend work, and respective insufficient recovery times have been shown to increase atherosclerosis (Krause et al. 2007; Wang et al. 2016), incident cardiovascular disease, and mortality (Coenen et al. 2018a; Li et al. 2013). The dose-response relationship and thresholds between OPA and health outcomes are not yet completely understood and may also differ for specific activities, such as constrained body postures (e.g., sitting or standing), degree of involvement of small muscle groups (e.g., in manufacturing work), degree of static work required (e.g., for holding tools or carrying objects), or performance of biomechanically and/or cardiorespiratory highly demanding tasks (e.g., heavy lifting). Low and moderate levels of OPA may exert their influence on health primarily through relatively small physiological changes that accumulate over years before causing clinically manifest chronic diseases (e.g., hypertension or ischemic heart disease), while high or peak levels of OPA may have more immediate health consequences (e.g., heart attack, sudden cardiac death, or hemorrhagic stroke).

PA can have beneficial or harmful effects at both leisure and work depending on its specific characteristics. The explanation of the PA health paradox is that the work and leisure domains comprise very different environmental settings and social constraints that influence the type of PA, body postures and movements, and their duration and intensity and determine rest and recovery periods. LTPA often includes dynamic movements of an intensity level that could lead to improved cardiorespiratory fitness, being performed over relatively short time periods (often less than 1 h) and with enough time for recovery. In contrast, OPA more often comprises static and awkward postures, repetitive movements, or monotonous activities being performed over long duration (for several hours or even an entire work shift), mostly without sufficient intensity to increase cardiorespiratory fitness and metabolism and frequently without sufficient recovery time. These contrasting characteristics of PA performed at work and leisure are causing different acute and long-term physiological effects, which in the end lead to the contrasting health effects reported in the epidemiological literature ranging from acute to chronic musculoskeletal symptoms, CVD, and mortality. In the following, we will describe how the different characteristics of OPA and LTPA lead to acute and long-term physiological adaptations explaining the PA health paradox. An overview of these various mechanisms relevant for cardiovascular health is given in Table 1.

The Duration of PA

As described in the previous section, the duration of PA is of importance for the acute and long-term health effects of PA. While LTPA normally lasts for relatively short

Table 1 Overview of mechanisms explaining the differential cardiovascular health effects of OPA and LTPA

		Occupational physical activity	Leisure-time physical activity
Activity characteristics	Types of activities	Prolonged postures and manual handling	Dynamic movements with large muscle groups
	Duration	Long periods (several hours or even a full shift, for many consecutive days, weeks, and even years)	Short periods (less than 1 h)
	Recovery	Little	Much
	Intensity	Relatively low (<60% of the maximum aerobic capacity)	Relatively high (>60% of the maximum aerobic capacity)
Physiological responses		Chronic increase in ventilation, heart rate, blood pressure, metabolism, and inflammation markers	Instantaneous short increase in ventilation, heart rate, blood pressure, metabolism, and inflammation markers
		Increase 24-h blood pressure and heart rate	Decreased 24-h blood pressure and heart rate
		Mechanical stress and injury of the arterial wall (atherosclerosis)	Fitness improvements
Health outcomes		Cardiovascular health deterioration	Cardiovascular health improvement
		Higher risk of mortality	Lower risk of mortality

time (often less than 1 h), OPA occurs over many hours per day and typically over many consecutive days. While the relatively short duration of conditioning LTPA can lead to reductions in 24-h heart rate and blood pressure, OPA performed over longer durations causes elevations in 24-h heart rate and blood pressure. Because elevated 24-h levels of heart rate and blood pressure are harmful for the cardiovascular system and strong independent predictors of CVD and mortality (Korshøj et al. 2015a; Banegas et al. 2018), these hemodynamic effects alone could explain the negative health effects of OPA.

