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PHYSICAL FITNESS AMONG OLDER MANUAL WORKERS

BY
KRISTOFFER LARSEN NORHEIM

DISSERTATION SUBMITTED 2020

AALBORG UNIVERSITY
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PHYSICAL FITNESS AMONG OLDER MANUAL WORKERS

PHD THESIS

by

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Dissertation submitted

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CV

Kristoffer Larsen Norheim (KLN) received his Bachelor degree in sport science in 2014 from the Norwegian School of Sport Science, Norway, which included an exchange semester at Montana State University, USA, and summer school at University of Jyväskylä, Finland. He received his Master degree in human physiology in 2016 from University of Copenhagen, Denmark.

With a grant from the Danish Working Environment Research Fund, KLN was enrolled as a PhD-student at the doctoral school of the Faculty of Medicine at Aalborg University. The PhD-project is a collaboration between Aalborg University and Aalborg University Hospital under the supervision of Professor Pascal Madeleine and co-supervision of Associate Professor Afshin Samani, Associate Professor Jakob Hjort Bønløkke, and Professor Emeritus Øyvind Omland.

During his PhD, KLN has given oral presentations at the 6th annual Ramazzini seminar (Ramazzini seminar, 2017, Sønderborg, Denmark), the 20th International Ergonomics Association Conference (IEA, 2018, Florence, Italy) and 10th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders (PREMUS, 2019, Bologna, Italy). Additionally, KLN has presented posters at the 9th annual meeting of the Danish Society of Biomechanics (DBS, 2017, Aarhus, Denmark) and the 24th annual Congress of the European College of Sport Science (ECSS, 2019, Prague, Czech Republic). He is also a reviewer for Experimental Gerontology and Sports Medicine.

ENGLISH SUMMARY

Life expectancy has increased over the last decades. To accommodate the growing population of older adults, retirement age is currently being raised in many countries. Because aging is associated with a decline in physical fitness, this may be problematic for workers in physically demanding occupations. Although regular physical activity is an important component in slowing the aging process, controversy exists regarding the influence of manual work on physical fitness. Especially for older adults, very little knowledge exists regarding the influence of age and manual work on physical fitness. Delineating age-related changes in physical fitness among older manual workers could point toward physical deficiencies that should be targeted for future interventions. This could provide a better work ability and secure a meaningful retirement for all workers.

The overall aim of this thesis was to investigate physical fitness among manual workers in their last two decades of working life. Further, it aimed to investigate the effects of musculoskeletal complaints on motor control tasks and fatigue development. To accomplish this, a series of five studies were conducted. Study I described the protocol for the experimental assessments that constituted the four latter cross-sectional studies. In Study II it was demonstrated that age and the stage of musculoskeletal pain (acute vs. chronic) differentially affects the structure of handgrip force variability in manual workers. Similarly, Study III showed an age-dependency on the effects of musculoskeletal pain on lower extremity function and dynamic balance. In Study IV, the response times during a hammering task were markedly slower for older manual workers compared with younger controls. Surprisingly, this was not accompanied by differences in hammering accuracy. Lastly, results from Study V indicated that all domains of physical fitness deteriorates with aging in manual workers. Greater handgrip strength and body size, but poorer cardiorespiratory fitness and pulmonary function was found compared with general populations.

In summary, the present thesis indicated that manual workers do not improve their physical fitness by being in jobs in which they are physically active every day. Especially cardiorespiratory fitness, pulmonary function, and motor control seemed to be negatively affected, whereas handgrip strength may be maintained to some extent in these older workers. Of note, physical fitness was more strongly associated with physical work ability after age 60, suggesting physical fitness as a limiting factor only among the oldest workers. Future studies are encouraged to investigate the effects of interventions aiming at increasing cardiorespiratory fitness and reducing fat mass among older manual workers.

DANSK RESUMÉ

Levealderen er steget i løbet af de sidste årtier. For at imødekomme den voksende befolkningsandel af ældre mennesker, hæves pensionsalderen i mange lande. Da aldring er forbundet med et fald i fysisk kapacitet, kan dette være problematisk for arbejdstagere i fysisk krævende erhverv. Selvom regelmæssig fysisk aktivitet er en vigtig komponent i at bremse aldringsprocessen, eksisterer der uenighed om påvirkningen af manuelt arbejde på fysisk kapacitet. Især for ældre voksne findes der meget lidt viden om påvirkning af alder og manuelt arbejde på fysisk kapacitet. En beskrivelse af aldersrelaterede ændringer i fysisk kapacitet blandt ældre håndværkere kan pege på mangler, der bør målrettes mod i fremtidige interventioner. Dette kan give en bedre arbejdsevne og sikre en meningsfuld pensionisttilværelse for alle arbejdstagere.

Det overordnede mål med denne afhandling var, at undersøge fysisk kapacitet hos håndværkere i deres sidste to årtier af arbejdslivet. Endvidere havde den til formål, at undersøge virkningerne af muskel-skeletbesvær på motoriske kontrolopgaver og træthedsudvikling. Til dette blev der udført en serie af fem studier. Studie I beskrev protokollen til de eksperimentelle målinger, der udgjorde de fire følgende tværsnitsundersøgelser. I Studie II blev det påvist, at alder og stadiet af muskel-skeletbesvær (akut vs. kronisk) differentielt påvirker strukturen i håndgrebskraftvariabilitet hos håndværkere. Tilsvarende viste Studie III, at virkningerne af muskel-skeletbesvær på underekstremitetsfunktion og dynamisk balance var aldersafhængige. I Studie IV var responstiderne under en hammeropgave markant langsommere for ældre håndværkere, sammenlignet med unge kontroller. Overraskende var dette ikke ledsaget af forskelle i hammerpræcision. Endelig indikerede resultater fra Studie V, at alle områder af fysisk form forværres med aldring hos håndværkere. Større håndgrebsstyrke og kropsstørrelse, men dårligere kredsløbskondition og lungefunktion blev fundet sammenlignet med generelle populationer.

For at opsummere, så indikerede denne afhandling, at håndværkere ikke forbedrer deres fysiske kapacitet ved, at være i fysisk krævende erhverv. Især kredsløbskondition, lungefunktion og motorisk kontrol syntes at være negativt påvirket, hvorimod håndgrebsstyrken i nogen grad kan opretholdes hos disse ældre arbejdstagere. Det bemærkes, at fysisk kapacitet var stærkere forbundet med fysisk arbejdsevne efter 60-årsalderen, hvilket tyder på, at fysisk kapacitet kun er en begrænsende faktor blandt de ældste arbejdstagere. Fremtidige undersøgelser opfordres til, at undersøge virkningerne af interventioner, der sigter mod at øge kredsløbskondition og reducere fedtmassen hos ældre håndværkere.

ACKNOWLEDGEMENTS

The present thesis could not have been completed without the generous financial support of The Danish Working Environment Research Fund, the recruitment help of the United Federation of Danish Workers, and the people who volunteered to participate in the experiments. I would also like to thank the Otto Mønsted foundation for travel grants enabling participation in scientific conferences.

First and foremost, I would like to thank my main supervisor Pascal Madeleine for the enormous effort you have put into helping me not only with my PhD, but also with my future plans and aspirations. Thanks also to my co-supervisors Afshin Samani–for your attention to detail and for keeping me sharp; Jakob Hjort Bønløkke–for your guidance in the field of occupational and environmental medicine; and Øyvind Omland–for sharing your wisdom and for believing in me as a researcher. Thanks also to the rest of the ALFA-group for scientific sparring throughout the PhD project.

Thanks to my colleagues at Sport Sciences for creating a positive and motivating work environment. Special thanks goes to Ramtin, Silvia, and Rasmus for being excellent office mates and friends.

Thanks to my mom and dad for enduring long phone calls made in frustration and for all your support throughout these three years. Lastly, I would like to thank my girlfriend Lea for all your support and for being a source of inspiration.

- Kristoffer

March 2020, Aalborg

LIST OF STUDIES

This thesis is based on the following articles hereafter referred to by their Roman numeral in the text. The included studies are provided in the appendices section.

STUDY I

Norheim KL, Hjort Bønløkke J, Samani A, Omland Ø, Madeleine P. The Effect of Aging on Physical Performance Among Elderly Manual Workers: Protocol of a Cross-Sectional Study. *JMIR Res Protoc*. 2017

STUDY II

Norheim KL, Samani A, Bønløkke JH, Omland Ø, Madeleine P. The effects of age and musculoskeletal pain on force variability among manual workers. *Hum Mov Sci*. 2019

STUDY III

Norheim KL, Samani A, Bønløkke JH, Omland Ø, Madeleine P. On the role of ageing and musculoskeletal pain on dynamic balance in manual workers. *J Electromyogr Kinesiol.* 2020

STUDY IV

Norheim KL, Samani A, Madeleine P. Whack-a-mole and the effects of age on response time, accuracy and shoulder/arm kinematic. *Submitted.*

STUDY V

Norheim KL, Samani A, Bønløkke JH, Omland Ø, Madeleine P. Physical performances show conflicting associations in aged manual workers. *Sci Rep.* 2020

ABBREVIATIONS

ALFA	Aldring og fysisk arbejde (Aging and physical work)
BIA	Bioelectrical impedance analysis
BMI	Body mass index
COPD	Chronic obstructive pulmonary disease
CRP	C-reactive protein
FEV_1	Forced expiratory volume after 1 second
FFM	Fat-free mass
FVC	Forced vital capacity
HGS	Handgrip strength
HR	Heart rate
IL-6	Interleukin-6
LyE	Lyapunov Exponent
MVC	Maximal voluntary contraction
RFD	Rate of force development
RPE	Rating of perceived exertion
SaEn	Sample entropy
STS	Sit-to-stand
$\dot{V}O_2max$	Maximal rate of oxygen uptake

PREFACE

The present thesis concerns physical fitness among older manual workers. Because there may be several ways to interpret and define *older*, *manual workers*, and *physical fitness*, following is a list of how these terms are defined within the context of the present thesis. It is acknowledged that other definitions exists.

Age may be defined as the time since a person was born (chronological age), measured or self-perceived health (functional/biological age), social or self-perceptions about one's age (psychosocial age), job tenure (organizational age), and home situation (life-span age) (1). In the present thesis, age refers to chronological age and older workers are considered as those aged ≥ 50 years.

Manual workers may be defined as people who are working in an occupation that requires physical work done by humans. Related terms include blue-collar workers, physical workers, and laborers. In the present thesis, manual workers refer to people who are actively working in or who are retired from a skilled occupation that requires physical activity such as carpenters, bricklayers, and plumbers.

Physical fitness may be defined as a set of health and skill-related attributes (2). Although physical fitness was not defined and operationalized in the individual studies of this thesis, it is included herein as the overarching concept describing all studied outcomes, relating not only to performance but also to health. Related but not equivalent terms include physical performance and physical capacity. In the present thesis, physical fitness refers to attributes that relate to the ability to work and perform physical activities and be in good health. The operationalization and measured items are shown in **Figure 0-1**.

