PhD thesis

Health economic analysis of back disorders and inequity: Job exposure, access and income

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To my endlessly supportive husband and wonderful daughters.

Papers in the thesis

This thesis is based on and incorporates text from the following papers:

Paper I

Wiben, A., Skovsgaard, C., Søgaard, K., Schiøttz-Christensen, B., and Olsen, K. R., Tip of the iceberg: unveiling the impact on back disorders from cumulative physical job exposure and evaluating bias from the healthy worker effect using a nationwide longitudinal cohort study. *European Spine Journal*. DOI: 10.1007/s00586-024-08212-x

Paper II

Wiben, A., Skovsgaard, C., Søgaard, K., Schiøttz-Christensen, B., and Olsen, K. R., Assessing physician-driven equity in access to public, free of charge rehabilitation after back disorder. Under review in *The European Journal of Health Economics*.

Paper III

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Abbreviations

CRS	Danish civil registration system
DaRD	Danish spine database/register
D(letter)(number)	Danish version of ICD-10 (version2016)
DiD	Difference-in-differences
DISCO-88	Danish version of the international standard classification of occupation
DOC*X	Database Danish occupational cohort with exposure data
GP	General practitioner
HWE	Healthy worker effect
JEM	Job exposure matrix
NPR	National patient register
PJE	Physical job exposure
SES	Socioeconomic status
VHI	Voluntary health insurance

Dansk resumé

I hele verden er der en stigende forekomst af kroniske helbredsproblemer. Blandt disse er rygsygdomme en af de væsentligste årsager til invaliditet og funktionsnedsættelse. I Danmark blev det i 2017 anslået, at op mod en femtedel af befolkningen levede med rygsygdom. Disse lidelser påvirker ikke blot individets livskvalitet, men har også store økonomiske konsekvenser for samfundet gennem tabt arbejdsproduktivitet og direkte behandlingsomkostninger. Afhandlingen undersøger derfor de socioøkonomiske uligheder og langsigtede konsekvenser forbundet med rygsygdom med fokus på erhvervsmæssige risikofaktorer, adgang til rehabilitering og indkomsttab.

Undersøgelsen er struktureret omkring tre artikler, som belyser forskellige aspekter af rygsygdom. Den første artikel fokuserer på sammenhængen mellem fysisk arbejdsbelastning og risikoen for rygsygdom. Her påvises det, at risikoen for hospitalsdiagnosticerede rygsygdom stiger markant efter blot fire års kumulativ fysisk arbejdsbelastning inden for en tiårsperiode. Samtidig dokumenteres en "Healthy Worker Effect", hvor sundere individer fortsætter i fysisk krævende jobs, mens dem med helbredsproblemer ofte skifter til mindre belastende roller. Dette medfører, at risikoen for rygsygdomme undervurderes i tværsnitsstudier.

Den anden artikel undersøger adgangen til kommunal rehabilitering for patienter med rygsygdom og afslører en tydelig pro-fattig indkomstgradient. Lavindkomstgrupper har større sandsynlighed for at

blive henvist til gratis rehabilitering end højindkomstgrupper, også når der tages højde for behov. Arbejdsgiverbetalte sundhedsforsikringer og højere uddannelsesniveau reducerer sandsynligheden for at anvende offentlige rehabiliteringstilbud, hvilket antyder en præference for private alternativer blandt disse grupper. Resultaterne indikerer, at lavindkomstgrupper prioriteres i det offentlige sundhedssystem, men peger også på potentielle uligheder i tilgængeligheden af private behandlingsmuligheder.

Den tredje artikel analyserer de langsigtede økonomiske konsekvenser af rygsygdomme med fokus på unge voksne i begyndelsen af deres karriere. Resultaterne viser betydelige og vedvarende indkomsttab efter diagnosen. Mænd oplever typisk de største økonomiske tab umiddelbart efter diagnosen, mens kvinder i højere grad påvirkes langsigtet gennem reduceret arbejdsmarkedet tilknytning og øget afhængighed af sociale ydelser som førtidspension. For personer i fysisk krævende jobs er konsekvenserne særligt alvorlige, med markante og vedvarende indkomsttab.

På tværs af artiklerne fremhæves de store udfordringer forbundet med fysisk krævende arbejde. Arbejdstagere i sådanne jobtyper står over for en "dobbelt straf" i form af både øget risiko for rygsygdomme og mere alvorlige økonomiske konsekvenser, hvis de rammes. Derudover peger resultaterne på kønsforskelle i sygdomsforløb og konsekvenser, hvor kvinder i højere grad lider af langsigtet arbejdsmarkedsfrafald, mens mænd rammes hårdere økonomisk på kort sigt, særligt hvis de arbejder i fysisk krævende job.

Afhandlingens resultater kan have politiske implikationer. Forebyggelse kan prioriteres, herunder bedre arbejdsforhold og skræddersyede rehabiliteringstilbud til personer i fysisk krævende roller. Derudover kan kønsforskelle adresseres gennem målrettede indsatser, der kan hjælpe kvinder med at opretholde arbejdsmarkedsdeltagelse og støtte mænds hurtige tilbagevenden til arbejdsmarkedet efter sygdom. Endelig fremhæves behovet for at revurdere politikker som tidlig pension og arbejdsmarkedsrettede reformer, så de i højere grad tager højde for fysisk arbejdsbelastning og dens konsekvenser.

Sammenfattende viser afhandlingen, at rygsygdomme har omfattende og langsigtede konsekvenser for både individers helbred og samfundets økonomi. Ved at belyse uligheder i jobeksponering, adgang til rehabilitering og indkomsttab bidrager forskningen med et fundament for at reducere sociale og økonomiske uligheder samt forbedre arbejdsmiljø og sundhed.

English summary

Across the globe, there is a rising prevalence of chronic health problems. Among these, back disorders have emerged as one of the leading causes of disability and reduced functionality. In Denmark, it was estimated in 2017 that up to one-fifth of the population lived with a back disorder. These conditions not only impact individuals' quality of life but also carry substantial economic consequences for society through lost workplace productivity and direct treatment costs. This dissertation examines the socioeconomic inequalities and long-term consequences associated with back disorders, focusing on PJE, access to rehabilitation, and income loss.

The study is structured around three papers, each highlighting different aspects of back disorders. The first article explores the relationship between physical workload and the risk of back disorders. It demonstrates that the risk of hospital-diagnosed back disorders increases significantly after just four years of cumulative physical workload within a ten-year period. Additionally, a "Healthy Worker Effect" is documented, where healthier individuals remain in physically demanding jobs, while those with health problems often transition to less demanding roles. This effect leads to an underestimation of back disorder risks in cross-sectional studies.

The second article investigates access to free of charge rehabilitation for patients with back disorders based on hospital physician's referral decisions, revealing a clear pro-poor income gradient. Low-income groups are more likely to be referred for rehabilitation than high-income groups,

even when medical needs are accounted for. Employer-paid health insurance and higher education levels reduce the likelihood of utilising public rehabilitation services, indicating a preference for private alternatives among these groups. The results suggest that low-income groups are prioritised within the public healthcare system but also point to potential inequalities in access to private treatment options.

The third article analyses the long-term economic consequences of back disorders, focusing on young adults at the beginning of their careers. The findings show significant and persistent income losses following a diagnosis. Men typically experience the greatest immediate economic losses, while women are more affected in the long term through reduced labour market participation and increased reliance on social benefits such as disability pensions. For individuals in physically demanding jobs, the consequences are particularly severe, with substantial and sustained income losses.

Across the papers, the significant challenges associated with physically demanding work are underscored. Workers in such roles face a “double penalty” of both an increased risk of back disorders and more severe economic consequences if they are affected. Furthermore, the results highlight gender differences in disease trajectories and outcomes, with women more likely to experience long-term labour market detachment, while men are more severely impacted economically in the short term, especially if they work in physically demanding jobs.

The findings of this dissertation carry some policy implications. Prevention could be prioritised, including improving working conditions and providing tailored rehabilitation programmes for individuals in physically demanding roles. Gender differences could also be addressed through targeted initiatives, such as supporting women to maintain labour market attachment and assisting men in returning to work quickly after illness. Finally, it is a possibility to revisit policies such as early retirement and labour market reforms to better account for physical workload and its consequences.

In summary, this thesis demonstrates that back disorders have extensive and long-term consequences for both individuals' health and society's economy. By shedding light on inequalities in PJE, access to rehabilitation, and labour market outcomes, the research provides a possible foundation for addressing social and economic disparities, improving working conditions, and enhancing public health.

Preface

My journey into health economics began during my previous work as a physiotherapist in various locations across Denmark. Through my clinical experience as a physiotherapist, I observed how patients from different regions and with diverse diagnoses received varying treatments. This sparked a growing interest in understanding the factors behind these disparities, which ultimately led me to pursue a master's in health sciences at the University of Southern Denmark. It was during my studies that I was first introduced to health economics by Eva Draborg. I quickly realised that the field extends beyond cost calculations, delving into critical topics such as inequality, prioritisation, and human capital. This discovery set my desire to further explore health economics. After some years in clinical practice as a physiotherapist, my passion for the health economic field led me to a role as a research assistant at the Danish Centre for Health Economics, where I co-authored my first scientific publication. The study focused on the occupational distribution of individuals with incident back disorders, marking the beginning of my PhD journey. Working alongside Christian Volmar Skovsgaard, Berit Schiøtt-Christensen, and Kim Rose Olsen, and later also guided by Karen Søgaard, I developed the PhD protocol that would shape my research. Although I use "I" throughout this thesis, the work presented in the papers has been created in close collaboration with this fantastic team of supervisors.

The focus of this thesis is back disorders, a subject that has driven much of my academic work. As a PhD student in health economics with a clinical background, I have often encountered the challenge of bridging the theoretical and methodological gaps between health sciences and social science research. However, my experience has shown me that the core aim of both fields remains the same: to generate new insights or validate existing knowledge to improve the wellbeing of individuals and society. Despite this shared objective, I have found it particularly challenging to present the results of an analysis in a way that is fully understood and accepted by diverse audiences, co-authors, and especially peer reviewers. Observing readers may therefore notice variations in writing style and terminology across the included papers due to these challenges. Nevertheless, I firmly believe that examining back disorders through the lens of economic theories and methodologies offers a unique perspective that would otherwise be unattainable.

My time as a PhD student has been marked by a steep learning curve, yet it has also been an incredibly rewarding and inspiring experience that has deepened my development as a researcher.

1. Introduction

Most Western countries experience a demographic transition with an aging population and the prevalence of chronic health problems is increasing. Among these, back disorders have emerged as one of the leading causes of disability and reduced function. According to the Global Burden of Disease 2021 study, back disorders are now the foremost cause of global disability (4), and it is estimated that up to one-fifth of the Danish population lived with a back disorder in 2017 (5).

Conditions like back disorders affect not only an individual's quality of life but also a society's overall productivity and economic performance. Health problems generate both direct costs for treatment and rehabilitation (5), as well as indirect costs related to lost work capacity and reduced productivity (6, 7). Understanding the economic consequences of back disorders and identifying effective strategies for prevention, treatment, and rehabilitation is therefore essential (8, 9).