The Intensity of PA

To condition the cardiovascular system and to improve cardiorespiratory fitness, PA of a relatively high intensity is required. As a rule of thumb, the intensity needs to be of at least 60% of maximum oxygen consumption equivalent to about 60% of heart rate reserve (estimated as the difference between resting and maximal heart rate) for improving cardiorespiratory fitness (Åstrand and Rodahl 1986). During various sports (e.g., soccer, running, swimming) and certain daily activities (e.g., stair climbing, brisk walking, and cycling), the intensity of PA is relatively high and can reach this 60% intensity level. These activities predominantly occur during leisure time. However, during work, the intensity of PA rarely reaches the 60% threshold (Jørgensen et al. 2019). In fact, even workers in manual jobs need to pace themselves and avoid breaking into sweats (one sign of reaching intensity levels sufficient for improving cardiorespiratory fitness) because they need to continue the same work for hours and usually in the same working clothes. Thus, even though workers in manufacturing, farming, construction, cleaning, elder care, and many other blue-collar and service sector jobs perform OPA for several hours per day, their level of cardiorespiratory fitness is not improved (Coenen et al. 2018b; Jørgensen et al. 2019). For example, cleaners have been observed to walk more than 20,000 steps per day without experiencing any improvements in cardiorespiratory fitness (Korshøj et al. 2013).

Prolonged Standing, Sitting, and Heavy Lifting

Predominant body postures like sitting and standing also differ during work and leisure and may contribute to the observed PA health paradox. Generally, large fractions of higher socioeconomic groups hold jobs involving much sitting at work, such as office workers. Mostly sitting during leisure time has been consistently associated with poor health (van Uffelen et al. 2010). In contrast, the evidence regarding sitting at work has been summarized by early reviews as equivocal (van Uffelen et al. 2010) and has since remained inconsistent. Occupational sitting has been linked with increased mortality (Kikuchi et al. 2015) but also with better cardiovascular health outcomes when compared with mostly standing and/or walking at work (Hall et al. 2019; Smith et al. 2018). The simplest explanation for paradoxical health effects of occupational and leisure-time sitting could be that those who are on their feet all day at work prefer to rest after work and thus sit or lie (often to keep their feet elevated) a lot during leisure. The increased health risks of these demeaningly labeled "couch potatoes" may therefore be due to the combination of fatiguing OPA and a resulting extensive time sitting at leisure (Gilson et al. 2019). Accordingly, studies that identified daily hours of sitting and watching TV at home as health risks may have missed a root cause for this behavior: an exhausting combination of long work hours including high levels of OPA and prolonged upright work postures (Bláfoss et al. 2019). Another explanation for the divergent health effects of sitting at work and leisure can be due to differences in the degree of continuous sitting at work and leisure. Long continuous bouts of sitting are particularly harmful for health (Saunders et al. 2018). For blue-collar workers overall, long bouts of continuous sitting occur much more often during leisure than during work (Hallman et al. 2015).

Globally, and even in modern Western economies, large proportions of the work force, even a majority of workers in the lower socioeconomic groups such as farm workers, construction workers, industrial blue-collar workers, healthcare providers, and the growing ranks of low-wage service workers, are exposed to prolonged standing at work. Even relatively short bouts of standing at work of less than 2 h have been associated with increases in fatigue and acute discomfort, swelling, and pain of the lower extremities and lower back in both laboratory and field studies (Coenen et al. 2016; Coenen et al. 2017). Prolonged standing has not only been associated with fatigue, discomfort, pain, and musculoskeletal disorders in feet, legs, hips, and the lower back (Waters and Dick 2015). It has also been identified as an independent risk factor for varicose veins and related venous disease complications (Tabatabaeifar et al. 2015); peripheral artery disease (Mäkivaara et al. 2008); accelerated progression of carotid atherosclerosis (Krause et al. 2000); the incidence of coronary heart disease, myocardial infarction, and heart failure (Smith et al. 2018); and cerebrovascular diseases such as transitory ischemic attack and stroke (Hall et al. 2019). For example, Smith et al. reported that the risk for heart disease doubled among Canadians who predominantly work in a standing position (with some walking) compared to those who predominantly sit at work (Smith et al. 2018). Hall and colleagues reported a similar twofold risk for transitory ischemic attacks ("mini-strokes") among women with baseline CVD who were reported "sitting and standing about equally" in their current job, followed by 36% risk increases among those "mostly standing" at work (Hall et al. 2019).