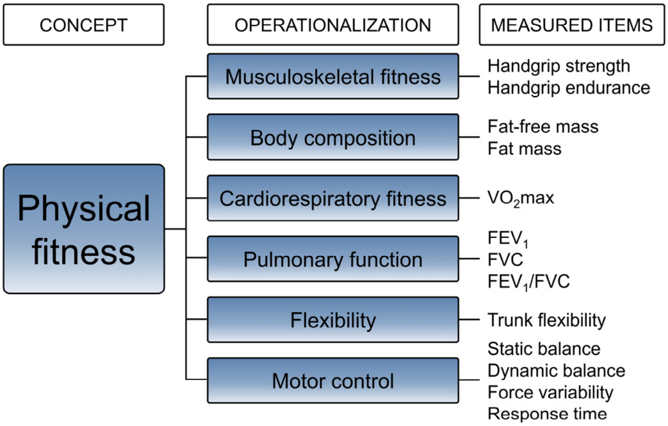

Figure 0-1. Definition of physical fitness within the thesis. *VO_2max, maximal rate of oxygen uptake; FEV1, forced expiratory volume after 1 s; FVC, forced vital capacity.*

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CHAPTER 1. INTRODUCTION

Across the world, people are living longer and by the year 2050, it is expected that one in every six people worldwide will be above the age of 65 years; in Europe, this number is one in four people (3). To accommodate the growing population of older adults, retirement age is currently being raised in many countries (4). This may be problematic for older workers in physically demanding occupations because physical work-demands stay at the same level regardless of age (5–7) and aging processes do not necessarily influence life expectancy. Although a decline in physical fitness with aging is probably inevitable (8), regular physical activity remains an important component in slowing the aging process (9). Does that mean that manual workers to some extent maintain their fitness by being in jobs in which they are physically active every day? Alternatively, does the daily strain of manual work exceed a threshold of adaptation thereby causing physical degeneration?

In this chapter it is outlined how aging leads to adverse outcomes and deconditioning of six important aspects of physical fitness. The effects of manual work upon these changes are thereafter described thereby building the theoretical framework on which the aims and hypotheses of the current thesis are constructed.

1.1. PHYSICAL FITNESS AMONG OLDER MANUAL WORKERS

Aging is a natural phenomenon affecting all species. In humans, the complex and heterogeneous process of aging involves several molecular, cellular, and organ system changes (10). Through an impaired ability to respond to stressors, aging also increases the susceptibility to diseases caused by external factors (11). Physical fitness–encompassing attributes related to both health and skill (2, 12)–gradually declines with aging. This process seems inescapable even in the absence of disease (8). Researchers are seeking out biomarkers of aging in an attempt to find a valid marker of *biological age* (13). To date, no single marker is able to predict the complex process of aging (14), but there does seem to be agreement that several aspects of physical fitness represent healthy aging (15–17).

1.1.1. MUSCULOSKELETAL FITNESS

Skeletal muscle strength and endurance play an integral part in daily life. Musculoskeletal fitness is fortunately among the most well preserved aspects of physical fitness with aging. However, with old age even opening a glass of jam or rising from a chair may become a challenge.

Maximal strength develops from childhood through adolescence and peaks around the early 30s (18). From thereon strength can be maintained to some extent until age 50–

at which time it inevitably starts to decline with annual rates of loss between 1-4% per year (19–22). Compared to muscle strength, power and the ability to produce rapid movements are lost at even faster rates (22, 23), whereas muscle endurance may be unchanged or even slightly increased before a decline is observed after age 70 (24). It is important to note that the rate of change can be greatly affected by exercise or inactivity. People who are initially sedentary may increase their strength by more than 50% if starting to exercise (18), thereby attaining their peak lifetime strength much later than age 30 (**Figure 1-1**). Although the response to exercise may be mitigated by old age (25), improvements can be seen even at very old ages (26). Contrary, acquiring an injury or musculoskeletal disorder could potentially accelerate the age-related decline in muscle strength. Unfortunately, below a certain strength threshold impairments in strength may start to interfere with activities of daily living and lead to disability (27–29). Indeed, low muscle strength is linked with greater risk of hospitalization (30) and mortality (15).

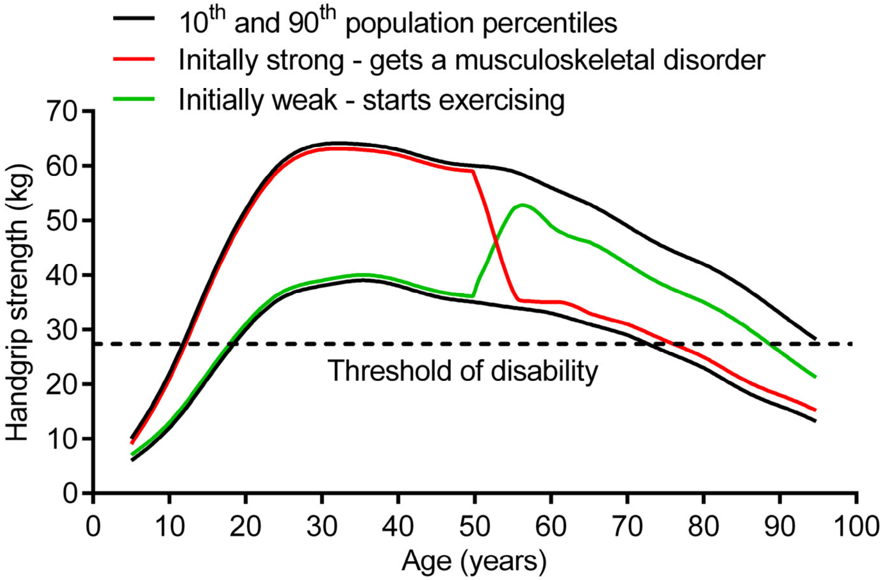

Figure 1-1. Changes in muscle strength across the life course. *The two black lines indicate 10th and 90th percentiles based on handgrip strength data for males from (31). The red line shows muscle strength across the life course of a person with high initial strength who acquires an injury or musculoskeletal disorder at age 50. The green line shows muscle strength across the life course of a person with low initial strength who starts exercising at age 50. The threshold of disability signifies the 27 kg cut-off value used to define sarcopenia among males* (32)*. Adapted from (27).*

Manual work that continuously challenges the neuromuscular system should intuitively maintain musculoskeletal fitness more than sedentary work; however, conflicting evidence exists on this topic. Age-related reductions in muscle strength have been demonstrated in several manual occupations (33–35). Interestingly, maintained maximal strength with age (34) and greater strength compared with controls (35) have been observed thereby suggesting a protective effect of manual work. Contrary, others find no effect (36, 37) or even a detrimental effect (38) of manual work upon muscle strength. The low socioeconomic status associated with some manual professions could negatively affect strength in old age (39). Moreover, manual work may be characterized by static awkward postures, short recovery between bouts of activity, and poor worker control (40). The prevalence of musculoskeletal complaints is therefore particularly high among manual workers (41, 42). Thus, even if manual workers are initially strong at the beginning of their careers (43), muscle strength may not be maintained and could be negatively affected by manual work if workers acquire an injury or musculoskeletal disorder.

1.1.2. BODY COMPOSITION

The worldwide prevalence of obesity has increased over the last decades (44). The loss of skeletal muscle mass that accompanies aging has resulted in an older population suffering from sarcopenic obesity (45). Such changes in body composition are strongly related to negative health outcomes (46).

Although an age-related loss of muscle relative to total body mass may be observed from the early 20s, absolute changes in muscle mass probably occur starting around age 50 (47, 48). Annual rates of decline in muscle mass are estimated at about 0.5% per year (49), which notably is 2-5 times slower than that of muscle strength (19, 20). This process seems to accelerate with age (50)–with changes being especially pronounced in the lower extremities (48)–and the observed share of older adults with sarcopenia is about 40% in those aged over 80 years (45). Sarcopenia is associated with functional impairments and disability (51). Obesity may exaggerate this age-related loss of muscle mass through noninfectious inflammation (52). Indeed, visceral fat secretes adipokines such as interleukin 6 (IL-6) which is linked with systemic C-reactive protein (CRP) levels and chronic diseases (53). Interestingly, obesity seems to be a cause of disability among older adults even independently of chronic disease (54, 55). Among other explanations, the physical effort of having to carry around a body that is lacking in muscle mass and in excess of fat mass may be a reason for disability (56).

Knowledge on the effects of manual work on body composition is scant. An age-related increase in fat mass and a decrease in lean body mass has been observed among construction workers (34) and fire fighters (57). Similar to muscle strength (39), there is a social gradient in body composition changes (58). However, more muscle mass and less body fat was found for production compared with administrative workers in their fifties (59). In lack of further evidence, it could be speculated that muscle mass follows the same trajectory as that of muscle strength in manual workers, but further studies are warranted. Although a more indirect measure of adiposity, body mass index (BMI) has been used in several studies showing that obesity is prevalent among manual workers and about 65-70% can be classified as overweight or obese (56, 60).

Unhealthy behaviors such as high alcohol intake (61) and poor diet (62) among manual workers could potentially explain this. Importantly, obesity has a negative impact on work ability–especially when combined with high physical workloads (56).

1.1.3. CARDIORESPIRATORY FITNESS

Aerobic exercise performance is mainly determined by cardiorespiratory fitness (63). Although physical activity has a strong positive effect on cardiorespiratory fitness, it cannot completely eradicate the negative changes accompanying aging (64). Everyday tasks will therefore pose an increasingly greater relative aerobic strain as people age.

The loss of cardiorespiratory fitness–as measured by maximal oxygen consumption ($\dot{V}O_2$max)–that happens with aging may occur starting from the early 30s (65). Average annual reductions in $\dot{V}O_2$max of 1% per year have been reported (66). Similar relative rates of decline are seen among sedentary and endurance-trained people (65), which could be due to a higher baseline $\dot{V}O_2$max among active individuals. Nonetheless, $\dot{V}O_2$max is still much greater in older adults with a history of aerobic exercise training compared with sedentary people (65, 67). The proposed mechanisms explaining the effect of old age on $\dot{V}O_2$max are rooted in both central and peripheral adaptations. Maximal heart rate (HR) and stroke volume decreases with age (68, 69) and together these central adaptations reduces cardiac output and thus $\dot{V}O_2$max (69). Peripheral adaptations include changes in body composition–mainly loss of muscle mass–and altered oxygen delivery and/or utilization by the muscle tissue (70). Cardiovascular diseases associated with aging may exacerbate these changes (71). Having a poor cardiorespiratory fitness level is independently predictive of all-cause and disease-specific mortality (72).