There is a strong connection between health and socioeconomic status (SES) and the long-term consequences of back disorders can be severe. Many individuals experience chronic pain that can lead to prolonged absences from work, long-term sick leave, and reduced work capacity. Socioeconomic differences play a crucial role in how this burden manifests, as factors such as education, employment, occupational physical and psychosocial exposures and access to healthcare can influence both the

risk of developing a back disorder and the likelihood of receiving adequate treatment (10).

1.1. Socioeconomic status and health

The socioeconomic gradient in health is one of the most widely reproduced findings in health and social sciences (11). Studies show that this gradient tends to widen during working life and narrow in old age (12). While there is broad consensus on the existence of socioeconomic health differences, there is less agreement about the underlying causes (12-14). Epidemiological literature has traditionally assumed that SES influences health, whereas economists have often explored the reverse hypothesis, suggesting that health issues impact SES (13).

Health economics literature has often implicitly assumed that health events affect all SES groups above the poverty level uniformly. As a result, analyses have primarily compared the health of individuals at the bottom of the SES hierarchy with those above the poverty level, neglecting the broader and graded association between SES and health across all levels of the hierarchy (11). However, this assumption may be too restrictive, as significant heterogeneity in recovery and survival has been documented. For instance, individuals with higher education and greater health literacy are more likely to follow medical advice effectively and have better access to advanced medical technologies, leading to improved health outcomes (15-17). Furthermore, the need for good physical health in a job varies by

SES, as physically demanding jobs are more common among those with lower educational attainment (18, 19).

If there is substantial heterogeneity in how individuals respond to health shocks (a sudden, significant health event that can have substantial consequences on individuals), this could be a key factor in explaining how socioeconomic health differences develop (11). Previous studies have established a relationship between SES and back disorders, but the causal direction remains unclear. It is uncertain whether back disorders are influenced by SES or whether SES determines who develops back disorders (8, 9).

A notable research gap exists concerning the socioeconomic consequences of back disorders, particularly among young adults. Most research on health shocks has focused on conditions like cancer and heart disease, which predominantly affect older adults (20, 21). Limited studies assess the long-term economic impacts of back disorders on young workers, though research has shown that low SES and physically demanding jobs exacerbate the effects of health shocks (12). However, more knowledge is needed regarding income and labour market attachment particularly for the young adults with a potential long working life ahead.

Given the socioeconomic disparities in health outcomes, understanding how occupational factors contribute to the prevalence of back disorders can reveal critical insights into the broader inequalities affecting health and economic productivity.

1.2. Occupation and back disorder

Occupational factors are closely linked to the development and worsening of back disorders, and they can also reflect broader socioeconomic inequalities. Different types of work expose employees to varying degrees of physical strain, which can increase the risk of developing back problems. Jobs that involve heavy lifting, repetitive movements, and prolonged standing are particularly associated with a higher risk of back disorders (22-25). For instance, occupations such as manual labourers, hospital staff, and cleaners working primarily standing and walking have been shown to be associated with high prevalence of back disorders (22, 26, 27).

Individuals with lower levels of education are often employed in physically demanding jobs, limiting their opportunities to transition to less strenuous roles (18, 19). This dynamic can create a “double penalty” for those in physically demanding occupations as they are not only more vulnerable to developing back disorders but may also struggle to find alternative employment if they are affected. This can exacerbate socioeconomic inequalities through a vicious cycle (23).

Despite extensive epidemiological research on risk factors for work-related musculoskeletal disorders, many factors are still insufficiently documented. For back disorders, there is significant evidence of a strong association with physical strain, but accurately defining the boundaries for safe exposure remains challenging (24). National guidelines, such as the Danish Working Environment Authority’s regulations on lifting, pulling, and pushing, classify strain into categories (red, yellow, green), but lack

concrete and measurable thresholds, making it difficult to translate these guidelines into precise workplace practices (28).

Part of the complexity in understanding strain and back disorders arises from the challenges in accurately measuring exposure to physical strain. Many factors, such as weight, frequency, and distance in manual handling, require multiple measurements to assess the overall risk, but also age, gender, health and physical capacity can affect the risk (27). The relationship between physical strain and back disorders is often complex and cannot always be described linearly; the risk appears to be better explained by a U-shaped curve, where both insufficient and excessive activity can increase the risk of back problems (29-31). Moreover, symptoms are often measured as pain rather than specific diagnoses, making it difficult to determine precise exposure levels that lead to illness. Symptoms of back disorders can be periodic and develop over a prolonged period, further complicating the assessment of their temporal progression and the identification of specific injury mechanisms (32).

In epidemiology the link between job type and back disorders is well-documented, but there remain important gaps in understanding the cumulative, long-term effects of physical job demands across different occupations. Existing studies have largely relied on cross-sectional data, which may overlook the progressive impact of physical exposure over time. Additionally, there is limited research on how cumulative physical demands influence back health outcomes and economic consequences, particularly among socioeconomically diverse groups.

When back disorders occur, rehabilitation becomes a critical tool for enabling workers to return to their jobs and maintain their participation in the labour market. However, access to rehabilitation services can be influenced by socioeconomic factors and job conditions, potentially reinforcing inequalities between occupational groups. In Denmark, while near universal healthcare coverage ensures publicly funded rehabilitation services, the existence of private health providers and employer-paid health insurance introduces complexities. These mixed public-private dynamics can impact resource allocation, potentially creating disparities in access based on occupation or SES. Understanding access to healthcare services, beyond mere utilisation, is therefore essential to uncovering and addressing structural inequalities within the healthcare system, particularly in the management of back disorders.

2. Aim and objectives

The overall aim of this PhD project is to develop a deeper understanding of the health and socioeconomic inequities associated with back disorders. This includes examining occupational risk factors contributing to back disorders, socioeconomic disparities in access to rehabilitation, and the long-term consequences for individuals' economic outcomes and productivity. By highlighting both societal and individual implications of back disorders, the project seeks to provide actionable insights for addressing these inequities. This aim is pursued through three papers, each addressing specific objectives as outlined below.

Paper I

This study's primary objective is to assess the impact of **cumulative physical job exposure** on the risk of developing hospital-diagnosed back disorders. Paper I will be summarised in section 8.1.

Paper II

This study's primary objective is to assess whether referral to **publicly provided free of charge rehabilitation** for patients with back disorders based on hospital physician's referral decisions is subject to income gradients conditional on differences in need. Paper II will be summarised in section 8.2.

Paper III

The primary objective of Paper III is to the estimate **long-run labour market effects of early-career health shocks**, specifically focusing on incident hospital-diagnosed back disorder. Paper III will be summarised in section 8.3.

3. Back disorder

The following section covers back disorders, including their definition, causes, and prevalence. It outlines key risk factors influencing back disorders and focuses on prevention and treatment.

3.1. Definition and epidemiology of back disorders

A wide range of factors contribute to back disorders, including genetic predispositions, comorbid conditions, as well as biomedical and psychosocial elements (9). Although various factors influence patients with back disorders, traditional approaches to diagnosis and treatment have largely focused on biomedical aspects, linking specific phenotypes with imaging findings and treatment outcomes (33). Diagnosing and identifying back disorders can often be complex, and definitions of back disorders vary between contexts. In this PhD thesis, back disorders are defined according to the Danish Spine Database (DaRD)(34), where they are described as an incident hospital-diagnosed back disorder, indicated by one or more of the following diagnostic codes: Dm50*, DS13*, DM42*, DM47*, DM48*, DM495, DM51*, DM96*, DM53*, DM54*, DM809C, DM99*. This means that only patients who have been seen within the hospital system are included in this thesis.

In the following sections, back disorders will be discussed in general terms, as no literature was found that aligns precisely with our specific definition. In most of the broader literature, back problems are typically described in broad terms such as pain or disorder, without a distinct diagnosis; however, my articles consistently apply the specific definition based on diagnoses as outlined above. Many of the references focus on self-reported low back pain, which is often non-specific. Although this does not exactly match my definition, I consider the literature relevant and applicable, as nearly half of the individuals included are diagnosed with diagnostic codes that are categorised as 'undefined back pain' (2).

Prevalence

Despite decades of research identifying risk factors and developing preventative and treatment option, the burden of back disorders remains enormous in terms of prevalence and years lived with disability (4). Back disorders, alongside other musculoskeletal issues, present a major public health concern, restricting productivity and placing a considerable socioeconomic burden on society. They are the leading cause of disability worldwide, representing a well-documented and exceptionally common health problem (8). Globally, back disorders are the primary cause of activity limitations and work absences, imposing substantial economic strain on individuals, families, communities, industries, and governments alike. Annually, 15-20% of adults experience back pain, and 50-80% report at least one episode of back pain during their lifetime (35). In 2020, over half

a billion people worldwide were affected by back disorders. Although age-standardised rates have declined slightly over the past thirty years, projections indicate that by 2050, more than 800 million people globally will suffer from back disorders (4). As a result, both the disability burden and associated healthcare costs are expected to continue rising in the coming decades (9). In Denmark, 970,289 individuals reported to have back problems in 2017, contributing to additional costs of DKK 21 million due to lost productivity from workplace absences and premature mortality. Moreover, 38.1% of newly granted disability pensions were awarded for back problems, and 7.5% of all general practitioner (GP) visits were related to these issues (5).

Age and gender

Back disorders affect people of all ages, from children to the elderly (35). Some studies indicate that the incidence of new cases is highest in individuals in their twenties (8), while others suggest that prevalence generally increases with age (5). This pattern suggests that middle-aged adults are more likely to live with back disorders and may experience more frequent, recurrent, or severe episodes. Additionally, one of the strongest predictors of developing back problems is having experienced them previously (36). Therefore, focusing on younger individuals is crucial to support prevention efforts, which can also have long-term benefits for older generations.

Regarding gender, some studies report no difference in back disorder prevalence between men and women (8), whereas others find a higher prevalence among women (4, 5). Accordingly, studies highlight that women tend to experience worse consequences from back disorders than men, even when pain levels are similar. Hoy, Brooks (8) indicate that women are more likely to develop chronic and recurrent back disorders but also more likely to take time off and utilize healthcare service. Thus, the overall picture suggests that while there may not be a significant difference in prevalence between genders, women are likely to be more disproportionately affected, particularly regarding life impact and the likelihood of chronic pain but also more likely to seek help.

3.2. Risk factors

The risk of developing back disorders is multifaceted, encompassing work-related, psychosocial, and individual factors, each contributing in different ways to the likelihood and severity of back-related issues. These factors interact to influence both the onset and progression of back disorders, often in a cumulative manner referred to as a biopsychosocial concept.

Work-related risk factors

Epidemiological studies confirm that certain physical work activities and postures are associated with an increased risk of back disorders, as well as

other musculoskeletal issues (30, 37). Physically demanding jobs, especially those involving heavy lifting, pushing, pulling and carrying or repetitive tasks, are strongly linked to back pain and injuries. Jobs that involve heavy lifting, repetitive movements, and prolonged standing are particularly associated with a higher risk of back disorders (22-25), and in the EU approximately 35% of the employees report that work affects their health, with one in four experiencing work-related back pain (30, 38).