Few other studies have investigated body postures at work separately from body postures during leisure time. Some recent studies have used accelerometers to investigate differences in body postures at work and leisure time (Gilson et al. 2019). For example, accelerometer measurements of manufacturing workers over several working days have shown that they, on average, perform static standing at work for 2.8 h and being on their feet for 5.4 h (Jørgensen et al. 2019). However, very few studies differentiate between sitting, standing, and other types of light PA because they classify PA exclusively by broad categories of energy expenditure that typically combine sitting and standing in a single "sedentary" or "low-intensity" category (Ekelund et al. 2019). These studies are therefore unable to detect the posture-dependent health risks. Epidemiological studies that do not assess work postures, or combine sitting and standing postures into a single low OPA reference category, will lead to conservative misclassification bias when assessing the effect of high-intensity OPA relatively to low-intensity OPA. This is because the so-called "low" OPA comparison group includes not just predominantly sitting workers with low disease risks but many workers exposed to prolonged standing at work who are at substantial higher morbidity and mortality risks. This contamination of the reference low-risk group by high-risk workers will dilute the overall OPA risk estimates in such studies. This may in part be responsible for inconsistent findings regarding the health effects of OPA in general and for studies referring to "light standing" or "sedentary" work in particular. Exposure misclassification is further compounded by the fact that most studies on work postures did not measure the degree and amount of static and dynamic work performed. A worker standing may actually perform additional demanding static and dynamic work, for example, holding and swinging a heavy hammer. But such activities have most often not been measured or accounted for. This limitation is true for exposure assessment by both self-report and accelerometers; however, simultaneous measurements of posture, trunk, and extremity movements using multiple wearable sensors or observer-based ergonomic job analyses could overcome this limitation.

Posture-dependent health effects are products of pathophysiological processes and forces, not primarily generated by active skeletal muscle-induced movements but mostly by gravitational forces during standing that lead to increased hydrostatic pressures in blood vessels. For example, compared to lying down, arterial blood pressure in lower extremities increases by about 60–80 mmHg during standing. In addition to the gravitational forces, maintaining one's balance during standing requires co-contraction of agonistic and antagonistic muscles, particularly in the lower extremities. These relatively static contractions increase extravascular pressures leading to compression of arteries running through or near these muscles, thereby increasing peripheral resistance in those arteries. This requires harder pumping work of the heart and increased blood pressure to overcome this resistance for delivering oxygen to these muscles and other peripheral tissues or organs. These two mechanism alone – increased gravitational hydrostatic pressure and increased resistance of the peripheral arteries during prolonged standing – can lead to elevated blood pressure and functional and morphological changes in the blood vessels that, over time, result in stiffening of arteries (Wang et al. 2014) and atherosclerotic changes (Krause et al. 2000). These changes require even higher blood pressures to perfuse these arteries, thus generating a vicious cycle resulting in the development of hypertension, peripheral artery disease, and chronic kidney, cardiovascular, and cerebrovascular diseases. These mechanisms also operate during sitting, but to a much lower extent. This is because the vertical distance in height between the feet and the heart (determining the hydrostatic pressures) is much less during sitting, as is the need for static balancing muscle work, especially if the subject is being supported by back- and armrests, further reducing hydrostatic pressure and peripheral resistance.

Another pathophysiological hemodynamic mechanism triggered by a standing posture and the described increased hydrostatic pressures is venous pooling in the lower legs with plasma exudation into surrounding tissues, causing edema, swelling, and pain in the lower extremities (Antle et al. 2013) and reducing the circulating plasma volume (Lundvall and Bjerkhoel 1994). This will, in turn, increase the heart rate because of the need for the heart to pump the remaining blood volume more often through the body per unit of time, to deliver the same amounts of oxygen to tissues and organs.

Increases in heart rate due to change from a sitting to a standing position are observed during normal daily living at work and leisure (Coenen et al. 2018b). Since 24-h heart rates above a resting rate of 60 beats per minute are positively related to CVD and mortality (Zhang and Zhang 2009), the mechanism of heart rate increase through venous pooling provides an additional explanation for the detrimental health effects of prolonged standing. Finally, as already mentioned above, prolonged standing increases the risk for developing varicose veins, and these vessels in turn will increase the amount of venous pooling during standing creating another vicious cycle or feedback loop that further strains the cardiovascular system over time.