Age-related reductions in $\dot{V}O_2$max have been observed among workers in physically demanding occupations such as power line workers (33), fire fighters (57), and construction workers (34). Although physical activity–especially physical exercise training–is known to improve cardiorespiratory fitness, occupational physical activity does not seem to have this effect (73, 74). It has been suggested that a physical activity health paradox exists (75), in which physical activities performed during work and leisure have opposing effects on health (76). One hypothesized reason for this is that occupational physical activity is of insufficient intensity to elicit a training response and that it instead may lead to cardiovascular disorders (40, 74). Interestingly, when comparing young with old waste collectors and young with old controls, a larger difference in $\dot{V}O_2$max for the waste collectors than for controls has been observed (35). This difference could suggest an exaggerated decline in $\dot{V}O_2$max among adults with physically demanding occupations in agreement with e.g. (74, 77, 78). Thus, although few studies exist, they suggests that manual work does not maintain cardiorespiratory fitness and that it may even be detrimental for some.

1.1.4. PULMONARY FUNCTION

Unlike cardiorespiratory fitness, pulmonary function is not normally a limiting factor for physical performance and function–nor does physical activity lead to any large improvements in pulmonary function (64, 79). Consequently, pulmonary function may not always be included as one of the aspects of physical fitness (2, 80). However, when age-related changes are coupled with some environmental exposures, pulmonary function may not only impede performance but may also increase risk of developing obstructive lung diseases (11).

In healthy non-smoking adults, changes in pulmonary function may be observed as early as the mid-20s (81). After age 30, forced vital capacity (FVC) and forced expiratory volume after one second (FEV_1) decrease at annual rates of about 0.6% and 0.8% per year, respectively (79, 82). These changes can be considerably exacerbated by environmental exposures such as tobacco smoking and dust exposure (83). Of interest, chronic obstructive pulmonary disease (COPD), although most often associated with environmental exposures, has been characterized as an «accelerated aging phenotype» (11). The primary mechanisms behind age-related impairments in pulmonary function are increased alveolar size, reduced chest wall compliance, and reduced respiratory muscle strength (84). While physical activity may not mitigate the effects of the two former, reductions in respiratory muscle strength can potentially be slowed by exercise (64, 85).

Manual workers such as cement workers, coal miners, and construction workers are frequently exposed to different dust as well as gases and aerosols that may cause pulmonary obstructive diseases (83, 86, 87). Such exposure may lead to a twofold increased risk of mortality from COPD (86). Moreover, unhealthy behaviors such as tobacco smoking is about twice as common among workers in physically demanding occupations compared with the general population (61). Interestingly, workers exposed to dust and chemicals at work are more likely to smoke (88). Tobacco smoke is the leading cause of COPD and the age-related decline in pulmonary function among manual workers may therefore be exaggerated by both environmental exposures and tobacco smoke (89).

1.1.5. FLEXIBILITY

Aging may reduce joint flexibility, thereby limiting functional range of motion (90–92). Although changes differ depending on the joint, decrements of about 0.5% per year have been reported (59, 92, 93). Stretching exercises improve flexibility and are therefore sometimes included as a part of public exercise recommendations (2). It has been speculated that greater flexibility may prevent injuries (94). For instance, more flexible hamstring muscles change the angle-torque relationship during knee flexion so that peak torques occurs at a greater joint angle (95). In other words, the muscles are stronger at longer muscle lengths. This could be of importance because strain injuries typically occur when muscles are maximally elongated (96). However, controversy exists on this topic (94, 96, 97) and the exact mechanisms through which stretching causes greater joint range of motion are still unknown (98). Perhaps more important for the non-athlete population, it is uncertain whether an increase in flexibility actually translates into improvements in physical fitness (94, 98); that is, a person's ability to perform physical activity and be in good health (2). Indeed, although flexibility training increases range of joint motion, it seems to have little effect on physical function (98).

Workers with high occupational physical loads may have poorer flexibility compared with those exposed to lower loads (99). A higher prevalence of osteoarthritis among such workers may contribute to this (100). For manual workers, it could be speculated that poor flexibility would lead to more restricted movements and awkward postures, which could possibly affecting work ability negatively. Moreover, it has been suggested that greater flexibility may help in reducing work-related musculoskeletal disorders among manual workers (101). Seemingly, impaired flexibility may predict the development of musculoskeletal pain (102). Among vineyard workers with low-back pain, strengthening and flexibility training not only improved trunk flexibility but also increased pain thresholds (103). How aging affects flexibility among older manual workers and how these changes relate to work ability is currently unknown.

1.1.6. MOTOR CONTROL

In humans, motor control–sometimes referred to as neuromotor fitness (2)–relates to the subjective control of movement tasks such as balance, accuracy, and gait (104). Coupled with a decline in muscle strength, changes in motor control can impair e.g. the ability to rise from a chair with old age (105). Unfortunately, reductions in strength among already weak adults have larger consequences on motor tasks compared with changes among stronger adults (28). Aging is moreover associated with greater motor variability (106), which can be observed during static muscle contractions where an increase in force variability with aging could suggest a loss of motor units (108). More variable movements with age can compromise postural steadiness–measured as an increase in the velocity of displacement during static standing–which may decrease by up to 2% per year with age (109, 110). These changes may be further exaggerated by musculoskeletal pain and disease (111–113). Moreover, slower information processing cause reaction times to slow by about 0.3% per year while also becoming more variable with old age (114, 115). Coupled with slower movements, response times ultimately slow down and start to affect the ability to respond to external stimuli (116) thereby playing a negative role on physical function (117). Together, poor motor control cause older adults to be at an increased risk of falls (118), disability (119), and mortality (15).

Manual workers frequently report musculoskeletal symptoms including fatigue and pain (42), which could affect their motor control (120). Interestingly, the stage of pain may have different effects on variability (121); at the acute stage, variability may increase as the motor system attempts to find a non-painful motor solution for a given task, while as pain starts to become chronic variability may decrease to avoid the painful solutions (122). Little is known about how these stages may interact with aging. Although sensory manifestations of pain can occur and motor control strategies may change after only a few months of employment into a manual profession (123), this does not necessarily lead to disability in early age. Following a life-time of manual work, however, even basic abilities such as getting up from a chair may be challenged (38, 124). Physical demands at work are indeed negatively related to physical function (125) and manual workers may therefore be at a greater risk of disability after retirement (126).

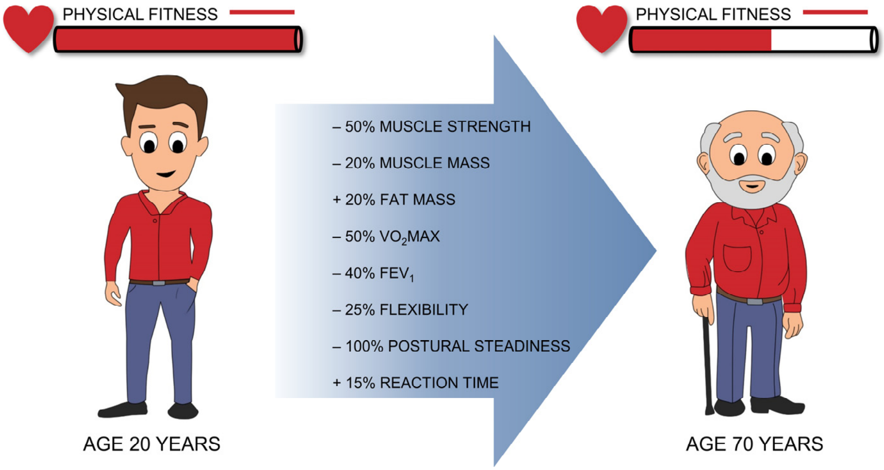

Figure 1-2. Effects of age on physical fitness. *Illustration of the effects of aging from an ideal 20 to 70 years on physical fitness. Values are approximates based on* (8, 47, 49, 66, 82, 92, 109, 115)*. VO$_2$max, maximal rate of oxygen uptake; FEV$_1$, forced expiratory volume after 1 s. Drawings credited to Øyvind Norheim.*

In summary, human aging inevitably leads to a gradual decline in physical fitness. Some domains of physical fitness may decline in a non-linear fashion possibly due to the effects of e.g. physical activity and musculoskeletal pain. On average, however, the physical fitness of a person aged 70 years may be about 60% that of their ideal 20 year old selves (**Figure 1-2**).

1.2. WORK ABILITY

Although many people maintain their ability to work until retirement, some still experience a decline–especially those with high physical work demands (127–129). Both old age and physically demanding work are negatively associated with work ability and older manual workers may therefore be particularly vulnerable to the impact of raising retirement age (130). Are old manual worker fit to work until retirement? An answer to this question is beyond the scope of the present thesis and is probably not dichotomous in nature. Nevertheless, before recommendations for future policies and interventions related to this question can be made, additional knowledge regarding the extent of change in physical fitness among older manual workers is needed. Indeed, people in physically demanding occupations are at an 18% increased risk of all-cause mortality compared with their sedentary counterparts (76), which signifies why this area of research is important (**Figure 1-3**).

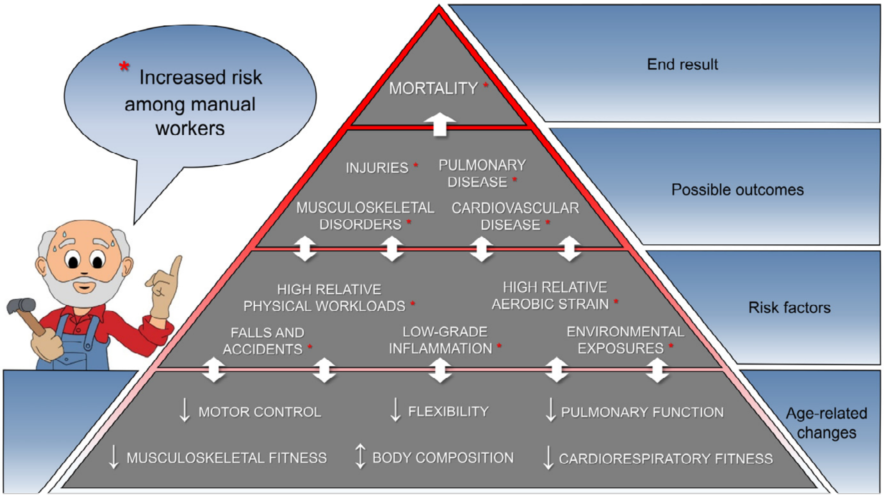

Figure 1-3. Aging and manual work. *Hypothetical pyramidal model of the possible role of manual work on age-related changes in physical fitness that may eventually end in mortality. Figure adapted from* (130) *and based on* (35, 38, 133–138, 42, 76, 77, 83, 100, 123, 131, 132). *Risk factors can be viewed as bidirectional; for example, age-related deficiencies in musculoskeletal fitness leads to higher relative physical workloads that may cause musculoskeletal disorders. Such disorders may increase relative physical workloads even further while also affecting musculoskeletal fitness. The bidirectional arrow besides body composition illustrates the age-associated increase and decrease in fat and muscle mass, respectively. Drawing credited to Øyvind Norheim.*

1.3. AIMS AND HYPOTHESES

The overall aim of this thesis was to investigate physical fitness among manual workers during the last two decades of working life. Further, it aimed to investigate the effects of musculoskeletal complaints on motor control tasks and fatigue development. To accomplish this, five studies were conducted. The aim of Study I was to create a study protocol to enhance transparency and reduce publication bias by selective reporting of research outcomes. The aim of Study II was to investigate the influence of age and stages of musculoskeletal pain (acute and chronic) on force variability during a sustained static contraction. The aim of Study III was to investigate the influence of age and acute musculoskeletal pain on lower extremity function and dynamic balance. The aim of Study IV was to investigate the influence of age on response time, accuracy, and motor control during a hammering task.