Physical load is assumed to have both an acute and a cumulative effect on the occurrence of back pain. A load that exceeds the failure tolerance of the tissue can cause back pain even if applied just once. However, cumulative load resulting from repeated sub-failure magnitude loads may be even more important as they are much more common exposures. In such cases, back pain is assumed to be the result of repeated application of loads or the long-term application of a sustained load. Moreover, a combination of cumulative and acute loads can also cause back pain (39).

Psychosocial risk factors

Psychosocial factors can also significantly impact the risk and trajectory of back disorders, especially concerning long-term disability and chronic pain. Key factors include low job control, limited social support, high job demands, job dissatisfaction, and poor relationships with supervisors or colleagues (30, 40). While it remains uncertain whether psychosocial factors independently increase the risk of developing back disorders, evidence suggests that these factors can amplify the impact of physical

strain, and they are particularly influential in cases where back disorders lead to sick leave or chronic pain conditions (5). Stress, anxiety, and depression further increase the risk, potentially creating a cycle where both physical and psychological strains perpetuate one another, ultimately intensifying the individual's pain experience (41).

Individual risk factors

Individual characteristics, including age, gender, genetics, and physical fitness, also play a crucial role in the risk of back disorders. Evidence shows that back disorders can vary significantly based on personal capacity, which is influenced by factors like gender, body size, muscle strength, and training state (30). For instance, older adults or those with lower levels of physical fitness may experience higher relative strain from the same occupational tasks than younger, more fit individuals. Women generally report a higher prevalence of back pain than men, potentially due to differences in physical capacity, task requirements, and exposure to certain repetitive or awkward movements (30). Additionally, poor overall health, lifestyle factors such as smoking and obesity, further increase the risk of back disorders, highlighting the complex interaction between individual factors and occupational demands (41).

3.3. Prevention

Preventing back disorders requires a multifaceted approach that extends beyond addressing ergonomic risks alone (37, 42). Although evidence supporting physical workplace training as a preventive and treatment measure for musculoskeletal disorders, including back pain, is strong, the effectiveness of ergonomic improvements by themselves remains limited (43). Danish studies, e.g., demonstrate that workplace-based physical training tailored to specific job roles and individual health profiles significantly reduces pain in the lower back, neck, shoulders, and elbows. These findings suggest that workplaces, with their established infrastructure, play a vital role in preventing both work-related and general musculoskeletal injuries (30).

The limited evidence supporting ergonomic interventions for prevention may be due to a lack of high-quality studies. A European review recommends a broader preventative approach that goes beyond ergonomic factors, incorporating reduced work hours, additional breaks in repetitive tasks, and technical aids to lower strain without reducing productivity (42). E.g., technical aids can reduce strain on the lower back and upper limbs, but interventions solely focused on proper lifting techniques, or the use of supportive back belts etc. show no preventive effects on lower back pain (30, 43). In contrast, more multifaceted studies including ergonomic focus have shown more promising results (44).

In addition to physical interventions, the most effective prevention strategies typically combine organisational, technical, and individual

measures, especially when approached collaboratively with employee input. This participatory approach allows employees and companies to contribute to the intervention process, improving outcomes (42, 45). Interventions should avoid peak loads, minimise prolonged static postures, and include adequate breaks in repetitive tasks to promote recovery. While ergonomic improvements alone may be insufficient, evidence supports that strategies addressing multiple aspects of work and health are more successful in reducing back disorder risks (46).

Given back pain often results from a combination of biological, psychological, and social factors, a multidisciplinary approach is essential for effective prevention. A biopsychosocial framework that considers physical (e.g., exposure and capacity), psychological (e.g., coping strategies), and social (e.g., workplace conditions) factors has been widely endorsed in recent intervention research (30). Such interventions often include ergonomic adjustments, tailored physical training, and cognitive-behavioural strategies for pain management. Employee involvement in designing and implementing these interventions enhances their effectiveness. However, high-quality studies are still needed to further support the effectiveness of this approach, especially regarding cognitive-behavioural components (42).

Recent studies show robust evidence that physical exercise effectively prevents and manages musculoskeletal pain. Danish studies underscore that workplace-based, high-intensity exercise tailored to specific job roles and individual capacities can alleviate pain in various areas, including the

neck, shoulders, and lower back. This "Intelligent Motion" approach, which includes short, frequent, high-intensity sessions conducted on-site, meets the unique needs of diverse job types, from office staff to manual workers (30, 47, 48).

While prevention efforts are primarily implemented in workplace settings, focusing on reducing risk factors and improving physical capacity, these initiatives complement rather than replace the role of the healthcare system in managing back disorders. The included studies in this thesis focus on treatment and rehabilitation, as observed through healthcare databases, which provide detailed insights into diagnoses and interventions but offer limited perspectives on preventive measures. This distinction highlights that while prevention plays a critical role in mitigating the onset of back disorders, the central focus of this research lies within the healthcare system's capacity to treat and rehabilitate affected individuals.

3.4. Treatment and rehabilitation

Treatment for back disorders, especially recent-onset low back pain (LBP), emphasises non-pharmacological approaches as the first line of care. Both the European and American guidelines recommend physical therapy, exercise, and patient education as foundational treatments for non-specific LBP (43, 49, 50). Similarly, the Danish National Clinical Guideline for recent-onset LBP underscores the importance of maintaining usual activity

levels and discourages prolonged rest, encouraging patients to stay as active as possible in daily routines. The guideline also advises against routine imaging within the first six weeks, except where red flags indicate otherwise, to avoid unnecessary procedures and potential overtreatment (43, 51, 52). For early-stage management, the Danish guideline supports supervised physical training and manual joint mobilisation as effective methods to alleviate symptoms. It also suggests that patient education, tailored to the individual's understanding and needs, can empower patients to manage their condition and potentially reduce anxiety associated with back pain (52, 53).

When pain is more persistent or if non-pharmacological methods alone are insufficient, the Danish guideline allows for cautious pharmacological treatment. NSAIDs may be prescribed as first-line medications, with opioids reserved for only the most severe cases or when other options have been exhausted, acknowledging the risks associated with opioids and their limited efficacy for long-term pain management (54, 55).

For patients at risk of developing chronic or recurrent back pain, a multidisciplinary approach that integrates psychological support and rehabilitation is essential to address the complex nature of long-term back disorders (55, 56).

4. Institutional settings

Denmark has an integrated system for healthcare and social care, with responsibilities divided among the state, regions, and municipalities. This organisation creates a cohesive network that ensures broad access to healthcare services and social support, regardless of citizens' economic status. In the following sections, the structure and function of the Danish healthcare and social care systems will be reviewed, with a particular focus on areas relevant to patients with back disorders.

4.1. The Danish healthcare system

The Danish healthcare system is organised across three administrative levels: the state, regions, and municipalities, creating a decentralised structure with regulation and planning at each level. The state is responsible for overarching regulation, supervision, and funding, as well as strategic functions such as quality monitoring, medical education planning, and the distribution of medical specialities within hospitals (57). The regions are responsible for hospitals and for planning and funding some primary care, delivered by privately practising healthcare professionals, including GPs, physiotherapists, and chiropractors. Municipalities handle free of charge rehabilitation, home care, long-term institutional care, dental care for children, and public health (58).

Funding and patient charges

The Danish healthcare system is primarily funded through progressive income taxation, which helps to promote equity in access to healthcare. The system is nearly universal and tax-funded, with most healthcare services, including hospital treatment and GP consultations, being free of charge. However, there are elements of out-of-pocket patient charges, covering around 20% of expenses for services such as dental care, prescription drugs, and private physiotherapy (59).

Private insurance

Voluntary health insurance (VHI) is purchased by approximately 42% of the population to cover patient charges for outpatient medicines, dental care, and other services, while about 32% of the population has supplementary insurance for expanded access to private providers. The growth in VHI uptake has been largely driven by increasing patient charges for certain services and changes to tax regulations for commercial health insurance in 2002 (60). Between 2002 and 2012, VHI payments made by employers were exempt from tax, provided the insurance covered all employees. The declared intention was to supplement rather than replace the tax-funded healthcare system, and to promote patient choice (59). However, as this tax exemption only applied to employer-purchased policies, it could be viewed as an indirect tax subsidy primarily benefiting the employed population. This practice has also raised questions regarding its potential challenge to

the foundational values of equity and solidarity within the healthcare system, as employer-paid insurance allows for enhanced access and shorter waiting times for treatment and rehabilitation services (59).

Primary healthcare

GPs act as gatekeepers within the Danish healthcare system and are often the first point of contact for patients. GPs can refer patients to secondary healthcare if specialised treatment or planned procedures, such as surgeries, are required. In 2017, consultations related to back problems accounted for 7.5% of all GP visits in Denmark, highlighting the high demand for GP services (5). In addition to GPs, privately practising physiotherapists and chiropractors provide services subject to patient charges or partial public funding. The patient charges associated with certain health services can influence patients' choice of treatment method and provider, making health insurance and co-payment models relevant in their decisions (61, 62).

Rehabilitation and pathways

Patients with back disorders in Denmark have different options for accessing treatment and rehabilitation, depending on their resources and preferences. First, patients can choose to visit private physiotherapists or chiropractors directly. This option requires full out-of-pocket payment unless they have a referral from their GP, in which case part of the cost is

subsidised. Second, patients with voluntary VHI may utilise their policies to cover costs associated with private care, including rehabilitation services.

The third route begins with consulting a GP, who assesses the need for further treatment and may provide a referral to hospital care. Following hospital treatment, if rehabilitation is deemed medically necessary (63), patients are referred to free of charge rehabilitation services at the municipality. While this pathway ensures access for all, it may involve longer waiting periods, which can delay recovery.

This multi-faceted system allows patients to choose between private treatment with either full or partial payment, using VHI for faster access, or navigating the free but longer public pathway through GPs and hospitals.

4.2. Social care

In Denmark, all individuals are entitled to equal access to social security benefits. This includes, when applicable, benefits for sick leave and disability pensions, though access to these has seen significant restrictions over the past two decades.

Sick leave benefits

In cases of illness, individuals are eligible for sickness benefits. For the first 30 days, the employer provides these benefits, after which the

responsibility shifts to the local municipality. Sickness benefits are available for a maximum of 22 weeks within a nine-month period, after which the municipality evaluates whether the benefit period may be extended. Over recent years, regulations for sick leave have tightened. Prior to 2008, employers could be reimbursed after two weeks, which was later amended to 21 days. In 2014, this threshold was adjusted to the current 30 days. Additionally, in 2014, the maximum period for receiving sickness benefits was reduced from 52 weeks to 22 weeks. Despite these resent time limits and restrictions, Denmark is still often regarded as a "best-case" scenario, likely representing a lower threshold for the economic impacts of conditions like back disorders on income compared to other developed countries, thanks to the comprehensive Danish social security measures.

Disability pension

In Denmark, individuals may be eligible for a disability pension if their health precludes them from self-sufficiency. However, a reform introduced in 2013 aimed to increase workforce participation and self-support, thereby restricting access to disability pensions. Under this reform, individuals under the age of 40 are generally not eligible for a disability pension; instead, they are offered a work assessment programme lasting one to five years, with the possibility of additional support if required in the longer term. Those over 40 must also complete at least one work assessment programme before being considered for a disability pension.