Because the total duration and degree of static standing is much higher during work than during leisure, it can be a potential explanation for the PA health paradox. For example, in the Danish DPhacto cohort, stationary standing was measured with accelerometers over several days in different occupational groups (Jørgensen et al.

2019). Manufacturing workers on average performed static standing at work for almost 3 h, while they stood for 1.6 h during leisure time. Moreover, the standing during work is likely to be more constrained and static than during leisure (particularly for blue-collar workers where static standing can be a requirement for performing the work tasks), thus imposing a more harmful effect during work than during leisure time.

Finally, upright work postures like standing are often combined with additional task-related muscle work that can be either static, such as holding tools or objects, or dynamic like hammering or a combination of both like in most common material handling tasks such as lifting and carrying of objects or persons. The static components of these tasks further increase peripheral vascular resistance and blood pressure with the detrimental consequences described above for prolonged postural work. The dynamic components of these additional tasks will also further increase blood pressure and heart rate and thus increase mechanical stresses in arteries that will cause micro-injuries of the arterial walls and a cascade of repair mechanism constituting inflammatory pathophysiological processes that cause atherosclerotic wall changes, which, in the long run, could lead to higher CVD incidence and mortality.

While the musculoskeletal health risks of manual material handling tasks have been extensively documented in the ergonomic and epidemiological literature, respective cardiovascular disease and mortality risks have rarely been studied. However, a few studies reported lifting or carrying objects to be predictive of cardiovascular diseases (Clays et al. 2012; Petersen et al. 2012). One recent Danish cohort study identified heavy occupational lifting at work as independent risk factor for ischemic heart disease with workers who reported carrying at least 10 kg at work experiencing an over 50% higher risk for ischemic heart disease, but no effect on all-cause mortality. Of note, the highest ischemic heart disease risks were experienced by male workers with occupational lifting who otherwise had lower levels of LTPA or OPA, indicating interactions between different types of PA (Petersen et al. 2012). Another Danish cohort study linked heavy occupational lifting to increases in blood pressure among users of antihypertensive drugs and to an increased incidence of hypertension among workers over 50 years old (Korshøj et al. 2019). Most recently, a study of 1.15 million Danish wage earners with 21.4 million years of follow-up that used a job exposure matrix to assess OPA reported occupational lifting to be positively associated in a monotone dose response up to a 9% (3–15%) and 27% (15–40%) increased risk of acute myocardial infarction in men and women who were exposed to more than 45 or 22 ton-years of occupational lifting, respectively (Bonde et al. 2019). However, these reported risks likely underestimate actual risks due to exposure misclassification, healthy worker bias, and overadjustment for factors that can be considered determinants (education, social position) of the OPA exposure.

Recovery

Long durations of PA without sufficient recovery time (e.g., excessive endurance sports or long work hours) can cause fatigue and exhaustion and may increase the risk of cardiovascular disease (Krause et al. 2009). Sports medicine considers an imbalance between PA load and recovery as “overreaching” or “overtraining,” which can cause injury and health impairments if sustained for longer periods of time (Elliott and La Gerche 2015). However, for most people, LTPA is of rather short duration (often much less than 1 h per day) with sufficient possibility for rest. On the contrary, in many occupations, work requires the worker to be physically active for several hours per day for several consecutive days, with limited possibility of rest periods within and between working days. This is particularly an issue in countries and job sectors without strict regulations regarding the number of working hours per day and week, paid vacation, and sick leave. Moreover, OPA is to a much lesser extent tailored to the individual person (e.g., age, cardiorespiratory fitness, symptoms, and fatigue) than LTPA. Thus, the differences in need for recovery and the ability to recover during work and leisure can also constitute a part of the explanation for the PA health paradox.

Future Perspectives for Strengthened Research and Prevention

The emerging epidemiologic evidence for the PA health paradox from a still inconsistent literature and several plausible physiological mechanisms have been described. Nevertheless, the existence of the PA health paradox has been questioned in a recent discussion paper that particularly questioned the epidemiological evidence for detrimental health effects of OPA (Shephard 2019). In contrast, despite of common methodological limitations (e.g., socioeconomic confounding), the positive health effects of LTPA are widely accepted and hardly ever questioned.