Finally, the aims of Study V were to investigate the extent of change in physical performances among older manual workers and to compare physical performances with general populations. This thesis is based on a study protocol (Study I) and four cross-sectional studies (Study II-V) as illustrated in **Figure 1-4**.

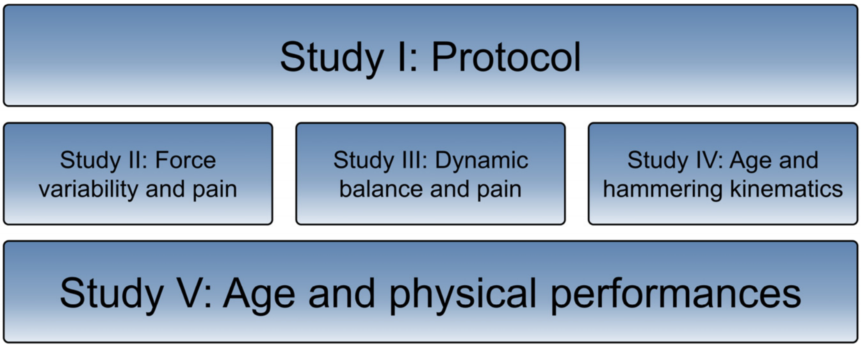

Figure 1-4. Included studies.

It was hypothesized that among manual workers, age would be associated with lower physical performances, larger force variability, poorer function and balance, and impaired response time. Thus, age was generally expected to be negatively associated with physical fitness among manual workers in their last two decades of working life. Musculoskeletal pain was expected to exacerbate the effects of age on motor control tasks and fatigue development.

CHAPTER 2. METHODS

The methodology used for this thesis is briefly outlined in this chapter. See Study I-V for more in-depth descriptions of the methods.

2.1. STUDY OVERVIEW

All experiments were carried out at the Laboratory for Ergonomics and Work-Related Disorders at Aalborg University, Aalborg, Denmark, between November 2017 and May 2019. The specific methods utilized for each of the four cross-sectional studies are presented in **Table 2-1**.

	Study II	**Study III**	**Study IV**	**Study V**
Questionnaire	✓	✓		✓
Blood samples				✓
Heart rate monitor				✓
Force dynamometry	✓			✓
Bioelectrical impedance analysis				✓
Spirometry				✓
Cycle ergometry				✓
Static posturography				✓
Dynamic posturography		✓		
3D motion capture			✓	

Table 2-1. Overview of methods used in Study II-V.

2.2. RECRUITMENT

This thesis was the third part of a larger project concerning older manual workers named the ALFA-project (Aldring og Fysisk Arbejde [Aging and Physical Work]). Given the recent raise in retirement age in Denmark, one of the major aims of the ALFA-project is to investigate attitudes toward retirement among manual workers (60). In Denmark, retirement age will from now on be regulated every five years based on life expectancy and at the inception of the ALFA-project only people born before 1967 were actually aware of the age at which they could retire. This corresponded to an age of 50 years in 2016 when the ALFA II questionnaire was sent out (see next section). The lower age limit for inclusion into the ALFA-project was therefore 50 years. An age-range encompassing two decades and including both current workers and retirees was chosen and the upper limit for inclusion was therefore 70 years (age range 50-70 years). The recruitment process for the ALFA III cohort, on which this thesis is built, has been described previously (Study I). Briefly, ALFA I is a register-based cohort of all citizens born before 1967 who (i) had worked in the construction industry after 1 January 2008, (ii) had been members of the United Federation of

Danish Workers (3F) or other relevant unions for manual workers for at least 2 years, and (iii) were registered in an unemployment insurance fund at the end of 2015. The ALFA II cohort is a randomly chosen sample of workers from the ALFA I cohort who answered a postal or online questionnaire. Workers who in this questionnaire indicated that they would like to participate a clinical examination of physical fitness were screened for eligibility. Exclusion criteria included previous neurological, musculoskeletal or mental illnesses and heart diseases that contradicted physical testing. Eligible workers were contacted first through e-mail and second by telephone when addresses were available. After being informed about the purpose of the study, workers who were still interested in participating were invited to an experimental testing session. Ninety-seven participants successfully arrived at the laboratory and completed the tests thus representing the ALFA III cohort (**Figure 2-2**). These participants were tested 1-2 years after the initiation of the ALFA-project and their age was therefore 51-72 years. Out of these, 66 participants were currently working and 31 participants had retired from a manual profession.

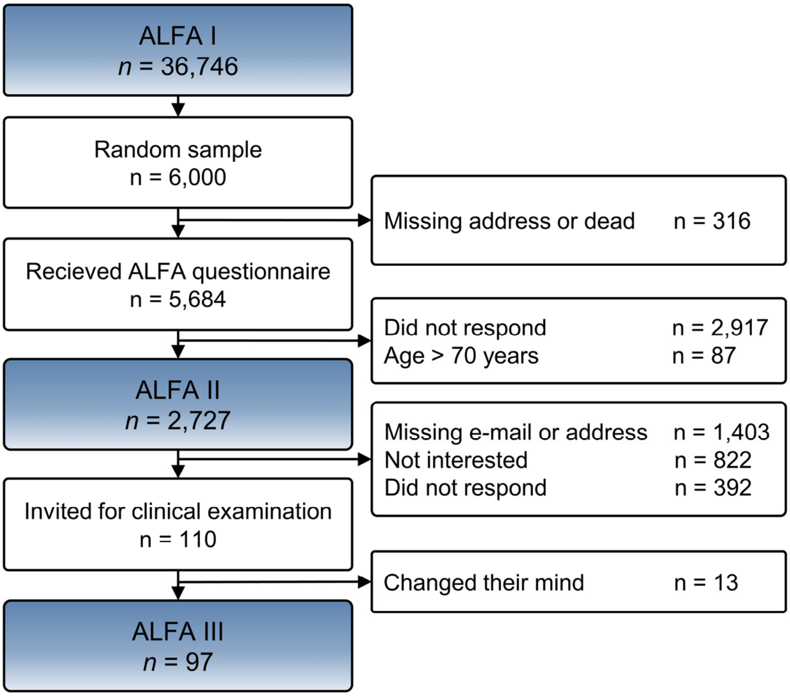

Figure 2-1. Flow chart of recruitment to the ALFA cohorts.

Gender-stratification could not be done in any studies because only one female worker ended up being part of the ALFA III cohort. Only males were therefore included in the analyses of the studies. Thus, in Study II and V, 96 male manual workers from the ALFA III cohort were included. Six participants in the ALFA III cohort did not complete the sit-to-stand (STS) test and Study III therefore includes 90 participants from the ALFA III cohort. In Study IV, only right-handed male participants asymptomatic of musculoskeletal symptoms in the upper extremities (139) were included from the ALFA III cohort (n = 23). Additionally in Study IV, sixteen young right-handed asymptomatic males were included to serve as a comparison group. These participants were staff and students at Aalborg University. Characteristics of the participants within Study II-V are shown in **Table 2-2**. All participants gave written and oral informed consent to participate after being informed about the purpose of the study, which was approved by The North Denmark Region Committee on Health Research Ethics (N-20160023) and carried out in accordance with the Declaration of Helsinki.

	Study II, V	**Study III**	**Study IV**	
			Young	Old
n	96[a]	90[a]	16	23[a]
Age (year)	60.5 ± 5.8	60.4 ± 5.8	29.1 ± 3.1	60.1 ± 5.6
Height (cm)	176.9 ± 6.7	177.0 ± 6.8	178.4 ± 5.8	178.2 ± 5.0
Body mass (kg)	88.0 ± 13.0	87.7 ± 13.1	80.2 ± 11.5	86.5 ± 10.6

Table 2-2. Participants within Study II-V. *Values are mean ± SD.* [a]*Participants of the ALFA III cohort.*

2.3. MEASUREMENTS OF PHYSICAL FITNESS

The methods used to measure physical fitness have been described in detail previously (Study I-V). A brief description of the battery of tests used on the ALFA III cohort follows. The test battery was designed to measure six important domains of physical fitness: musculoskeletal fitness, body composition, cardiovascular fitness, pulmonary function, flexibility, and motor control. The non-randomized order of the test-battery was chosen to ensure as little as possible carryover fatigue from previous tests. To validate this, heart rate (HR) data from 64 participants who wore HR monitors (Polar A300, Polar Electro Oy) throughout the test-battery starting from the pulmonary function test was used to calculate percent HR reserve to represent aerobic workload (140). Additionally, the Borg 6-20 scale (141) was used to assess inter-test ratings of perceived exertion (RPE). Although the length of the test-battery starting from the pulmonary function test varied between participants (mean ± SD, 80 ± 8 min), it was carried out in the same sequence for all participants. Changes in percent HR reserve across 20 time-normalized epochs of the test sequence with accompanying RPE are illustrated in **Figure 2-3**. Prior to the estimated $\dot{V}O_2max$ test, percent HR reserve was < 20%, which in agreement with the RPE corresponds to very light activity (80) and is lower than the occupationally induced aerobic workload seen among manual workers (77).

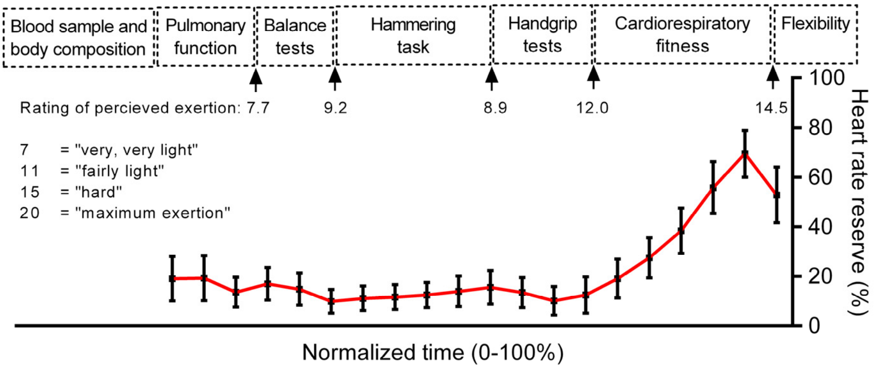

Figure 2-2. Test battery sequence. *Percent heart rate reserve and ratings of perceived exertion between physical tests and for the total test-battery are shown. Note that the heart rate monitor was started after the pulmonary function test. Values are mean ± SD. BIA, bioelectrical impedance analysis; HGS, handgrip strength;* VO_2max*, maximal rate of oxygen uptake.*

2.3.1. MUSCULOSKELETAL FITNESS

A digital hand dynamometer (Model G100, Biometrics Ltd, Gwent, UK) was used to measure isometric maximal voluntary contraction (MVC) force and handgrip endurance in Study V and II, respectively (**Figure 2-4**).