Benefits provided during these programmes align with standard social assistance rates, which are generally lower than disability pension benefits. Data on disability pensions indicate a rise until the 2013 reform, after which numbers dropped significantly (64). For musculoskeletal conditions, this trend similarly declined post-reform but began to rise again toward the end of 2015. This may suggest that the reform has not fully achieved its objective of reducing the number of disability pensions in this area, possibly only postponing outcomes by placing individuals in work assessment programmes (65). While these provisions support individuals facing various health challenges, the following section focuses specifically on how patients with back disorders navigate this system and the associated implications.

4.3. Back disorder patients in the Danish system

As explained in section 4.1, patients with back disorders in Denmark navigate a system were treatment options span multiple providers. GP consultations are free, but patients often face significant out-of-pocket costs for private physiotherapy and chiropractic care, costs that are higher compared to other conditions where private treatment is not a prerequisite for hospital treatment. Guidelines for back disorders require most patients to attempt treatment in private practice before being referred to hospital care (52, 53), further increasing reliance on VHI. VHI, excluding

Sygeforsikring ‘danmark’, covers 816 million DKK annually for private physiotherapy and chiropractic care, which is more than the amount publicly funded in subsidies following referral from the GP (66).

The burden of disease report estimates over one million additional annual contacts with physiotherapists and chiropractors due to back disorders (5). Despite these high contact rates, only around 12,000 patients were referred to public free of charge rehabilitation services in 2018 (67), Furthermore, back disorders remain a leading cause of disability pensions, accounting for 38.1% of all new awards (5). This highlights both the significant societal and individual impact of back disorders in Denmark.

5. Theoretical framework

5.1. Importance of a theoretical framework

The focus of this thesis is on empirical investigations of the interactions between socioeconomic variables, health, and access to healthcare services. While empirical methods, including natural experiments, have enhanced the ability to establish causal relationships, they often provide answers within a limited context. Theory is therefore necessary, helping to build a broader understanding of the underlying mechanisms that might create health inequalities between socioeconomic groups (68, 69).

My focus is on using the Health Capital Theory developed by Michael Grossman as a framework to discuss the inequality hypotheses in my three papers. The figure 2 below illustrates the inequity dimensions in the papers. The first paper assesses the effect of occupational exposure on the risk of back disorder - i.e. it assesses how SES impact health. The second paper relates to the link between SES and access to health, and the third paper assesses the effect of back disorders health shock on income.

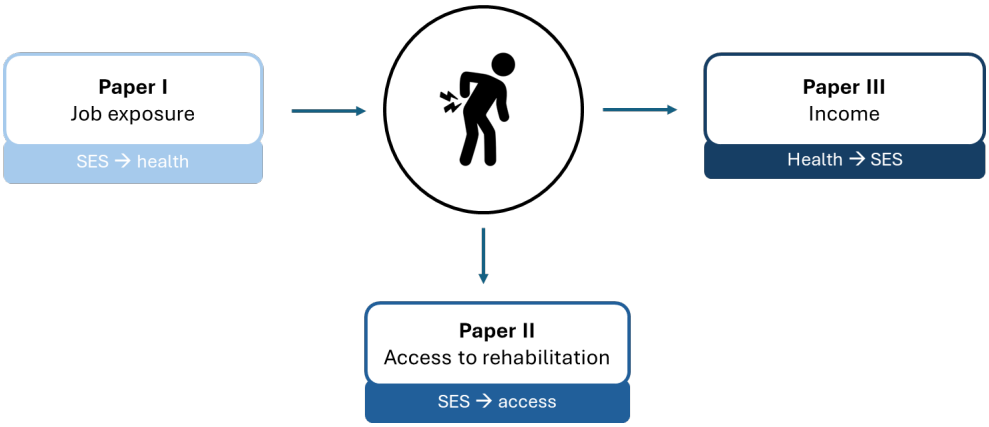

Figure 1: Overview of the PhD thesis.

In the following sections, I will discuss types and definitions of inequality and equity and how they relate to the studies in my thesis. Second, I will present the fundamental health economic framework for the understanding the interactions between health, SES and access to healthcare - the Health Capital Theory developed by Grossmann (70).

5.2. Types of inequality

Chapter 34 in Handbook of Health Economics by Wagstaff and van Doorslaer (68) discusses types of inequality within health systems and how they affect fairness in both the financing and delivery of healthcare services. Further, the chapter highlights that inequality can take many forms, influenced by factors such as SES and geographical location.

Equality vs equity

It is important to distinguish between *equality* and *equity* as two fundamental concepts in the assessment of disparity and the papers of my thesis varies in their focus of these two dimensions. This section will clarify the distinction of the two concepts and discuss how the three papers relate. Equality involves providing the same healthcare services to everyone, while equity considers individual health needs and socioeconomic differences. In a health policy context, the goal of equity is not necessarily to achieve equal allocations but rather to ensure that resources are allocated according to need, promoting fair treatment for all (68).

The primary objective of Paper I is to assess the impact of cumulative physical job exposure (PJE) on the risk of developing hospital-diagnosed back disorders in Denmark. The focus of Paper I is hence on equality of health. By examining whether individuals with varying levels of physical job demands have differing risks of back disorders, this study highlights disparities in health risks associated with job type, but without consideration of fair distribution (equity) in exposure-related health outcomes.

Paper II, which investigates whether referral to free of charge rehabilitation for back disorder patients is subject to income gradients conditional on differences in need, centres on equity. This study specifically assesses if rehabilitation access is distributed fairly across income groups when accounting for individual health needs.

The primary objective of Paper III is to estimate the long-term labour market effects of early-career health shocks, particularly hospital-diagnosed back disorders, and addresses equality by examining whether these health shocks disproportionately affect individuals' career outcomes. However, if results indicate that lower-income individuals face more severe impacts, the study also indirectly highlights equity concerns regarding the differential socioeconomic consequences of health shocks.

Horizontal vs vertical

Another important distinction is between *horizontal equity*, treating individuals with similar health needs equally, and *vertical equity*, which entails adjusting treatment to address differing needs or resources among individuals. This approach helps create a fair health system where both equal needs and varying requirements are effectively addressed, ensuring that resources are used in a way that aligns with the diverse health needs of the population (68).

In all three papers, we examine horizontal equity by assessing whether individuals in similar situations, regarding PJE (Paper I), need for rehabilitation (Paper II), or health shocks (Paper III), are treated equally. Paper II also incorporates vertical equity by analysing whether differences in need justify differences in access to rehabilitation.

5.3. Health Capital Theory

The Health Capital Theory developed by Grossman (70), is rooted in the broader Human Capital Theory by Becker (71), provides a foundational framework for understanding the interplay between health and socioeconomic factors, which is a recurring theme in all three of my articles. Grossman's model posits that health is a form of capital that individuals both invest in and draw upon throughout their lives, similar to financial assets or educational investments (70)

Central to the theory is the concept that individuals care about their utility or well-being, which is dependent on consumption derived from labour income as well as from their health. This results in a trade-off between time spent generating income and time devoted to improving or maintaining health. Individuals face continuous choices on whether to invest in activities that sustain health or to allocate time and resources elsewhere, such as work or leisure. According to Grossman, each person has an optimal level of health investment, which is determined by factors like age, income, and personal preferences (10).

Fundamentally, the theory help explain why people sometimes engage in unhealthy types of consumption or unhealthy types of occupational activities even if this is detrimental to their health (72). Such decisions can reflect a conscious "trade-off" where the benefits of higher income or immediate satisfaction are prioritized over long-term health, a concept known as *disinvestment* in health. E.g., a person may choose a higher

paying but physically more demanding job, accepting that the higher income partially compensates for the health risks involved (73-75).

Health is viewed as both a form of human capital and a critical factor affecting one's ability to work and earn income, which in turn influences SES (10). This two-way relationship highlights health as not only a determinant of socioeconomic outcomes but also as an outcome affected by one's socioeconomic position. The model underscores the complex, mutual relationship between health and SES, showing how health can drive productivity and economic success, which then feeds back into opportunities to further invest in or neglect health (19, 70).

In the following sections, I elaborate on how human capital theory forms the basis for each of my three papers.

Occupational choice and health

Occupational choice and health, as examined in Paper I, can be framed within an expanded view of Grossman's health capital model. Although Grossman's original model did not explicitly consider occupational choices as a factor in health capital, subsequent work by Ravesteijn, Kippersluis and Doorslaer (76), (77) has extended this model to account for how occupational choices might represent a form of disinvestment in health. They argue that individuals may accept harmful occupational exposures in exchange for higher income, a concept also known as the compensating wage differential (73-75).

Ravesteijn et al. further hypothesise that part of this increased income might be reinvested in health to offset the damage caused by occupational exposure. However, within this framework, the healthy worker effect (HWE) may occur when the health deterioration from occupational stressors exceeds what can be offset through additional investments, leaving the individual with limited options, either switching occupations or exiting the labour market. Thus, the hypothesis in Paper I that cumulative PJE increases the risk of back disorder aligns with this expanded Grossman model, incorporating occupational choice as a key determinant of health capital.

Inequity in access

Grossman's Health Capital Theory provides a foundational perspective for understanding how individual health investment decisions are influenced by factors such as income, education, and access to resources. In the context of Paper II, the theory helps explain why individuals with greater economic resources might choose private rehabilitation options or services through health insurance, rather than relying solely on free of charge public rehabilitation services. This preference can be influenced by three main factors:

- Higher health literacy, which enables wealthier individuals to better navigate the healthcare system and identify alternative options (17).
- A greater willingness and capacity to invest in their health (10).
- A desire to avoid waiting times associated with public services (78).

According to this framework, individuals with higher economic resources may thus have different health preferences and access to private insurance, which can lead them to seek alternatives outside the public system, potentially impacting equity in access to public healthcare.

Drawing on this theory, Paper II sets forth three hypotheses regarding socioeconomic gradients in healthcare access. Hypothesis 1 suggests that referral for free of charge rehabilitation may be subject to income gradients, with higher-income individuals more likely to explore private alternatives. Further expanding on the concept of dual public-private healthcare systems, some literature indicates that even in universal systems, income gradients, or disparities in access based on income, can arise due to both financial and social barriers, where individuals with higher incomes may prefer private care, potentially freeing up public resources for those more reliant on them (Besley, Hall and Preston 1999). This dynamic introduces potential inequality in access, as individuals with greater financial means can bypass public systems, indirectly altering the resources available for others.

Building on this, hypothesis 2 proposes that health insurance serves as a mediating factor between income and referral to free of charge rehabilitation, as those with private insurance may bypass public services. Lastly, Propper's "poor services for the poor" proposition suggests that public healthcare systems can risk devolving into residual services primarily used by those without private options, potentially leading to disparities in service quality and accessibility over time (Propper 2000).

Accordingly, hypothesis 3 posits that income gradients in healthcare access persist even when controlling for other socioeconomic factors, such as education and occupation, suggesting that financial means alone, irrespective of other SES indicators, significantly influence healthcare access. This hypothesis aligns with Propper's theory, implying that the presence of private and insurance-based options could exacerbate inequality in access and service quality within the public system. These hypotheses form the basis for investigating how socioeconomic gradients affect access to healthcare services, specifically free of charge rehabilitation for back disorders, in a Danish context. By applying these frameworks from Grossman, Besley, and Propper, I aim to evaluate the impact of income gradients on horizontal equity, allowing for an understanding of how intended universal access may be shaped by socioeconomic differences in practice.