It is indeed important to critically discuss the evidence underlying the PA health paradox and to recognize inconsistencies and study limitations in future research. However, this examination needs to be applied to all domains of PA because inconsistencies and very similar methodological limitations exist also for the epidemiological evidence regarding the health effects of LTPA. For example, recent research among Finnish middle-aged men found no independent effects of LTPA on cardiovascular mortality (hazard ratio of 0.95, 95% CI 0.84–1.06) or all-cause mortality (hazard ratio of 0.99, 95% CI 0.94–1.04) among healthy men. Moreover, among the subgroup of workers with existing CHD, each additional weekly hour of LTPA resulted even in an elevated risk of 14% for cardiovascular mortality (hazard ratio of 1.14, 95% CI 1.04–1.26) and of 10% for all-cause mortality (hazard ratio of 1.10, 95% CI 1.03–1.18), respectively, in models controlling for 19 potential confounders including OPA (Krause et al. 2017). In the following, we discuss the most relevant limitations of the existing evidence of the PA health paradox and how these limitations ought to be addressed in future research. We also discuss how the existing evidence already provides new promising avenues for more effective disease prevention among working populations.

A Need for More Evidence and from Other Geographic Areas and Worker Populations

It has been suggested that there is still limited evidence for the PA health paradox and that most of the epidemiological evidence is restricted to studies from mainly

Scandinavian and Western European countries (Shephard 2019). We believe that the relatively good working conditions in Western European and Scandinavian countries that frequently use advanced technologies and ergonomic approaches to limit excessive workloads, regulate work hours, mandate paid vacation and sick leave, and provide universal access to medical care for free or at very low cost would actually attenuate negative health effects of OPA. We therefore expect that studies from countries with overall higher OPA and less worker protections might find even stronger negative OPA health effects.

In recent years, researchers around the globe have addressed the PA health paradox. For example, in the last couple of years alone, several new studies originated from Germany (Bahls et al. 2018), Switzerland (Wanner et al. 2019), Finland (Krause et al. 2017; Mikkola et al. 2019), Norway (Hermansen et al. 2019), Japan (Sakaue et al. 2018), China (Fan et al. 2018), and the USA (Hall et al. 2019). Despite of this growing body of literature, there is a need for additional research on the PA health paradox from other parts of the world. As a first, feasible, and relatively fast step, researchers all over the world should investigate the PA health paradox in existing longitudinal cohorts. Such research should also study potential explanations and mechanisms underlying the PA health paradox. Future studies should not exclude workers with pre-existing health conditions but instead use stratified analyses to identify groups of people that are particularly vulnerable to the negative health effects of high levels of OPA and in need for targeted interventions. For example, the effects of high OPA among people with pre-existing CVD, lower levels of cardiorespiratory fitness, or who are exposed to additional cardiovascular risk factors with potential synergistic health effects such as job stress (Ferrario et al. 2019a), air pollution, and environmental heat should be studied.

Better Measures of PA Needed

Most exposure assessments in existing epidemiological studies on the PA health paradox are based on questionnaires with relatively low validity (Koch et al. 2016). Also, most studies used rather crude categories for PA and often further merged these categories in the analysis stage, which may have led to misclassification bias. Future research should be based on more accurate PA assessment methods. Preferably, new studies should use device-based continuous measurements able to provide detailed information on temporal and compositional aspects of PA in all domains covering 24 h per day over multiple days. Moreover, additional PA characteristics need to be investigated including intensity, breaks, recovery time, postures, biomechanical loading, static work, relative aerobic workloads taking cardiorespiratory fitness into account, and cumulative workloads (using repeated measures and complete work histories). Wearable sensors such as accelerometers and heart rate monitors are now widely available and can be incorporated in large epidemiological studies. Although some cohort studies have already used accelerometer-based measurements of PA linked with prospective health outcomes (Ekelund et al. 2019), they often failed to differentiate between OPA and LTPA.