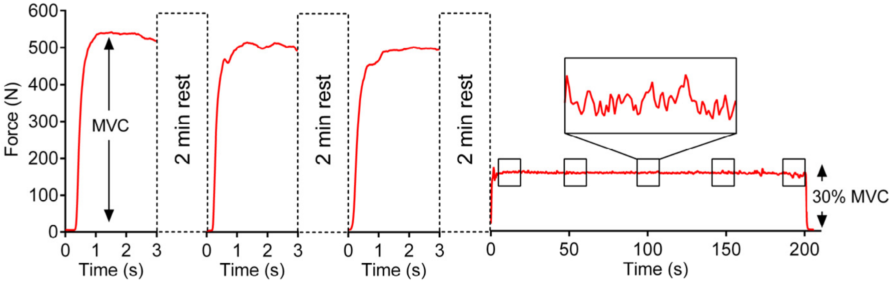

Figure 2-3. Handgrip tests. *Handgrip strength and endurance was included in Study V and II, respectively. Force variability was also included in Study II (see 2.3.6 Motor control). N, Newton; MVC, maximal voluntary contraction.*

For the MVC measurements in Study V, participants were asked to squeeze the dynamometer «as hard as possible» using their dominant hand (142). The highest force measured across three 3-s trials was defined as MVC. For Study II, following these trials, participants performed a fatiguing trial in which they were asked to maintain a force of 30% MVC for as long as possible. Visual feedback of the target force and the output force was provided on a computer screen in front of the participants. The trial ended when the force fell below 28% MVC for more than five consecutive seconds (see 2.3.6. Motor control). Two minutes rest were provided between all trials (142). For Study V, MVC was defined as maximal handgrip strength

(HGS) and was included as a measure of whole-body strength (143). Poor HGS has been related to cognitive impairments and disability (17, 29), mortality (15), and HGS is a reliable measure of muscle strength (144) even in patients with musculoskeletal symptoms (145).

2.3.2. BODY COMPOSITION

A direct segmental multi-frequency bioelectrical impedance analysis (BIA) machine (InBody 370, Biospace) was used to estimate body composition (146). Participants were advised not to exercise 24 h prior to the test and to avoid food intake for at least 2 h before arriving to the laboratory. No fluid intake restrictions were set prior to the test so as not to affect the results of the rest of the test-battery. Participants thoroughly wiped their feet and hands with alcohol swaps before stepping onto the machine. The test duration was ~45 s and imposed no invasiveness or discomfort. In a pilot study (147), we found high intra- and inter-day (48 hours between tests) reliability among 48 university students (age 20-28 years) for both fat percent and FFM (intraclass correlation coefficient > 0.9). Moreover, BIA is generally found to be a valid measure of body composition (148, 149) although less so when trying to estimate individual body compartments e.g. appendicular FFM (150). Thus, the outcomes whole-body FFM and fat percent were included in Study V.

2.3.3. CARDIORESPIRATORY FITNESS

The maximal rate of oxygen uptake ($\dot{V}O_2max$) was estimated using the Åstrand-Ryhming cycle ergometer test (151). Participants cycled on a bicycle ergometer (Ergomedic 874E, Monark AB, Varberg, Sweden) while wearing a Polar A300 HR monitor (Polar Electro Oy). After a brief 8-minute warm-up, resistance was gradually added until HR exceeded 120 bpm. The test was terminated once HR was stable within 4 bpm over a period of 2 min. Cardiorespiratory fitness, expressed as absolute ($L\cdot min^{-1}$) and relative ($ml\cdot kg^{-1}\cdot min^{-1}$) $\dot{V}O_2max$, was estimated from steady state HR and resistance (watt) using the computerized version of the Åstrand-Ryhming nomogram (152). These outcomes were included in Study V. The Åstrand-Ryhming test is widely used in both intervention studies e.g. (153) and large scale cohorts e.g. (154, 155) and seems to be a reliable and valid estimation of cardiorespiratory fitness (156). Although this submaximal test only estimates $\dot{V}O_2max$, maximal exercise tests using indirect calorimetry require extreme degrees of physical exertion and may not be feasible in older populations (157). This was further supported in the ALFA III cohort by eleven of the participants not even being able to complete the submaximal test due to premature exhaustion or musculoskeletal complaints.

2.3.4. PULMONARY FUNCTION

Pulmonary function was measured according to American Thoracic Society/European Respiratory Society guidelines (158). Disposable turbine flowmeters were attached to a Spirobank II SMART spirometer (Medical International Research [MIR], Rome, Italy). From a standing position, participants were instructed to fully inhale followed by a maximal expiration into the spirometer while wearing a nose clip. At least three acceptable trials had to be performed. Acceptable trials were defined by the MIR winspiroPRO software (version 6.5.0), which was used to calculate FEV_1 and FVC from each trial. In accordance with (158), the largest FEV_1 and FVC were recorded from trials independent of each other; that is, FEV_1 could potentially occur in a different trial than FVC. The FEV_1/FVC ratio was calculated from these recordings and together these three metrics were included as outcomes in Study V. A 3 L airtight syringe was used to calibrate the spirometer daily. When carried out according to published guidelines, spirometry is regarded as the gold standard for measuring pulmonary function (158).

2.3.5. FLEXIBILITY

Trunk flexibility was assessed using the fingertip-to-floor test, which is a reliable and valid test even in patients with musculoskeletal symptoms (159, 160). A custom-built box with a vertical beam attached to one side was used (103). The beam had a metal ruler with a movable magnet attached to it. Participants were instructed to stand on top of the box with their feet together and thereafter to bend forward. With their knees, arms, and fingers fully extended, they slowly pushed the magnet attached to the metal ruler down as far as possibly. Jerking movements were not allowed. The distance from the top of the box to the top of the magnet was noted. This distance could be both positive and negative (if pushed below the height of the box) and was included in Study V. Negative values express a larger range of motion.

2.3.6. MOTOR CONTROL

Static balance was measured using a force platform (AMTI AccuSway, Watertown, MA, USA). Participants were instructed to stand as quietly as possible while (i) keeping their eyes fixated on a spot at eye level one meter in front of them, (ii) keeping their eyes closed, and (iii) keeping eyes open and audibly counting out backwards from 30 to 0 by subtracting 3. Each condition lasted for 60 s and for the latter, participants restarted counting from 30 whenever they reached 0. For Study V, only the total mean velocity of sway during the eyes closed condition was included as a single measure to represent static balance in line with (109, 110).

Dynamic balance and lower extremity function were assessed using the five-repetition sit-to-stand (STS) test (161, 162). Participants were instructed to rise from a chair and sit back down «as fast as possible» for five consecutive repetitions with their feet on the force platform. Dynamic balance was expressed as the range, velocity, SD, maximal Lyapunov Exponent (LyE), and SaEn of center of pressure displacement in the anterior-posterior, medial-lateral, and free moment directions. LyE has previously been used in studies to assess postural stability (163) and may be used to identify people at risk of falls (164). SaEn has been used to quantify the complexity of physiological time-series (165) and is influenced by both age and musculoskeletal pain (166). Lower extremity function was expressed as total completion time, stand time, and sit time, as well as the rate of force development (RFD) in the upward and downward movement phases during the STS test. Dynamic balance and lower extremity function outcomes were included in Study III. Total completion time was also included as an outcome in Study V.

For study IV, a «Whack-a-mole» hammering task (Hammertime version 1.0, Aalborg University, Aalborg, Denmark) was implemented to assess response time, accuracy, and shoulder/arm kinematics. Participants stood in front of a computer monitor while holding a rubber mallet. On a table, which was adjusted to 20 cm below elbow height (167), lay a square force platform with nine points. The computer monitor showed a similar square with nine open circles. During the task, one of the open circles on the computer monitor turned black coupled with an auditory cue. The filled black circle randomly changed location every 1.8 s to one of the other nine open circles. Participants were instructed to hit the target on the force platform corresponding to target that turned black on the computer monitor as «quickly and accurately as possible». Active markers attached on the mallet, arm, and thorax of the participants were tracked by the Visualeyez II™ motion capture system set up with two VZ4000 trackers (Phoenix Technologies Inc., BC, Canada). The task lasted 120 s. The «Whack-a-mole» task was also tested on asymptomatic young adults. These participants were tested under the same conditions as the ALFA III cohort. For more details, see Study IV.

Force variability was assessed during the handgrip endurance test. For Study II, the standard deviation (SD), coefficient of variation (CV), and sample entropy (SaEn) of the force signal during the endurance trial was used to measure force variability as described by others (168–171). These metrics were measured over five epochs normalized between participants (**Figure 2-3**).

2.4. BLOOD SAMPLES

Systemic levels of CRP and IL-6 were used to control for inflammatory status in Study V. CRP levels seem unaffected by food intake (172–174), while diverging evidence exists for IL-6 showing either an increase (174) or a decrease (173) in postprandial levels possibly due to sampling procedures (175). However, food restriction in terms of fasting was not imposed to increase the feasibility of the study. Non-fasting venous blood samples were therefore collected from the antecubital vein into 6-mL ethylenediamine tetraacetic acid tubes. Following centrifugation, plasma was extracted and stored at -80 °C until analyzed for CRP and IL-6 levels using enzyme-linked immunosorbent assay kits. High levels of CRP and IL-6 are related to disability and mortality (15–17).

2.5. QUESTIONNAIRE

Answers to the ALFA II questionnaire was used to compare participants in the ALFA II and ALFA III cohorts in Study V. This was done to test the external validity and enable generalization of the clinical findings. Because these answers were more than one years old at the time of the ALFA III examinations, some of the ALFA II questionnaire was repeated for the ALFA III cohort (see Appendix in Study I).

In Study V, questions concerning smoking and leisure-time physical activity (176) were used as covariates. In Study II and III, questions from a modified Danish version of the Standardized Nordic Questionnaire (139) were used to stratify participants according to musculoskeletal symptoms in the upper and lower extremities, respectively.

In Study II, participants reporting > 3 months of pain within the last year while also reporting having a pain intensity > 3 on a scale from 0-10 within the last week in the upper extremities were defined as having chronic pain (177). Those with < 3 months of pain within the last year but who still had > 3 on a scale from 0-10 within the last week were defined as having acute pain. The rest of the participants were defined as having no pain in the upper extremities. This was done because there is evidence to suggest that changes in motor control are dependent on the stage of pain (121, 178).