Impact of health shocks on SES

The effect of health shocks on SES, as studied in Paper III, is most directly explained by the health capital model. According to the Grossman model, a sudden decrease in health implies a reduction in health capital, which in turn lowers productivity and impacts SES (10). This is well-documented, with studies often showing immediate decreases in labour supply, income, and productivity following severe health events. However, much of this literature has focused on older adults, where health shocks like cancer, stroke, or heart disease generally occur (20, 79). The economic theory

underlying these studies suggests that health shocks reduce an individual's "health capital", which in turn diminishes their productive capacity and thus their economic output. This effect is intensified for workers with limited educational qualifications and high physical job demands, as they face greater challenges in adapting to non-physical roles after a health shock (12).

The Health Capital Theory assumes that health capital depreciates with age indicating that the stock of health capital may be highest at younger age. It can therefore be expected that experience of a health shock among younger workers bring specific considerations. Younger individuals have more potential working years ahead, which makes the cumulative financial impact of any productivity loss potentially substantial (80). For those in physically demanding roles, such health shocks may limit their ability to return to similar jobs, potentially leading to income reductions and even a shift away from the labour force altogether. Based on this understanding, I hypothesised, in Paper III, that physically demanding work increases the incidence of back disorders, which not only affects health but also exacerbates long-term economic consequences by limiting future employment opportunities and contributing to income inequality among early career workers.

6. Empirical framework

In this chapter, I present the empirical framework used in my thesis trying to investigate relationships between job exposure, back disorder, access to rehabilitation and income. The goal, of my research, has been to provide evidence that can guide policymakers by identifying associations that gets as close to having causal interpretations as possible, where causality is defined as the relationship between a cause (treatment) and its effect on an outcome (81). Reaching causal interpretation in observational studies is difficult and to approach causal inference in the observational studies, carried out in my thesis I have carefully crafted the analytical designs aiming at mitigating the most critical analytical challenges for the primary research question. For Paper I, that assess how PJE affects the risk of back disorder, I have specifically tried to approach the healthy worker bias using accumulated exposure methods. For Paper II, that assess the income gradients in access to free of charge rehabilitation based on hospital physician's referral decisions the focus has been on assuring adequate controls for differences in need while the analytical design of Paper III, that assesses the effect on income of being exposed to back disorder the focus has been on assuring that the back disorder event can be thought of as exogenous. In this section I will start by a short presentation of the main analytical challenges of observational studies followed by a more specific description of the main analytical challenge in each paper and how the chosen analytical design has tried to mitigate these challenges.

6.1. Observational study designs

The gold standard

Randomised controlled trials (RCTs) represent the gold standard for estimating causal effects, as they eliminate confounding factors through random assignment. RCTs ensure that any observed differences in outcomes between treated and control groups are due to the intervention itself, rather than underlying differences between groups. However, RCTs are often not feasible in public health research due to ethical concerns, logistical challenges, or high costs (82, 83). When RCTs are impossible, quasi-experimental designs offer a valuable alternative seen in Figure 3.

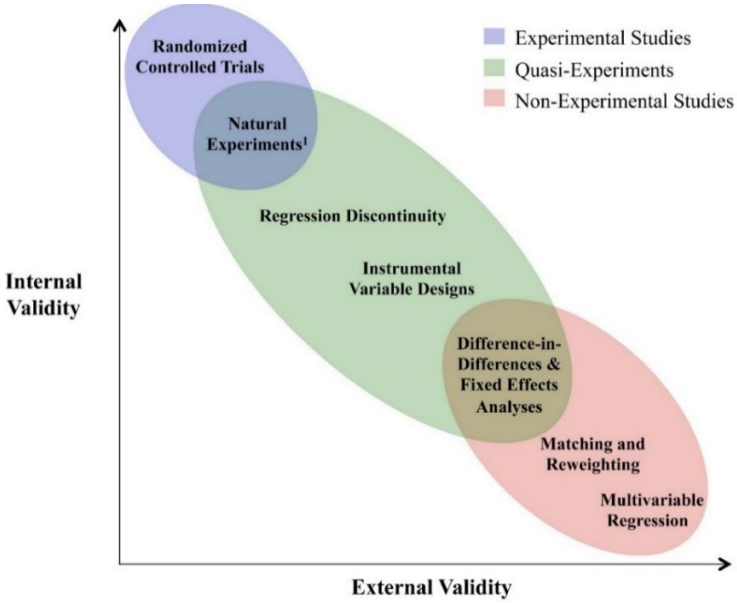

Figure 2: Solutions to the selection problem. Source: Geldsetzer and Fawzi (83)

Quasi-experiments

Quasi-experiments can be defined as observational studies that involve an exogenous explanatory variable which the researcher does not control (83, 84). These studies differ from non-experimental studies in having a higher likelihood that the assumption of no residual confounding holds, and from experimental studies in that participants are not randomly assigned to different treatments (85).

Quasi-experiments, such as difference-in-differences (DiD), allow researchers to approximate experimental conditions by leveraging natural experiments. These methods exploit exogenous events or policy changes that introduce variation in treatment or exposure, mimicking the randomisation process of RCTs. By doing so, they help mitigate selection bias and allow for the estimation of causal effects in settings where randomisation is impossible. While quasi-experiments are not perfect, they often represent the best available option for identifying causal relationships in observational data (83).

Association vs causation

It is crucial to distinguish between association and causation when analysing observational data. While an association between two variables may suggest a relationship, it does not imply that one variable causes the other. This distinction is relevant in all three of my studies, where the aim of the first study is to understand the relationship between PJE and back

disorder, the second to assess access to rehabilitation after back disorder based on hospital physician's referral decisions grounded on SES, and the third to investigate health shocks on labour market outcomes.

A significant challenge to claim causality is reverse causality, where the outcome may affect the exposure rather than the reverse. E.g., individuals with back pain might opt for or be assigned to less physically demanding jobs, potentially distorting the actual relationship between job type and health. Addressing reverse causality requires careful methodological choices to control for these biases. Unobserved confounding is another challenge, as hidden factors (such as health status, lifestyle habits, and personal characteristics) may influence both exposure and outcomes, making it difficult to isolate the true effect of independent variables (e.g., physical workload or income gradients) on dependent variables (e.g., risk of back disorders or access to rehabilitation). Additionally, selection bias further complicates establishing causal relationships across all three papers, as differences in group composition can obscure or exaggerate associations between exposure and outcomes.

6.2. Choice of research design in relation to data and research context

The choice of research design is heavily influenced by data availability and the specific research questions. In my studies, I was constrained by the fact that RCTs were not feasible due to practical constraints. Therefore, I

selected research methods that could mitigate the most challenging analytical problems.

Analysing the impact of physical work on the risk of back disorder

In Paper I the association between PJE and back disorder is assessed. The main analytical problem in Paper I is the HWE, which can lead to bias in assessing the risk of back disorders associated with different types of occupations. To elaborate, the HWE is a form of selection bias that occurs in occupational studies because healthier individuals are more likely to be employed, while those with health issues are less likely to join or remain in the workforce. This bias can lead to underestimation of health risks in working populations, as the study group is inherently healthier than the general population, potentially masking associations between workplace exposures and adverse health outcomes (86).

Numerous studies have explored the association between specific occupations and back disorders, primarily focusing on non-sedentary professions such as health service workers, social workers, and blue-collar workers. These studies generally conclude that employees with a strenuous physical workload face a higher risk of back disorders. However, these studies are often limited by several factors that can cloud the HWE. Firstly, many of these studies rely on questionnaires and small sample sizes, increasing the risk of recall and selection bias. Secondly, a significant

number focus on nonspecific back pain symptoms or self-rated back disorders, which can lead to imprecise diagnoses. Thirdly, only a few studies employ longitudinal data, which is crucial for accurately capturing the HWE and avoiding an underestimation of the risk of back disorders.

To address these study limitations and the potential impact of the HWE, we used logistic regression to calculate the cumulative risks for incident hospital-diagnosed back disorders. This approach allowed us to control for relevant confounding variables, such as age, gender, and higher education, thus helping to reduce bias in the results due to differences across population subgroups. To mitigate the HWE, we took several specific steps: First, we selected a younger population cohort, as younger individuals are less likely to have experienced chronic back disorders and are therefore less likely to have transitioned to sedentary work, reducing potential bias in the findings. Second, we excluded individuals with diagnosed back disorders prior to 2006. Third, persons without a valid job code in 1996 were excluded to ensure they had entered the labour market. Lastly, and most importantly, we used a longitudinal approach, tracking cumulative exposures over a 10-year period to mitigate the HWE.

A remaining analytical limitation of this study is the potential for exposure misclassification, as using the job exposure matrix (JEM) can introduce such errors. JEMs do not allow for individual-level exposure assessment and assume uniform exposure within each job category, which may be problematic as workers in the same role can experience different levels of physical exposure. However, this issue is somewhat mitigated by the wide

range of job-specific average exposures represented in the JEM (87, 88). Another limitation is the lack of data on leisure activities and lifestyle factors, which may influence the risk of back disorders. To address this, we controlled for higher education, as it is associated with healthier lifestyle choices (89, 90).

Analysing the income gradients in access to rehabilitation

The aim of Paper II is to assess the association between access to free of charge rehabilitation after back disorder based on hospital physician's referral decisions and income gradients, thereby indirectly examining whether there is inequality in access. We do this by following the modelling approach of Wagstaff and van Doorslaer (68), which assesses whether persons in equal need of treatment receive similar treatment, regardless of their income. Since need is not clearly defined in Danish legislation, we include several indicator variables that have been found to be clinically important in assessing the need for rehabilitation. These indicators include gender, age, diagnosis, MRI scanning, surgery, use of opioids, and the number of visits to GPs, physiotherapists, and chiropractors.

The main challenge in regression-based tests of inequity in access to healthcare services is to ensure adequate control for need (68). If we fail to control for differences in need for the given healthcare service, there is a risk of wrongly interpreting differences in access as unequal while it is

simply due to differences in need. Hence, the main analytical challenge is one of unobserved confounding. A second challenge is the need for careful consideration of the risk of adjusting for "bad controls" defined as variables that may blur the income gradient. Specifically, it should be carefully considered how controlling for human capital affects the interpretation of the income gradient.

In Paper II, our analytical strategy follows the unconfoundedness assumption, with income as the primary exposure variable that are likely to be confounded by need. Additionally, other literature highlights significant variation across Danish regions (34) so we add regional fixed effects to account for these differences. Further we add measures of differences in need as need is a legitimate source of difference in access. However, there has been a good deal of confusion in the literature about whether to include other variables than proxies for need (68, 91). Variables capturing differences in human capital might on the one hand account for further differences in need not captured directly by the need variables but on the other hand they might be bad controls if they associate with income. Either way results might be biased.

Back disorders are often associated with factors such as education and occupation, which are also significant determinants of income and may therefore serve as potential bad controls. Hence, the income gradients may be confounded, and the study therefore assesses how educational and occupational levels affect the gradients by cautiously include them in the analysis one at a time. Additionally, since income is related to access to

health insurance and some rehabilitation services for back disorders are provided privately, the study examines whether private health insurance may mediate any effects related to income.