Better Dealing with Confounding

Control for confounding factors may have been insufficient in some studies of the PA health paradox. However, potential residual confounding is often claimed as an alternative explanation for unexpected results regardless of the quality and comprehensiveness of confounder control. This includes whether, and if so, how accurate other confounding factors (including socioeconomic, body composition, lifestyle, and health factors) are measured. We argue that residual confounding (from socioeconomic or other factors) is not likely to explain the PA health paradox, as support for the PA health paradox is found in studies adjusting for, or stratifying on, socioeconomic position, enrolling participants from the same occupation only, or adjusting for virtually all known biological, behavioral, and psychosocial risk factors for CVD.

Nevertheless, more effective ways of confounding control should be employed. For example, individual participant data meta-analyses can deal with nonstandard confounder assessment across studies because they have the large sample sizes necessary for comprehensive confounder control by combining several existing cohorts for reanalysis and harmonizing adjustment for confounders across cohorts. Controlled experimental studies, such as randomized controlled trials, may be able to even control for unknown or unmeasured confounders as long as randomization is successful. As far as we are aware, there are no randomized controlled trials investigating the health effects of exposing people to high OPA vs. high LTPA. As such trials may not be feasible, alternative research designs need to be considered for making causal inferences in the face of some remaining uncertainty. Various examples of such alternative designs have been suggested in the literature (Schelvis et al. 2015). For example, a natural experiment of an occupational group making a transition from high OPA work to robotized physically inactive work could be analyzed. A suitable occupational group in such a study could be garbage collectors. Garbage collecting used to be a highly physically demanding job, but much of the manual work has now (at least for some workers) been taken over by machines. Studying this occupational group before and after such a major transition, in which no inherent changes to factors other than physical demands are expected, and comparing this group to a relevant reference group might shed light on the causality of the health effects of OPA.

Opportunities for Improved Disease Prevention in Working Populations

As mentioned at the beginning of this chapter, current PA guidelines and other initiatives to improve PA among the general public are all based on the basic assumption of “the more PA, the better,” no matter the domain, environment, or context in which the PA occurs. The PA health paradox, however, suggests that this assumption may be wrong and that prevention strategies need to distinguish occupational from leisure-time PA. The potential benefits and risks of OPA also depend on individual worker characteristics such as age, cardiorespiratory fitness, cardiovascular health status, and physical limitations due to other comorbidities such as pulmonary diseases or musculoskeletal disorders. There are large groups of workers in our societies who are at an increased health risk due to unfavorable combinations of these individual characteristics and specific OPA patterns. According to the current evidence, these vulnerable worker populations include (a) middle-aged and older workers with pre-existing cardiovascular diseases such as varicose veins, atherosclerosis, hypertension, or ischemic heart disease who are especially vulnerable to the potential detrimental effects of high-intensity OPA; (b) workers with prolonged standing or other static work postures; (c) workers restricted to sedentary work with infrequent bouts of high-intensity OPA (e.g., truck drivers performing heavy-lifting tasks during delivery); (d) low-wage workers working longer hours or multiple jobs without sufficient recovery time including immigrant workers additionally trying to cope with wage theft, job insecurity, blacklisting, or fear of deportation; (e) children, women, and workers with health-related physical limitations and low cardiorespiratory fitness required to perform OPA at intensity levels that exceed their physical capacities; (f) and blue-collar manufacturing workers and large numbers of workers in agriculture, construction, warehousing, or in the hospitality, healthcare, and retail sectors who are highly active at work and sedentary during their leisure time (Gilson et al. 2019) and workers with high OPA combined with poor psychosocial work environment (Allesøe et al. 2017; Clays et al. 2016; Ferrario et al. 2019b). Most of these workers are at a double disadvantage; they suffer the negative health consequences of high OPA and do not benefit from the beneficial health effects of conditioning LTPA.

One primary prevention objective is to fit physical work demands, leisure-time activities, and recovery time to the individual workers' capacities and needs. Existing PA guidelines seem to be of little help in this respect. For example, the 2016 European guidelines on CVD prevention in clinical practice do not differentiate between OPA and LTPA, recommend at least 150 min of moderate PA per week regardless of domain, and state that benefits of PA outweigh the risks while acknowledging that the "the lower and upper limit of aerobic PA intensity, duration, and frequency to exert a beneficially effect is unknown." These guidelines furthermore warn that "individuals who exercise only occasionally seem to have an increased risk of coronary events and sudden cardiac death during or after exercise" (Thompson et al. 2007) and advise that "clinical evaluation, including exercise testing, may be considered for sedentary people with cardiovascular risk factors who intend to engage in vigorous PA and sports" and that "especially for older and deconditioned individuals a relative intensity measure is more appropriate" (Piepoli et al. 2016, pp. 2344–2345).