In Study III, the effect of having pain in the lower extremities at the time of the sit-to-stand test was of interest. Therefore, participants were defined as having pain if they reported a pain intensity > 3 on a scale from 0-10 within the last week, regardless of pain duration within the last year. The robustness of the stratification was assessed by doing sensitivity analyses using both higher and lower levels of pain intensity as cut-off values.

Self-perceived physical work ability was assessed by a single-item question taken from the Work Ability Index (179), as described previously (60). Participants rated their physical work ability on a 5-point scale: poor, fair, good, very good or excellent. Retired workers were asked to respond to this question relating to the physical demands of their last held manual job.

2.6. DEVIATIONS FROM THE PROTOCOL

The aim of Study I was to create a study protocol to enhance transparency and reduce publication bias by selective reporting of research outcomes. However, issues arose after the protocol had been published which led to some slight deviations that warrant justification.

A power calculation was conducted to estimate the number of participants needed to attain a power of 0.8 for detecting a significant predictor variable a multiple regression analysis with either FEV_1 or FVC as the dependent variables and age, smoking status, and height as independent predictors. Based on equation 18 in (180), an estimated number of 102 participants was calculated. This number could not be reached because some of the invited participants changed their mind in the last minute.

RFD–which is a measure of explosive strength–was not calculated from the HGS trials because this measurement is sensitive to test instructions. Specifically, participants were instructed to contract «as hard as possible» because this typically leads to greater peak forces than «as fast as possible»; however, the opposite is found for peak RFD where the emphasis should be on the speed of the execution (142). The true peak RFD value was therefore probably not reached and was therefore not included.

In line with a similar study of force variability during isometric elbow flexion (171), 20% of MVC was considered as appropriate for the endurance handgrip test. Pilot testing indicated that some volunteers were able to hold this force for > 20 min which far exceeded the ~6 min seen in (171). Therefore, a higher force of 30% MVC was chosen as the target force for the endurance handgrip test to increase the feasibility of attaining a measure of performance fatigue rather than perceived fatigue (181).

During the hammering task, the force platform could not be used for reliable estimations of response time and accuracy because the sampling frequency of 100 Hz was too low. The motion capture system was instead used not only to track shoulder/arm kinematics, but also to estimate the hammer trajectory and thereby response time and accuracy.

2.7. STATISTICS

The statistics in the present thesis and within Study II-V were made using SPSS 25.0 (SPSS Inc., Chicago, Illinois, USA) and MATLAB versions R2018a and R2019a (The MathWorks Inc., Natick, MA, USA). In all studies, continuous outcomes were assessed for normality using the Shapiro-Wilk test and were log transformed if the criteria for normality were not met. Statistical significance was considered at $P < 0.05$.

In study II, the aim was to investigate the influence of age and stages of musculoskeletal pain (no pain, acute pain and chronic pain) on force variability. To accomplish this, full factorial analysis of variance models were created using time as the within-subject repeated factor and age and pain stage as between-subject factors. Age was used a fixed factor by dichotomizing between participants aged 50-59 years and 60+ years. The Bonferroni *post hoc* correction was applied for pairwise comparisons of significant factors.

In study III, the aim was to investigate the influence of age and acute musculoskeletal pain on lower extremity function and dynamic balance. A multiple linear regression model fitting the outcome measures was used to investigate the effect of age and pain. Between-subject factors age, pain, age × pain, and additionally work status (working/retired) and work status × pain were fitted to the models.

In study IV, the aim was to investigate the influence of age on response time, accuracy, and motor control during a hammering task. A linear mixed model fitting the outcome measures was used to investigate the effect of age (182). Target was added as a within-subject repeated factor in addition to the interaction term age × target. Subject was used to identify repeated measures and to define a random factor. The Bonferroni *post hoc* correction was applied for pairwise comparisons of significant factors.

In study V, the aims were to investigate the extent of change in physical performances among older manual workers and to compare physical performances with general populations. To accomplish this, linear regression models were created using age as the independent variable and performance outcomes as dependent variables. As suggested by Cole (183, 184), performance outcomes were log transformed and multiplied by 100 to assess the extent of percent change in performance per one-year increase in age expressed as β-coefficients and 95% confidence intervals (CI). This was done to enable comparisons between variables and with other studies. Models were progressively adjusted for covariates height, smoking status, leisure-time physical activity, CRP, and IL-6. The squared semi-partial correlation coefficient was calculated for all predictor variables in the fully adjusted models. Population differences in physical fitness were estimated by comparing outcomes with reference values from the general population of Denmark (185), United States (186), Norway (79), Switzerland (146), and Great Britain (31) using z-scores.

Additional analyses that had only been presented orally or in abstract form (187) were included in this thesis. Related to Study V, this involved analyzing the association between objectively measured physical fitness outcomes and subjectively measured physical work ability. Specifically, cumulative odds ordinal logistic regression with proportional odds was used (60) to assess the odds of reporting greater physical work ability based on these outcomes. Moreover, population differences in trunk flexibility that were not included in Study V are included in this thesis by comparing values with those of a relatively small study from Norway (93) using z-scores. Related to Study III, the interacting effects of age and pain on static balance during the three measured conditions were analyzed. Similar analyses to those in Study III were used, with the addition of a repeated measure analysis of variance to assess the effects of condition.

CHAPTER 3. RESULTS

The main results of Study II-V are presented in this chapter. Additional results that have only been presented orally or in abstract form are included. See Study II-V for more in-depth descriptions of the results.

3.1. HANDGRIP FORCE VARIABILITY AND PAIN (STUDY II)

Chronic and acute upper extremity pain was reported by 24% and 17% of the participants, respectively. Endurance time was 41.3 s longer for participants aged 60+ years compared with those aged 50-59 years. A significant effect of time on SD, CV and SaEn indicated a U-shaped change in SD and CV, and an inverted U-shaped change in SaEn across the endurance trial. No interactions between time × age, time × pain stage, or time × age × pain stage were observed. An age × pain stage interaction was found for SaEn, which revealed that participants aged 50-59 years with acute pain had larger SaEn than both those without pain and those with chronic pain within the same age group (**Figure 3-1**). Differences between age groups were only seen in the no pain and chronic pain groups with higher SaEn values in the 60+ years group. No effects of either age or pain were seen on SD and CV (Study II).

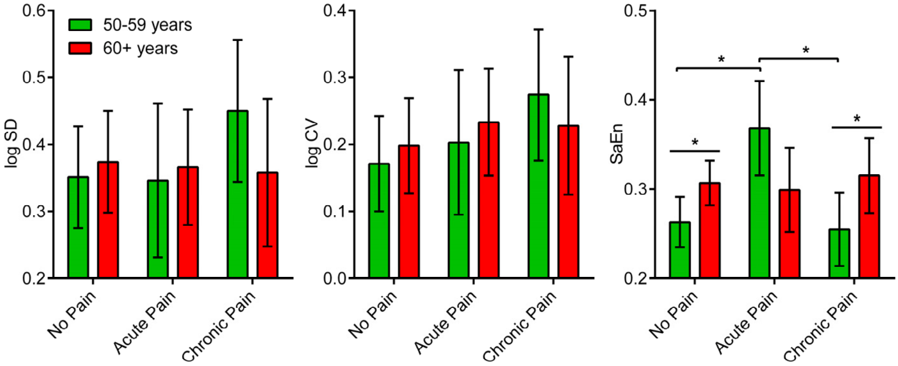

Figure 3-1. Age, pain stage, and handgrip force variability. *Note that SD and CV were not normally distributed and are presented on a logarithmic scale. Values are mean (95% CI). *P < 0.05. SD, standard deviation; CV, coefficient of variation; SaEn, sample entropy. Adapted from Study II.*

3.2. STATIC AND DYNAMIC BALANCE AND PAIN (STUDY III)

Lower extremity pain was reported by 47% of the participants. Interactions between age and pain indicated that lower extremity function was negatively related to age among participants without pain, but positively related to age among those with pain. The effects of work status were similar but generally smaller than the effects of age. Comparable findings were seen for dynamic balance (Study III). Although not included in Study III, analyses into the effect of age and pain on static balance found no age × pain interactions such as those seen for dynamic balance. For example, only a main effect of age was found for the total mean velocity of sway during three different static balance conditions. Notably, all conditions significantly differed from each other with the eyes closed condition showing the largest velocity of sway (**Figure 3-2**).

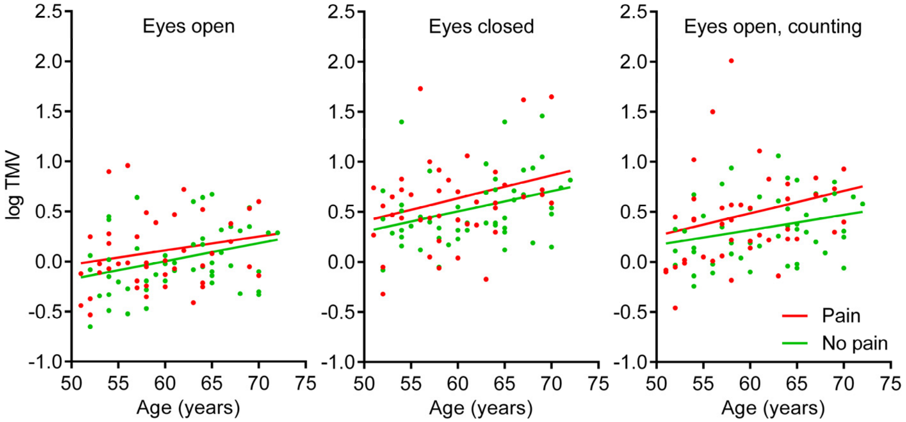

Figure 3-2. Age, pain, and static balance. *Total mean velocity of sway (TMV) during static standing with eyes open, eyes closed, and eyes open while counting backwards from 30 in multiples of three. Note that values were not normally distributed and are presented on a logarithmic scale. Individual values are shown as dots with lines representing linear regression lines for participants with (red) and without (green) lower extremity musculoskeletal pain.*

3.3. AGE AND HAMMERING KINEMATICS (STUDY IV)

The older manual workers had response times about twice that of the young participants as illustrated by none of the mean response times overlapping between age groups (**Figure 3-3**). No marked differences in hammering accuracy were observed. Despite these findings, the old participants utilized a hammering strategy wherein they had less hammer displacement and shoulder range of motion, effectively decreasing the biomechanical load (Study IV).

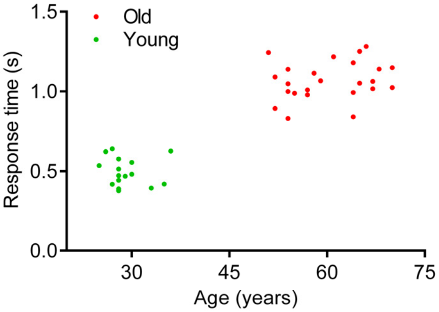

Figure 3-3. «Whack-a-mole» response times for young and old participants. *Mean values across all nine targets are shown for each individual. Adapted from Study IV.*

3.4. AGE AND PHYSICAL PERFORMANCES (STUDY V)

Demographics of the ALFA II and ALFA III cohorts did not markedly differ except for a greater proportion of bricklayers in the latter cohort (Supplementary material in Study V).