It is essential to recognize the analytic limitations of this study, as the model may not fully reflect patient preferences and referral dynamics. Future studies should consider incorporating direct measures of rehabilitation need, quality, and patient preferences. Insights into these factors could enhance the fairness and accessibility of free of charge rehabilitation services for all patients, regardless of SES.

Analysing the effect of back disorder on labour market outcomes

In Paper III, we examine how back disorder impacts labour market outcomes, measured primarily through income. The primary analytical challenge is determining whether the timing of the back disorder as a health shock can be considered exogenous. If the back disorder is not exogenous, it raises concerns about the suitability of DiD as a study design. Furthermore, if back disorders are associated with individuals who have other systematic differences (e.g., low-income occupations), the control group may lack appropriateness.

Although one might expect less exogeneity in back disorders compared to strokes or heart disease, severe back issues in young adults are typically unanticipated and often developing without clear warning signs (8, 9). This

makes back disorders comparable to other sudden health shocks in terms of their unexpected impact on labour market outcomes.

To better capture potential causal effects, we use a staggered DiD design, which leverages the varying timing of health shocks across individuals to create natural variation in exposure. This method allows us to compare income trends over time between those affected at different times and those not yet affected, improving the accuracy of potential causal estimates. By using not-yet treated individuals as a control group rather than never treated individuals, this approach enhances the common trend assumption (12, 92).

Unlike matching approaches, the DiD method reduces bias from time-invariant, unobserved group differences and from unrelated common time trends (93). In Paper III, time-invariant variables may include non-systematic characteristics of back patients, such as genetic factors. Focusing on a younger population may thus be advantageous, as they may not yet be significantly affected by their genetic predispositions as the prevalence rises with age (5). Additionally, reducing bias from common time trends is beneficial, given the extended period covered by the study.

The key assumption, for the DiD model to be valid, is that income trends would have remained parallel between groups in the absence of back disorder. To test this assumption, we apply an event-study, two-way fixed effects (TWFE) model. While traditional TWFE models have been criticised for potential bias (94), we address this by using the XTHDIDREGRESS estimator in Stata 18, which aligns with the CSDID estimator proposed by

Callaway and Sant'Anna (95) thereby accounting for treatment timing differences and providing more reliable estimates.

One remaining analytical limitation of this study is the potential for reverse causality, as early-life back disorders could influence an individual's educational and career trajectory. Therefore, an observed income gradient might not solely reflect SES but could be a consequence of pre-existing back problems. However, this has been accounted for by selecting a young population with no prior history of back disorders and requiring a job code in 2005.

7. Data

The articles included in this thesis are based on Danish registry data stored on RYGDATA:SDU , which contains information from Danish public registers (96) and data from DOC*X, which is a nationwide occupational health database (97).

7.1. RYGDATA:SDU

RYGDATA:SDU is a research data infrastructure focusing on the course, diagnoses and treatment of people, who experience back disorders or consult healthcare professionals after experiencing back disorders, within the Danish primary care sector, hospitals and municipalities. It is a register-based database that contains information from Danish registers, hospital records, etc.

Danish registry data

The registries in RYGDATA:SDU are made available by Statistics Denmark and the Danish Health Data Authority.

In Denmark, there is a long-standing tradition of routinely collecting data on the population's health, demographics, and SES, which is stored in various registries (98). A challenge when working with these data is that most are not collected for research purposes but rather for administrative

functions, such as public health monitoring and resource allocation, but by utilising unique identifications numbers (CPR numbers) (99), which all residents in Denmark possess, the registries can be linked together. Furthermore, since individuals cannot opt out of 'data collection' associated with their CPR number, everyone in Denmark is included in these registries. Table 1 provides an overview of the registries from RYGDATA:SDU used in this thesis.

Some of the key strengths of using Danish registries are that they cover the entire Danish population of approximately 6 million people, offer large datasets, and have a longitudinal nature. Additionally, there is relatively easy access to the data for researchers, as registry-based research in Denmark is exempt from ethical review. Further advantages and strengths of using registry data include that it is prospectively collected, eliminating the need for formal data collection. This reduces confirmation bias and selection bias, such as non-response bias in surveys, and attrition bias, which can occur in RCT studies due to loss to follow-up (98). Despite these numerous strengths, there are also some weaknesses associated with the use of registry data. One limitation is that researchers are restricted to the variables available in the registries, which may result in missing information on important covariates and/or explanatory variables. An example in my case is that registration of full-time equivalent working hours was not introduced until 2008, making it impossible to analyse data on this variable prior to that year.

Table 1: Utilized national Danish registries and examples of content.

Registry	Example of variables	References
Socio demographic		
The Danish Civil Registration System	Age, gender[a], civil status, region and municipality, etc.	(99)
The Income Statistics Register	Disposable income, transfer payments, etc.	(100)
The Population's Education Register	Highest completed level of education, etc.	(101)
Danish Register for Evaluation of Marginalization (DREAM)	Weeks of received social benefits due to disability pension, sick leave, and unemployment, etc.	(102)
Health		
The Danish National Health Service Register	Primary care procedures, treatment expenditures, etc.	(103)
The Danish National Patient Registry	In and outpatient somatic activities, e.g. diagnosis, procedures, bed days, etc.	(104)
The National Prescription Registry (limited)	Number of pain relief prescriptions.	(105)
Non-employee data from E-income (Health Insurance)	Submissions for the annual tax assessment including employer-paid health insurance.	(106)

[a] "Gender" refers to the binary gender as indicated by the individual's CPR number.

Job exposure matrix from DOC*X

As previously mentioned, DOC*X is a nationwide occupational health database that contains information on employment for all Danes from 1964 onwards. It is an open research resource and serves as a platform for occupational health research, knowledge sharing, and unique data access. The database includes information on individuals' year-by-year employment history, based on the Danish version of the International Standard Classification of Occupations (DISCO-88) (97, 107).

In my studies, I have been granted permission to use the job exposure matrix known as the Lower Body Job Exposure Matrix (JEM), which is developed and published in 2014. It is a tool designed to assess mechanical exposures to the lower extremities in epidemiological studies (108). The matrix was developed by five experts in occupational health. Four of them had extensive experience, each with at least 10 years of work in departments of occupational medicine, while the fifth expert was specialising in occupational medicine at the time of development. Together, they developed the Lower Body JEM, where they classified job groups, defined exposure levels, and ranked exposures associated with a wide range of occupational titles.

The development of the JEM followed several stages. The five experts began by reviewing a list of 2,227 occupational titles from D-ISCO 88. They screened the list, removing obsolete or rare titles and identifying those with minimal exposure to the lower limbs. The criteria for minimal exposure included less than 6 hours per day of standing/walking, less than 30

minutes per day of kneeling/squatting, less than 2 hours per day of whole-body vibration, lifting less than 2 tonnes per day, or lifting loads weighing 20 kg or more fewer than 10 times per day. This screening process reduced the list to 689 occupational titles that required further assessment for potential inclusion in the JEM. The experts then grouped the remaining occupational titles into categories based on anticipated similar exposure patterns across five mechanical exposures: standing/walking, kneeling/squatting, whole-body vibration, total daily load lifted, and the daily frequency of lifting loads weighing 20 kg or more. This process resulted in the creation of 121 job groups, each consisting of 1 to 34 occupational titles. Next, the experts independently rated the exposures for each job group, focusing on the average daily duration (in hours) of standing/walking, kneeling/squatting, and exposure to whole-body vibration. They also estimated the total daily load lifted (in kilograms) and the number of times per day that loads of 20 kg, or more were lifted. The JEM was then constructed using the mean values of the experts' final ratings for each exposure variable within each job group. The final JEM comprised 121 job groups, providing quantitative exposure estimates for each group. It is based on the complete set of current job titles from DISCO-88 on one axis, and corresponding ratings of specific lower-body exposures on the other (see Table 2 for examples)(97). To ensure the reliability and validity of the JEM, the researchers conducted several assessments, including inter-rater agreement and face validity. The Lower Body JEM has demonstrated predictive validity for various outcomes, such as the risk of total hip replacement and acute myocardial infarction (109, 110). However,

prior to our studies, it had never been applied to investigate the risk of back disorders.

In this thesis, I have focused on the three objectively measured exposures that the supervisor group and I believe have the most significant impact on the back: total load lifted in kilograms (Total Load), the stand/sit ratio (Stand/Sit ratio), and the number of times lifting more than 20 kg per day (Times > 20). To be classified as an 'exposed,' individuals must have been subjected to all three exposures, as these exposures are highly correlated.

The Lower Body JEM offers several strengths. One of the key advantages is that it provides objective measurements of occupational exposures based on job titles, eliminating the need for subjective self-reporting. This reduces recall bias, which is often a problem in survey-based research or self-reported data. By standardising exposure assessments across job titles, the JEM allows for systematic comparisons between job groups, ensuring data consistency and reliability across different study populations. Another significant strength is that the JEM covers all relevant Danish job titles, making it applicable to the entire population. This enables the analysis of large datasets without the need for detailed individual exposure data. Furthermore, because the JEM was developed by experienced occupational health experts, the validity of the exposure estimates, particularly regarding mechanical strain, is considerably enhanced. Additionally, the JEM can estimate exposures over long time periods using historical DISCO-88 codes, which is especially useful in retrospective studies where data on past exposures may be missing or incomplete.

However, there are also some limitations. The JEM does not account for changes in working conditions over time. If job tasks or environments have evolved significantly, the accuracy of the JEM's estimates may diminish. Another challenge is that the JEM provides estimates based on average conditions within job groups, which does not account for individual variation. Some workers may experience higher or lower exposures than the average for their job title, potentially leading to misclassification bias. Despite these limitations, I do not anticipate significant issues in this thesis, as I am focusing on large populations where group-level averages are more relevant to the analysis.

Table 2: Examples of exposed and non-exposed job titles.

DISCO-88	Job title	Standing/ walking time	Sitting time	Total kg lifted	Number of times lifting 20 kg
Exposed					
D5133	Home care assistant	5.44	2.29	1003.33	9.82
D2223	Veterinarian	4.2	3.8	280	1.4
D7141	Painting	6	1.9	810	6.2
Non-exposed					
D3432	Legal secretary	0	0	0	0

7.2. Ethical considerations

All the papers in the thesis are based on micro-data and analysed at a server on Statistics Denmark. Data are only available for Danish Research Institutions and cannot be shared outside the server. The study complies with GDPR and Danish data security regulations and is approved by the University of Southern Denmark's legal service with list no. 10.107.

8. Summary of papers

The next three subsections provide a summary of the three papers that explore the research questions outlined in section 2. Each subsection offers a brief rationale for the research question, describes the methodology, summarizes the findings, and presents the conclusions. For a comprehensive analysis, the reader is encouraged to refer to the full papers included with the thesis.

8.1. Paper I

Paper I is published in European Spine Journal with the title: "*Tip of the iceberg: unveiling the impact on back disorders from cumulative physical job exposure and evaluating bias from the HWE using a nationwide longitudinal cohort study*" (1).