In contrast, long-standing recommendations by work physiologists and the International Labor Organization (ILO) specifically address OPA and advise that the average relative aerobic workload during an 8-h work day should not exceed 30–33% aerobic workload (Bonjer and Parmeggiana 1971). These recommendations were developed in the 1960s based on physiological parameters of excessive exertion indicating an acute inability of the body to eliminate as much serum lactate as it produced during PA; they were not considering chronic disease or mortality risks. A 22-year prospective cohort study supported this recommendation, finding that men without CVD at baseline who exceeded 33% of relative aerobic workloads had 64% (95% CI 10–142%) and 30% (95% CI 7–57%) increased risks of CHD and all-cause mortality, respectively (Krause et al. 2017). However, even values below that recommended average level of relative aerobic workload can increase morbidity and mortality risks in exposed workers. In fact, the same study of Finnish middle-aged men showed that each 10% of relative aerobic strain increased the risks of acute myocardial infarction by 18% (95% CI 8–28%) (Krause et al. 2015), CHD mortality by 30% (95% CI 14–49%), and all-cause mortality by 15% (95% CI 7–24%) (Krause et al. 2017). Therefore, keeping relative aerobic workloads below this established physiological limit is insufficient for prevention of CVD. Nevertheless, this limit represents a modest minimum goal for preventing excessive fatigue at the workplace. Achieving this minimum goal should be considered a first step in the desired direction of reducing harmful levels of OPA. For this threshold to be implemented, the relative workload is recommended to be measured under real-world conditions. This is because the relative workload of the worker does not only depend on the worker's physical capacity (determined by pre-existing cardiorespiratory conditions or the level of aerobic fitness) and physical work tasks but also other working conditions including air quality, noise level, environmental temperature, need to wear personal protective equipment, work-rest schedule, and psychosocial job stressors (Ferrario et al. 2019b). Ideally, all these factors should be considered, and recommendations should be tailored to the individual worker and specific work demands.

Reductions of excessive relative aerobic workloads can be achieved by three approaches: reduction in the absolute physical workload, increase in aerobic fitness, and increase in recovery time, either alone or in combination. Accordingly, some researchers have suggested to reduce CVD risks by exercise training at work of sufficient intensity to increase cardiorespiratory fitness to reduce the number of workers whose relative aerobic workloads exceed the maximum ILO-recommended level (Korshøj et al. 2012). A recent randomized workplace intervention trial among cleaners in Denmark showed that relatively few sessions of intensive aerobic exercise during paid worktime indeed increased fitness and reduced relative aerobic workloads. However, the intervention also resulted in significant increases in both resting and 24-h ambulatory blood pressure (Korshøj et al. 2015b). These mixed results prompted the authors not to recommend this approach at this time because of remaining safety concerns. Moreover, for aging workers and for workers with existing CVD or with exercise-limiting pulmonary or musculoskeletal disorders or other functional limitations, fitness training may not be feasible or insufficient to achieve adequate reductions in relative aerobic strain. While increased LTPA after work can be beneficial for individuals with low levels of OPA, results for individuals with high levels of OPA have been inconsistent (Clays et al. 2013), and fatigue, long or irregular work hours common in manual jobs, and scheduling issues may remain barriers for engagement in LTPA.

Primary prevention that is safe and not relying on individual workers' behavioral changes, especially among older workers with high OPA levels, may instead need to address the discrepancy of individual cardiorespiratory fitness and physical job demands by reduction of physical job demands, daily or weekly work hours, and increases of recovery time (Krause et al. 2009). While automation has reduced physical workloads over the past decades for skilled workers in some industries (e.g., motor vehicle production), workers in other industries have been faced with work intensification (e.g., in the growing healthcare, hospitality, and retail sectors) (Krause et al. 2005). In some sectors the heaviest work is now performed by low-wage immigrant workers who are underrepresented in national surveys and epidemiological studies (e.g., custodial, construction, farm, and hotel and restaurant workers). General public health messages exclusively recommending increased PA may be appropriate for the sedentary part of the working population and the subgroup of workers who tend to participate in workplace health promotion programs. However, such messages do not sufficiently address the sizable working populations performing heavy physical labor; the increasing proportion of aging workers with pre-existing chronic cardiovascular, pulmonary, or musculoskeletal diseases; or workers unlikely to receive an offer for, or to participate in, respective workplace health promotion programs.