For most aspects of physical fitness, a negative association was found with age except for static balance for which a positive association indicated larger postural perturbations (poorer balance) with aging. In the fully adjusted models, age explained only a small part of the variance in fitness, whereas a larger part was explained by smoking and CRP. An illustration of the results from the simple linear regression analyses can be seen in **Figure 3-4**.

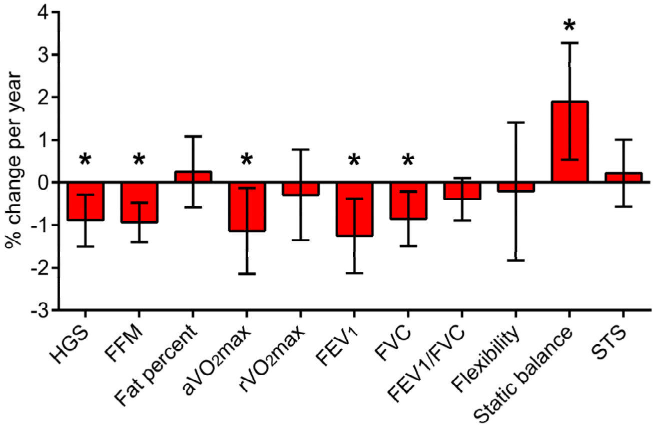

Figure 3-4. Estimated percent change in physical fitness based on age. *Values are β-coefficients with 95% CI. *P < 0.05. HGS, handgrip strength; FFM, fat-free mass; VO2max, maximal rate of oxygen uptake; FEV1, forced expiratory volume after 1 s; FVC, forced vital capacity; STS, sit-to-stand. Adapted from Study V.*

Comparisons with reference populations indicated that the included manual workers had higher BMI, HGS, FFM, and fat percent, but lower FEV_1/FVC and both absolute and relative $\dot{V}O_2max$ (Study V). Moreover, trunk flexibility was poorer for both the 50-59 years (z-score 6.05, $P < 0.05$) and 60-69 years (z-score 7.45, $P < 0.05$) age groups when compared with reference values from Norway.

An increase in FFM was associated with a decrease in the odds of reporting excellent physical work ability among participants aged 50-59 years. Contrary, an increase in HGS, FFM, absolute $\dot{V}O_2max$, FEV_1, and FVC was associated with an increase in the odds of reporting excellent physical work ability, whereas increased fat percent and flexibility (larger values express poorer flexibility) was associated with decreased odds of reporting excellent physical work ability among participants aged 60+ years (**Figure 3-5**).

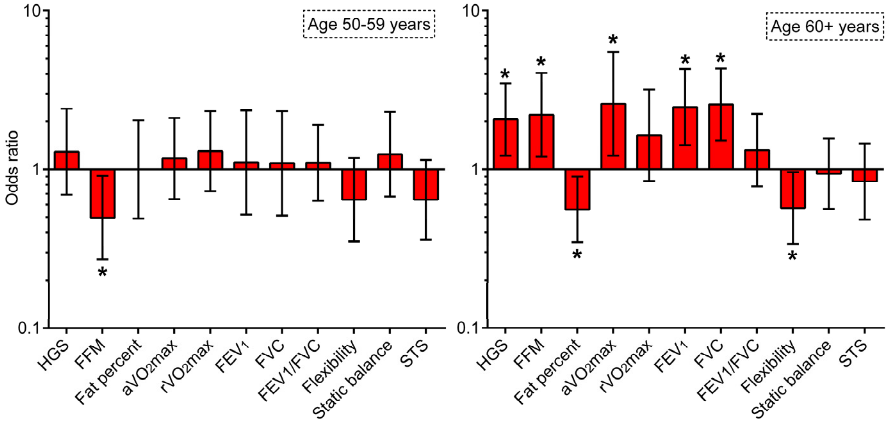

Figure 3-5. Physical work ability and physical fitness. *Shown are odds ratios (95% CI) of reporting greater physical work ability based on z-scores of physical fitness outcomes. *P < 0.05. HGS, handgrip strength; FFM, fat-free mass; VO_2max, maximal rate of oxygen uptake; FEV_1, forced expiratory volume after 1 s; FVC, forced vital capacity; STS, sit-to-stand.*

3.5. SUMMARY OF MAIN RESULTS

An overview of the main results from Study II-V is presented in **Figure 3-6**. Overall, negative associations were seen between most of the measured items of physical fitness and either age, manual work, or musculoskeletal pain.

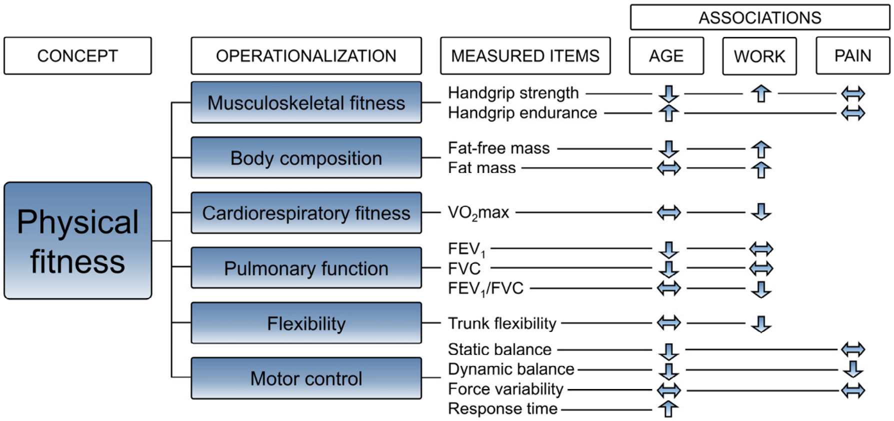

Figure 3-6. Overview of the main results from Study II-V. *Associations denotes the isolated relationships between age, work (manual workers vs. general populations), or pain (musculoskeletal pain) on the measured items of physical fitness. Downward, upward and horizontal arrows represent positive, negative, and no marked associations, respectively. For example, handgrip strength was positively associated with age; manual workers were stronger than general populations; and musculoskeletal pain had no marked effect on handgrip strength. For static and dynamic balance, downward arrows indicate poorer performances (larger perturbations with age and pain). VO_2max, maximal rate of oxygen uptake; FEV1, forced expiratory volume after 1 s; FVC, forced vital capacity.*

CHAPTER 4. DISCUSSION

Findings of the included studies have been discussed in detail previously (Study II-V). In this chapter, it is attempted to collect all these findings and to compare them against the weight of the evidence already present in the literature. Moreover, a number of mechanisms explaining these findings are suggested followed by some general strengths and limitations of the thesis. Lastly, conclusions are made based on these findings and perspectives and strategies for future investigations are suggested.

4.1. PHYSICAL FITNESS AMONG OLDER MANUAL WORKERS

Aging leads to a decline in physical fitness and exercise training is known to attenuate this change. Based on the findings of this thesis and other studies (75, 76, 188), manual work does not necessarily have the same benefits. A number of mechanisms may explain this conflicting association between physical fitness and either exercise training or occupational physical activity (40).

4.1.1. MUSCULOSKELETAL FITNESS

Handgrip strength was greater and showed a slower rate of decline with age compared with general populations (Study V). Manual workers being stronger than other workers is in agreement with some (35, 43, 99, 189) but far from all studies (36–38, 73, 125, 190–193). Notably, acute or chronic upper extremity complaints had no marked effect on HGS (Study II), indicating that greater strength may not necessarily protect against musculoskeletal symptoms, or reversely that pain may not necessarily affect maximal strength. Handgrip endurance was longer among the oldest workers (Study II) in agreement with other findings using relative loading (194, 195).

Resistance training is currently the most effective way to counteract the negative effects of age on muscle strength (196). Maximal muscle strength is diminished after an acute bout of heavy resistance exercise and following a period of recovery–typically 2-3 days–strength levels return to normal or a higher level (197). If chronic bouts of progressive resistance training are undertaken, maximal strength will increase over time (198). Manual work may differ from this model of adaptation in several ways. First, the acute physiological effects of a workday are currently unknown and probably differ from those of a 1-h resistance exercise session. Second, recovery is usually only from the end of the workday until the beginning of the next (~16 h). Third, resistance is not necessarily progressive; for instance, the weight of a hammer does not change. It thus seems unlikely that manual work increases musculoskeletal fitness similar to resistance training. However, the slow rate of decline with age in muscle strength found in this thesis lends credence to the belief that manual work to some extent may maintain muscle strength. Importantly, whether manual work maintains muscle strength will depend on the work tasks performed. The apparent discrepancy between studies on the effect of manual work on e.g. HGS could therefore be related to the extent of heavy gripping performed in different types of manual work. In other words, a bricklayer may maintain HGS whereas a power line worker may maintain overhead lifting strength (33). It is also possible that people who go into manual professions have a genetic predisposition to physically challenging work by being bigger and stronger than other people are from early adulthood (43). Indeed, if manual workers have a high initial muscle strength it requires much less volume and effort to maintain strength levels (199).

4.1.2. BODY COMPOSITION

Higher BMI was found compared with general populations (Study V) and about 70% of the manual workers were classified as overweight or obese in the ALFA II cohort (60) in agreement with (56). Possible misclassifications due to higher absolute FFM (a proxy for muscle mass) could contribute to this such as seen in very physically active populations (200); however, fat percent was also higher suggesting a relationship between manual work and excess body fat. Contrary to the effect of manual work, age was associated with a decline in FFM, but not related to changes in fat percent (Study V).

Aging leads to changes in body composition including reduced muscle mass and increased fat mass (45). In the short term, changes in muscle and fat mass are primarily regulated through physical exercise and energy balance (201). Whilst resistance training may lead to muscle hypertrophy (202, 203), inactivity and immobilization causes muscle atrophy (204, 205). Thus, similar to muscle strength, there may be a genetic component to older manual workers having higher FFM compared with general populations. Contrary to FFM, fat mass is less affected by exercise. Fat mass decreases under hypocaloric conditions and increases when calories are in excess (206). Although physical activity can increase total energy expenditure, compensatory mechanisms may increase hunger and energy intake thereby maintaining total body mass (201). Consequently, changes in fat mass are typically achieved through dietary intervention. The mechanism by which manual workers seem to have greater fat percent compared with other populations could therefore be differences in dietary patterns. Unhealthy diets often goes in concert with other unhealthy behaviors seen among manual workers such as high alcohol intake and smoking (61, 62).