Introduction

As mentioned in the previous sections, back disorders are a significant public health issue, limiting workplace productivity and placing a considerable socioeconomic burden on society (111). The aim of this study is to investigate the association between cumulative PJEs, measured annually over a 10-year period from 2006 to 2017, and hospital-diagnosed back disorders. Additionally, we hypothesised that a rise in cumulative PJE

would lead to an elevated risk of hospital-diagnosed back disorders. To evaluate the extent of the HWE, we compared the risk associated with cumulative PJE to that derived from simple cross-sectional models.

This study contributes to the existing literature by addressing several key gaps in research on the association between occupations and back disorders. While previous studies have primarily focused on non-sedentary professions such as healthcare workers , social work, and blue-collar industries, and often concluded that higher physical workload is linked to an increased risk of back disorders, our research tackles several limitations in these studies (23, 112-115). We utilize a larger, more comprehensive dataset that minimizes the potential for recall and selection bias. Additionally, by incorporating longitudinal data, we are able to account for the HWE, which has often been overlooked in prior research. Unlike earlier studies that frequently relied on nonspecific back pain symptoms or self-reported conditions, our study uses more precise diagnostic criteria for back disorders, providing greater accuracy. Furthermore, we examine how individuals move from physical demanding occupations over time, offering deeper insights into the risks associated with PJE, thereby giving a more complete perspective on occupational risks for back disorders.

Methods

The study uses data from the Danish registers and the Lower body JEM gathered at the RYGDATA:SDU. It is a longitudinal, nationwide cohort study,

including individuals aged 18–21 in 1996. A younger cohort was selected to minimise healthy worker bias, as they were less likely to have experienced back disorders or switched to sedentary roles to avoid back-related issues. Eligibility required a valid job code (DISCO-88) in 1996 to confirm labour market entry. Individuals with hospital-diagnosed back disorders before December 31, 2005, or who had died or emigrated between January 1, 1996, and December 31, 2017, were excluded. The final cohort comprised 129,179 individuals.

Participants were followed from January 1, 2006, until the first hospital-diagnosed back disorder, retirement, or the study end on December 31, 2017. Over this period, 20,854 back disorder diagnoses (16%) were recorded. To assess the cumulative PJE, we calculated annual exposure values over a 10-year look-back period (2006–2017) with a 1-year lag to capture the long-term relationship between cumulative physical workload, back disorders, and the HWE. Occupational histories from 1996 to 2017 were retrieved from the DOC*X database, with any missing data assigned zero exposure. PJE was derived from DISCO-88 codes, using the Lower Body JEM to assess total load lifted, the stand/sit ratio, and the frequency of lifting over 20 kg per day.

To control for potential confounders that may influence both job exposure and back disorder risk, such as gender, age, calendar year, education, and region of residence, the analysis adjusted for these variables. E.g., age and gender can affect health outcomes, while education and region may influence job type and healthcare access, potentially impacting exposure

and health risks. This approach enhances the accuracy of the relationship between job exposure and back disorders.

A logistic regression model, framed as a discrete-time survival analysis, was applied to estimate cumulative risks for hospital-diagnosed back disorders. These risks are presented as odds ratios (OR), interpretable as hazard ratios, with person-years as the statistical unit. Exposure was assessed using a 10-year retrospective window for each follow-up year from 2006 to 2017, and standard errors were clustered at the individual level to account for repeated measures.

To explore the HWE, three analytical steps were taken. First, the magnitude of the HWE was illustrated by showing the number of healthy survivors in PJE-intensive jobs from 2006 to 2017 for all individuals exposed in 2006. Second, cumulative risk estimates were compared to a naive cross-sectional estimate from 2006. Third, adjusted regressions were conducted for each year in the study period (2006–2017), and robustness checks were performed to confirm the sensitivity of these findings.

Results

The analysis indicates that men (61.1%) are more exposed to physical work than women (38.9%), with notable regional differences, particularly in the capital region. Individuals with secondary education constitute the majority of the exposed group (87.9%), while those with higher education are underrepresented. Cumulative PJE shows an increased risk of hospital-

diagnosed back disorders, peaking after 4 years of exposure (adjusted OR 1.31) before subsequently declining (Figure 4).

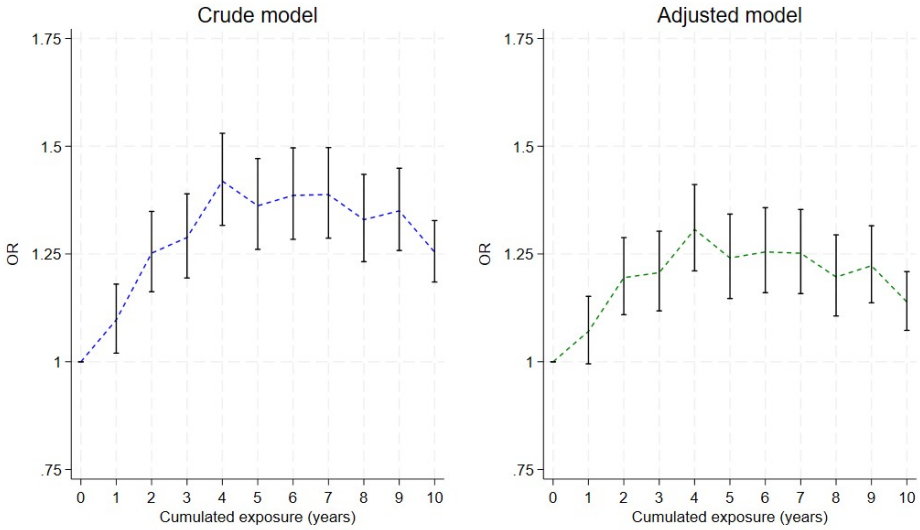

Figure 3: OR of incident hospital-diagnosed back disorder in relation to the cumulated years of PJE.

Over time, two-thirds of those initially exposed to physical work in 2006 had moved to sedentary occupations by 2017, leaving only one-third as "healthy survivors". This shift over time highlights the HWE, where healthier individuals continue in physically demanding jobs.

Ignoring cumulative exposure in cross-sectional models, such as the naive approach from 2006, significantly underestimates the true risk of back disorders. As the population ages and the healthier workers remain in

exposed occupations, the overall risk decreases, but this should be interpreted considering the HWE.

Conclusion

In conclusion, our study shows that the risk of hospital-diagnosed back disorders increases after just four years of cumulative PJE. The longitudinal estimate is four times higher than that of a simple cross-sectional model, indicating that cross-sectional studies significantly underestimate the risk due to the HWE. Longitudinal methods using survey and registry data yield similar estimates, with national registries offering greater accuracy. However, this likely represents only a fraction of the issue. If the same trend applies to nonspecific and self-reported back problems, enhancing physical work conditions could have substantial economic benefits.

8.2. Paper II

Paper II is under review in The European Journal of Health Economics with the title**:** *Assessing physician-driven equity in access to public, free of charge rehabilitation after back disorders (2).*

Introduction

Equity in healthcare, particularly equal access for equal needs, remains a critical issue, even in systems with near universal coverage like Denmark. Back disorders impose the largest disease burden in Denmark, costing approximately 1% of the GDP annually, highlighting the importance of equitable access to rehabilitation. This study investigates income-related disparities in referrals to free rehabilitation for back disorders based on hospital physician's referral decisions, focusing on whether disparities are mediated by employer-paid health insurance and persist after accounting for education and occupation.

This study contributes to the understanding of healthcare inequity by using detailed administrative data to analyse provider-driven disparities, offering a novel perspective compared to traditional utilization-focused research. It highlights how income-related inequities in referrals to rehabilitation are shaped, accounting for confounding factors like education and occupation. The findings provide new insights into the role of physicians and socioeconomic mediators.

Methods

This study utilise data from the Danish National Patient Registry linked with socioeconomic registers. The study population comprises 35,725 individuals aged 18–60 diagnosed with a back disorder in 2018. Access is defined as hospital referrals for rehabilitation, offering a provider-focused

perspective on inequities. Income is classified into tertiles, and need variables, including age, diagnosis, and healthcare utilisation, are accounted for to control for medically justified needs. Mediators such as employer-paid health insurance and confounders like education and occupation are analysed using logistic regression models with regional fixed effects to assess income gradients and potential mediation or confounding effects. Results were presented as odds ratios, with statistical inference based on a 5% significance level.

Results

The analysis revealed a significant pro-poor income gradient in access to free of charge rehabilitation, with individuals in the lowest income group being around 40% more likely to receive referrals compared to those in the highest income group. This gradient persisted even after adjusting for need, education, and PJE. The inclusion of employer-paid health insurance did not notably alter the income effect, indicating it does not mediate the income gradient. However, individuals with employer-provided health insurance and those with higher education levels were independently less likely to access free of charge rehabilitation, suggesting these groups may rely more on private rehabilitation options (Table 3).

Table 3: Income and referral to rehabilitation – results from logistic regression (OR)

	Model 1	Model 2	Model 3	Model 4	Model 5
Low income (reference)	1	1	1	1	1
Medium income	0.819**	0.833**	0.814***	0.874*	0.879*
High income	0.522***	0.545***	0.519***	0.569***	0.596***
Need	Y	Y	Y	Y	Y
Region	Y	Y	Y	Y	Y

Model 1: Adjusted for need and region of residence FE.
Model 2: Adjusted for need, education, and region of residence FE.
Model 3: Adjusted for need, PJE and region of residence FE.
Model 4: Adjusted for need, employer-paid health insurance, and region of residence FE.
Model 5: Adjusted for need, education, PJE, employer-paid health insurance, and region of residence FE.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Conclusion

The findings revealed a pro-poor income gradient, differing from patterns observed in rehabilitation for heart disease and stroke. The results suggest that, given equal needs, hospital physicians are more likely to prioritise individuals with lower income and education levels when making referrals to public rehabilitation programmes.

8.3. Paper III

Paper III is under review at Economics and Human Biology with the title*: Early career health shocks and long-run labour market outcomes (3).*

Introduction

The socioeconomic gradient in health, a well-documented concept in health and social sciences, indicates a strong link between SES and health outcomes. While there is general agreement on the existence of the socioeconomic gradient in health, there is less consensus on the underlying reason for it (12-14). One of the primary challenges in understanding this relationship is the issue of reverse causality: poor health can lower SES, and low SES can lead to worse health. This article focuses on the impact of early career health shocks, specifically back disorders, on labour market outcomes. Early career health shocks are particularly important due to their potential to cause long-term economic consequences given the extended number of working years remaining. This study aims to: 1) examine how back disorders long-term impact income, 2) analyse the channels of income reduction and, 3) explore the influence of physical workload.

This study makes several important contributions to the literature. First, it fills a gap by examining the long-term labour market effects of health shocks among younger individuals, focusing on back disorders, which are less studied compared to other conditions. Second, it highlights the

significant role of physical workload, revealing that individuals in physically demanding jobs face greater income losses and reduced employment opportunities following a back disorder. Third, it provides gender-specific insights, showing that men and women experience differing levels of income reduction and labour market attachment after a health shock.