In the absence of more controlled community-based intervention trials, it is difficult to compare the effectiveness of different approaches for primary disease prevention among workers with high OPA. It has recently been mentioned in the literature that two birds could be killed with one stone if we can design work in such a way that OPA becomes health enhancing (Holtermann et al. 2019). According to this idea, referred to as the Goldilocks principle, the aim is to design the work tasks, work organization, or environmental structures of the job in a way so that OPA becomes more similar to characteristics of LTPA and thus can contribute to improved health. However, the principle remains to be tested in different occupational groups during productive work.

Applying the precautionary principle of public health, the reviewed evidence has already important implications for the practice of occupational and rehabilitative medicine even in the absence of respective intervention trials. Primary disease prevention efforts may benefit from a reduction of the energy demands in physically demanding jobs. Jobs in agriculture, forestry, commercial fishing, construction, manufacturing, warehousing, cleaning, or retail are at especially high risk for excessive relative aerobic strain (Krause et al. 2017). Secondary and tertiary prevention efforts may be indicated for persons who do not have a sitting desk job. Occupational medicine and other occupational health professionals can assist in an individualized approach using inexpensive ambulatory heart rate monitoring during work hours to determine the ergonomic fit between individual aerobic capacity and workload. Specifically, relative aerobic workloads, estimated as percent heart rate reserve ($\%HRR = (HRwork - HRrest)/(HRmax - HRrest) \times 100\%$) (Wu and Wang 2002) using wearable heart rate monitors and standard procedures estimating maximum heart rate (HRmax) based on resting heart rate (HRrest) and age (Karvonen et al. 1957), can be used. %HRR should be routinely assessed in nondesk workplaces during placement of new employees and in the process of designing work modifications for employees returning to work after being diagnosed with CVD. Exercise testing and ambulatory electrocardiography (ECG) are indicated for workers with CVD and cardiovascular risk factors or for sedentary workers who plan to engage in high-intensity LTPA or sports per recommendations of existing guidelines (Haskell et al. 1989).

Intervention studies reducing physical job demands have so far only been conducted with the goal to reduce acute musculoskeletal symptoms through ergonomic interventions (using training, engineering controls, and changes in work organization). For obvious reasons, these studies did not evaluate CVD or mortality outcomes that require large samples and decade-long follow-up and more substantial resources. Nevertheless, ergonomic intervention studies could combine their traditional outcomes (fatigue, musculoskeletal pain, work-related injury, disability, return-to-work, productivity, costs) with short-term changes in cardiovascular risk factors such as blood pressure, heart rate, heart rate variability, pulse wave velocity, and arterial wall intima-media thickness at marginal extra costs. Similarly, large-scale epidemiological studies designed to evaluate real or simulated interventions for chronic musculoskeletal disease outcomes could, in addition to ergonomic exposure assessments, study cardiovascular disease and mortality outcomes assessed via record linkage with respective hospitalization and death registries.

Future intervention research needs to investigate the effectiveness and efficiency of possible interventions such as fitness-inducing exercise, increase of recovery time, and reduction of work hours and/or physical job demands. This is especially relevant today given growing high-risk populations of aging workers with pre-existing CVD and of particularly vulnerable low-wage immigrant workers that have been under-researched and underserved in occupational and public health.

Despite remaining questions about the PA health paradox and lack of evidence from intervention studies, our current understanding of the available physiological, ergonomic, and epidemiological evidence clearly indicates that more PA is not always better for health or longevity. Occupational and public health policies that reduce harmful excessive physical workloads, prolonged standing, long work hours, and the need for multiple jobs and that provide sufficient recovery periods and health-promoting PA at work and during leisure are promising complementary avenues for effective workplace-based disease prevention considering the PA paradox and its contextual root causes.

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