4.1.3. CARDIORESPIRATORY FITNESS

Although one study has shown a positive association between heavy manual work and higher cardiorespiratory fitness among young workers (43), most other studies indicate that $\dot{V}O_2max$ is not improved by doing manual work (33–35, 57, 73, 77, 78, 99, 193, 207). In lack of prospective studies, it is uncertain whether manual work actually causes degeneration of cardiorespiratory fitness. Nevertheless, there is no compelling evidence to suggest that manual work improves cardiorespiratory fitness and the findings in Study V strengthens this assumption.

The age-related loss of cardiorespiratory fitness can to some extent be mitigated following short but chronic bouts of aerobic exercise (65, 67, 208). Although recommendations for optimal exercise intensities are normally around 65% HR reserve (209), positive adaptations may occur over a wide range of intensities (210). Given that the average aerobic intensity during a day of manual work may be about 25-40% HR reserve (74, 77), some have hypothesized that the intensity during work is insufficient to improve cardiorespiratory fitness (40). However, the minimal threshold intensity for improving cardiorespiratory fitness may be as low as 30% HR reserve for individuals with $\dot{V}O_2max$ values below 40 $ml \cdot kg^{-1} \cdot min^{-1}$ (211). In Study V, $\dot{V}O_2max$ values were generally less than 30 $ml \cdot kg^{-1} \cdot min^{-1}$ similar to findings among construction workers (153), fire fighters (57), and municipal workers with high perceived workloads (73). Based on these findings, it could be speculated that aerobic intensities are indeed not too low and could both maintain and improve $\dot{V}O_2max$. Because this does not seem to be the case, other mechanisms may explain why there does not seem to be a training or maintaining effect of doing manual work on cardiorespiratory fitness–possibly related to duration and recovery (40). Notably, other exposures such as tobacco smoke may also influence $\dot{V}O_2max$ negatively (212). This relationship was not seen in Study V possibly due to a lack of statistical power.

4.1.4. PULMONARY FUNCTION

About 30% of the older manual workers had a pulmonary function below the lower limit of normal for Danish males of similar age and height (Study V). Still, without information about the working environment of the participants only speculations may be made regarding the effect of manual work on pulmonary function.

Considering that exercise has very little effect on the lungs (64, 79), the most effective way to maintain pulmonary function is to avoid environmental exposures such as dust and pollution, and to abstain from tobacco smoke (89). Surprisingly, leisure-time physical activity explained the largest amount of variance in pulmonary function (Study V). This could possibly be due to reversed causation wherein physical activity is lower among those with poor pulmonary function. Because manual workers typically smoke more tobacco than other people (61) and may–depending on the occupation–be exposed to environmental toxins (83), manual work may both directly and indirectly cause degeneration of pulmonary function. Similar to unhealthy diets, it is uncertain why people in physically demanding occupations use more tobacco. Some have suggested that the concern for the negative effects of smoking is reduced because of an omnipresent concern for work related hazards (61). In addition, there may be a socioeconomic gradient to these findings, wherein social inequalities contribute to manual workers engaging in such unhealthy behaviors (213). Therefore, the combination of age-related changes coupled with life-style factors and environmental exposures could potentially explain the poor pulmonary function among older manual workers.

4.1.5. FLEXIBILITY

Trunk flexibility was not associated with age (Study V), which is contrary to that seen in other populations (59, 90–92). Compared with reference values, average flexibility was poorer and resembled that of 70 to 80 year olds (93). Thus, it does not seem like manual work improves flexibility.

Age-related changes in flexibility may to some extent be counteracted by stretching exercise (2). Given that manual work bears little resemblance with stretching exercise, it was not expected that manual work would maintain or improve flexibility. Indeed, some find poorer flexibility among those with high occupational physical workloads compared with those exposed to lower loads (99), whereas others have found no effect of manual work on trunk flexibility (190). The reason for not finding an effect of age on flexibility (Study V) could be that lower levels of musculoskeletal pain in the oldest workers (Study II) mitigated the effects of age. Alternatively, noticeable reductions in trunk flexibility may start as late as in the 70s (93) and the cohort may therefore have been too young to detect such changes.

4.1.6. MOTOR CONTROL

Response times in a task that, at least for carpenters, one might expect to be familiar to older manual workers were twice that of younger controls (Study IV). This could be explained by both a decline in motor control and cognitive processing. Contrary to some findings (106, 214), the amplitude of force variability was not related with age or pain (Study II). Furthermore, similar to STS performance (Study III), the structure of force variability seemed affected by acute pain only among workers aged 50-59 years (Study II). STS performance was moreover poor compared with reference values (Study III) in agreement with (124). The velocity of postural sway was positively associated with age, which possibly indicated more instability among older workers (Study V). Unlike the structure of force variability and dynamic balance, static balance did not seem affected by musculoskeletal pain (findings not reported in Study II-V).

Musculoskeletal pain affects postural control and motor variability (113, 120, 215–217). The lack of a clear effect of pain on static balance and the amplitude of force variability during a static contraction could be due to the relatively low pain levels compared with others (216, 217). For a dynamic task such as rising from a chair, however, musculoskeletal pain levels may be exacerbated compared with static tasks and thereby become high enough to impede performance (Study III). Regarding the effects of age, both static and dynamic motor control tasks seemed affected (Study II-

IV) suggesting global motor performance deficits in these older manual workers (104).

4.2. WORK ABILITY

A somewhat surprising relationship between higher FFM and poorer physical work ability among workers aged 50-59 years was found. The opposite and more expected association was seen for those aged 60+ years. It is possible that in the 50-59 years workers, a large total body mass–regardless of body composition–has a negative effect on work ability. Indeed, the combination of a large body mass and high physical workloads have synergistic negative effects on work ability (56). For the oldest workers, however, age-related changes may have reduced muscle mass to such an extent that having too low levels may start to impose negative effects on work ability. Indeed, it seemed like most aspects of physical fitness were associated with self-perceived physical work ability only after age 60 (187). This could suggest that physical fitness becomes a limiting factor for physical work ability only in the oldest manual workers. The ability to perform the physical demands at work may therefore become difficult with an increase in retirement age. It should be mentioned, however, that beyond physical factors, good work ability relies on both psychological and social aspects not addressed in the present thesis (218). Moreover, given that about half of the workers aged 60+ years had retired, the perception of their physical work ability related to the physical demands of their last held manual job may have changed since retirement.

4.3. STRENGTHS AND LIMITATIONS

To the author’s knowledge, the present thesis provides the most extensive assessment to date of different aspects of physical fitness in manual workers aged 50 years and older. The protocol paper (Study I) and the use of state-of-the-art methods for measuring physical fitness strengthens the findings of this thesis. Given the similarity between the ALFA II and ALFA III cohorts (Study V)–the former being a random sample–the findings are considered to have high external validity towards Danish male manual workers in their last two decades of work. A number of limitations still need to be addressed.

First, the cross-sectional nature of the included studies limits interpretations to associations. The possibility of a healthy worker effect–where only the most physically fit workers remain in the workforce–could have underestimated changes in physical fitness. However, by including both current workers and retirees, this effect was probably reduced. This was supported by no marked differences between the demographics of the ALFA II and ALFA III cohorts (Study V).

Second, stratifications based on profession was not done in any of the studies due to the relatively small sample size. Potentially interesting differences between workers with e.g. high upper- vs. lower-body physical exposure was therefore missed.

Third, the effects of gender could not be addressed, which limits the generalizability of the findings. It was attempted to recruit both men and women, but only one woman was tested as a part of the ALFA III cohort. However, a similarly small proportion (2%) of the ALFA II cohort were women (Study V, Supplementary Information) suggesting that this represents the current landscape in terms of gender distribution among older manual workers in Denmark.

Lastly, it is acknowledged that the concept of «age» varies depending on its preceding adjective–e.g. psychosocial, organizational, biological (1)–and that in the current thesis, *age* was defined only as chronological age (time since birth). Other definitions may have yielded results different to those presented here.

4.4. CONCLUSIONS

The present thesis sought to address the issue of an aging workforce. Specifically, physical fitness among manual workers during the last two decades of working life was investigated.

Study I set the scene for the thesis as a whole. Results from Study II demonstrated that age and the stage of musculoskeletal pain differentially affects the structure of handgrip force variability in manual workers. Study III showed an age-dependency on the effects of musculoskeletal pain on lower extremity function and dynamic balance. Study IV found that response times during a hammering task were markedly slower for older manual workers compared with younger controls, which was not accompanied with differences in accuracy. Finalizing the thesis, results from Study V indicated that physical fitness deteriorates with aging in manual workers. Greater handgrip strength and body size, but poorer cardiorespiratory fitness and pulmonary function was found compared with general populations.

In summary, the present thesis indicated that manual workers do not improve their fitness by being in jobs in which they are physically active every day. Especially cardiorespiratory fitness, pulmonary function, and motor control seemed to be negatively affected, whereas handgrip strength may be maintained to some extent in these older workers. Of note, physical fitness was more strongly associated with physical work ability after age 60, suggesting physical fitness as a limiting factor only among the oldest workers. The frame of the findings are limited by the cross-sectional nature of the studies. Hence, no causal conclusions can be made as to whether manual work maintains or degrades physical fitness.

4.5. PERSPECTIVES

Workers in physically demanding occupations report that they could potentially stay longer in the workforce if physical work demands were reduced (219). Ergonomic interventions such as lift-assist devices have been incorporated in several manual occupations and it may not be feasible to reduce work demands further (220). An alternative way to decrease physical workloads could therefore be to decrease total body mass (56)–especially in professions that involve large amounts of locomotion (e.g. waste collection, cleaning, construction work). Considering that 65-70% of manual workers can be classified as overweight or obese (56, 60), weight loss may be a potential target for future interventions among manual workers. Reducing body mass would also improve cardiorespiratory fitness i.e. *relative* ($ml \cdot kg^{-1} \cdot min^{-1}$) $\dot{V}O_2max$.

The «Goldilocks principle» was recently proposed as a solution for promoting health and work ability (221). The principle suggests that work demands should be changed so that workers improve their physical fitness by working. Considering the huge variability in response to exercise (222) and the large amount of variables to be considered for optimal exercise programming even in controlled settings (2, 198, 223, 224), this vision seems unlikely both from a physiological and organizational viewpoint. Well-controlled interventions that actively improves physical fitness may therefore be needed, incorporated into either the workday or leisure. Previous studies have found favorable–albeit moderate–results of workplace physical exercise interventions on physical fitness among some groups of workers (225). In lack of age-stratified studies, it is currently unknown whether such interventions would improve physical fitness among older manual workers specifically. Moreover, a more thorough understanding of the physiological responses to manual work is needed. Investigations into the intramuscular and biochemical effects of a physically demanding workday could potentially help to elucidate whether manual work maintains or deteriorates physical fitness.

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APPENDICES

Appendix 1: STUDY I

Appendix 2: STUDY II

Appendix 3: STUDY III

Appendix 4: STUDY IV

Appendix 5: STUDY V

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