Methods

We use the same data and cohort as in Paper I. However, the primary change is a shift in focus: instead of requiring a job code in 1996 to enable long-term follow-up, this article centres on the period following the onset of back disorder. Consequently, the inclusion criteria here are that individuals must be 28-31 years old in 2006 (the first year we examine back disorder in both studies, equivalent to being 18-21 years old in 1996). In Paper III, individuals are required to have a job code in 2005, the year preceding the initial risk of hospital-diagnosed back disorder. These subtle differences result in a slightly smaller cohort of individuals with incident hospital-diagnosed back disorder than in Paper I (N=16,017 vs 20,854). The main outcome of interest in this study is total disposable annual personal income, which includes welfare benefits, measured in thousands of euros and adjusted to the 2017 price level. This serves as a proxy for productivity, reflecting an individual's contribution to economic output, with higher income typically indicating greater skills. Additionally, we examine secondary outcomes related to social benefits, including long-term sick

leave (30 days or more), disability pensions, labour force attachment, full-time equivalent working hours, and welfare payments. These variables help us understand how back disorders affect various aspects of an individual's working life and economic standing.

In a subgroup analysis, we investigate the effect of physically demanding work on back disorders, based on job exposure matrices that assess the physical workload of different occupations. This allows us to explore whether individuals with a higher physical workload experience more severe economic impacts from back disorders.

Our methodology employs a DiD approach, using not-yet-exposed individuals as controls to minimise selection bias, with a focus on ensuring parallel trends between groups before the onset of health shocks.

Results

The regression analysis using DiD shows that back disorders lead to a significant long-term income reduction. In the year following the shock, men experienced an income drop of 3-percentage points and women 1-percentage point, increasing to approximately 4.5-percentage point for men and 6-percentage points for women after 8 years. This highlights the long-term impact of back disorders on career trajectories and income levels (Figure 5).

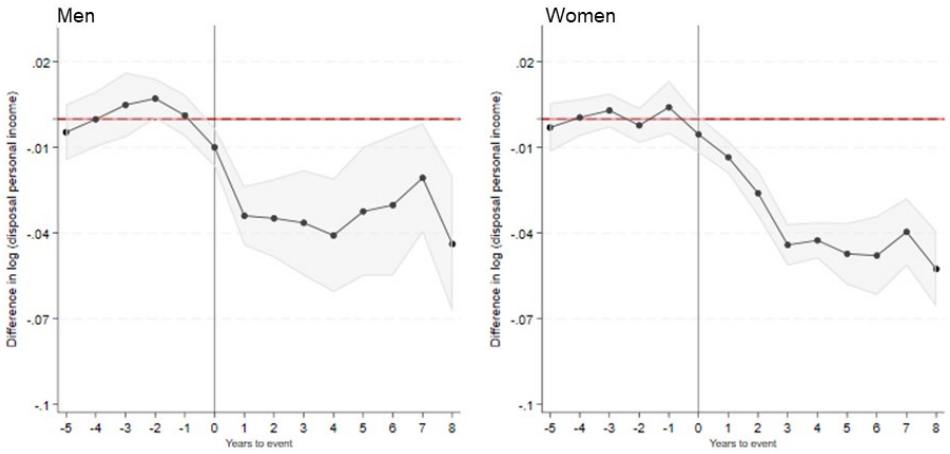

Figure 4: Effects of incident hospital-diagnosed back disorder on disposable personal income: estimates by gender. See full figure description in paper.

Further analysis reveals that long-term sick leave and reduced labour market attachment are significant factors contributing to the observed income loss, with women showing greater declines in both areas. Welfare payments and disability pensions also increased following the shock, especially for women. Moreover, full-time equivalent working hours dropped significantly after the health shock, with men showing a slight recovery after the second year, while women continued to experience declines.

For individuals in physically demanding jobs, the income effects were more severe. Men saw an 18-percentage point income reduction over eight years, while women experienced an 8-percentage point drop by the third year.

This suggests that physically demanding work exacerbates the economic impact of back disorders, particularly for men, emphasising the need for targeted interventions for this group.

Conclusion

In Paper III, we assess the effects of hospital-diagnosed back disorders on disposable personal income. Our findings indicate a significant and growing negative impact on income over the first eight years following the diagnosis. Additionally, we observe differences by gender and physical workload, with the most pronounced effects seen in men and women who work in physically demanding jobs. Considering the long-term consequences of early career health shocks, this prompts the question of whether policies could be introduced to assist affected individuals and their workplaces in adapting post-diagnosis. More targeted support or job retraining immediately after diagnosis may help mitigate the income loss. The findings offer valuable evidence for policy interventions aimed at improving work environments to reduce the socioeconomic impact of back disorders.

9. Discussion

Based on my papers and the introduction, context, theoretical and empirical sections I will provide a discussion on my work in relation to the broader aim of my thesis which was to:

> **"***Develop a deeper understanding of the health and socioeconomic inequities associated with back disorders. This included examining job exposure, access and income."*

The following sections discusses key findings and what the papers contribute with, the strength and limitations of the data and lastly policy implications.

9.1. Key findings and contributions to literature

Examining the results across my papers, several findings emerge that are relevant to a broader discussion. In this section, I will explore the outcomes of my research in relation to gender differences, physically demanding work, and the magnitude of the analysed associations and effects. Additionally, this section will summarise the academic contributions of my work.

Gender differences

Results in this thesis show a clear difference in the burden of back disorder between men and women. 61% of men are found to have physically demanding jobs, compared to only 39% of women. Further, results reveal that men experience a more significant economic impact during the first year after a back disorder, while women face more severe long-term effects. Women generally show a greater decline in labour market attachment and a sustained reduction in working hours compared to men. Additionally, more women receive welfare benefits, and a larger proportion are granted disability pensions. These findings suggest that women are, overall, more severely affected. This aligns with previous studies showing that women generally have higher prevalence of back disorders than men (4). However, men in physically demanding jobs represent a particularly vulnerable group. These findings underscore the importance of focusing on the long-term impacts for women and the immediate challenges faced by men in physically demanding jobs.

Physical demanding work

The findings of my research indicate that exposure to physically demanding work is a stronger risk factor for hospital-diagnosed back disorders than previously recognised. Individuals in physically demanding roles face a significantly higher risk of developing back disorders, and while prolonged exposure (more than four years out of ten) slightly reduces this risk, it

remains higher than for those in non-physically demanding jobs. Importantly, after experiencing a back disorder, individuals with extensive exposure to physically demanding work endure greater income losses compared to their counterparts in less demanding roles. For men, these losses are severe and persistent, whereas for women, income losses stabilise after three years, likely reflecting differences in job types and associated tasks. This suggests a 'double penalty' of back disorders for those in physically demanding roles: both heightened risk of injury and more significant long-term economic consequences.

Interestingly, despite their potentially greater need for rehabilitation to facilitate a return to work, individuals in physically demanding jobs do not appear to face disparities in access to free of charge rehabilitation. This indicates that occupational exposure does not influence physicians' referral patterns, raising questions about whether current rehabilitation practices adequately address the specific challenges faced by those in physically demanding jobs. These findings underscore the need for targeted interventions to mitigate the risks and consequences of back disorders in physically demanding occupations.

Magnitudes of effects

It is of interest to highlight the magnitude of the associations and effects across the papers. Although it is often challenging to determine when an estimated association or effect is large, it seems fair to say that the magnitude of the analysed associations is relatively high. Cumulative PJE

demonstrates a substantial impact, with risks of hospital-diagnosed back disorders exceeding 30% after four years of exposure within a ten-year period. These findings align with those of Jahn, Andersen (116) and prior research linking physical exposure to elevated back disorder risks. The observed decline in risk after prolonged exposure supports the 'healthy survivor effect,' suggesting that healthier individuals tend to remain in physically demanding roles. The inclusion of longitudinal data in the analysis strengthens these findings, mitigating biases such as the HWE.

The socioeconomic dimension also reveals significant disparities. Low-income groups are 40% more likely to receive referrals for free of charge rehabilitation compared to high-income groups suggesting that individuals with lower levels of human capital are prioritised within the public healthcare system. This pattern contrasts with findings in other health areas, such as heart disease, where access tends to favour wealthier individuals (117).

The economic consequences of back disorders are equally notable. Individuals experience an average income loss of 5% eight years after a hospital-diagnosed back disorder compared to unaffected individuals. This loss is more than three times higher for those in physically demanding jobs, highlighting the disproportionate economic burden borne by this group. These findings are consistent with broader research on the global burden of back disorders (4, 5).

Despite the significant magnitudes of the estimates, Denmark can be regarded as a "better case" scenario due to its near-universal healthcare

system and comprehensive social safety net, which includes sick leave benefits and other welfare provisions. This context suggests that our estimates, particularly regarding income loss, may be conservative, as the welfare system helps moderate the immediate economic impact of health shocks.

Academic contributions

Each study makes a unique contribution to the academic literature, focusing respectively on the HWE, access variable, and quasi-experimental study design.

Over 20 years ago, Hartvigsen, Bakketeig et al. (2001) drew attention to the challenges posed by the HWE. Since then, only a few studies have touched upon the concept in their discussions, recognising it as a potential source of bias (118). However, to the best of my knowledge, my work on cumulative PJE is the first to explicitly account for the HWE using a longitudinal design. It provides both longitudinal and cross-sectional results, clearly demonstrating that cross-sectional studies underestimate the risk. Furthermore, the findings reveal that only one-third of individuals in physically demanding jobs remain in such roles after 11 years. These results underscore the importance of adopting longitudinal approaches to accurately estimate the true risk of back disorders following exposure to physically demanding work.

Examining access to rehabilitation, this research adopts a relatively novel approach to studying inequality in access. Historically, such inequalities have primarily been analysed through patients' utilisation of healthcare services (68, 119, 120). However, a key limitation of using utilisation data is that it reflects the combined influence of both provider and patient preferences, making it challenging to disentangle whether inequities are driven by patient characteristics or provider behaviour inequity. By focusing on rehabilitation access as a variable, this study isolates provider-driven disparities from patient-driven factors. While I acknowledge that physicians' referral decisions may still be influenced by patient preferences through their interactions, this approach provides a more nuanced understanding of access. Consequently, it offers new insights that complement and enhance the existing literature on healthcare utilisation.

A key academic contribution of this research lies in the use of the quasi-experimental DiD approach. As elaborated in Section 6.1, the quasi-experimental design represents the closest approximation to a gold standard achievable with register data. By using DiD, this research achieves the strongest possible foundation for causal inference. However, the DiD approach requires that certain assumptions hold, including parallel trends in the pre-treatment period and the exogeneity of the health shock. To demonstrate that severe back disorders serve as a robust health shock, comparable to those used in previous literature, the analysis includes a comparison with AMI, stroke, and breast cancer. Interestingly, the comparison reveals that these conditions exhibit less consistent or similar parallel pre-trends compared to back disorders.

For a health shock to be considered exogenous, it must be unexpected by the individual, even if predictable in a broader sense. Severe back disorders in young adults (aged 28–31) generally meet this criterion, as they develop gradually without clear warning signs, making them largely unforeseen (8, 9). Health shocks such as stroke, heart disease, and cancer are often deemed exogenous due to their unanticipated timing (20, 92). However, selection bias remains a concern when comparing affected individuals to healthy controls. Recent studies address this issue by matching on observable characteristics and employing DiD to control for time-invariant unobservable factors (12, 18, 92, 121-123). Some studies further minimise selection bias by avoiding comparisons with healthy controls. For instance, Lundborg, Nilsson (12) analyse labour market effects within educational subgroups exposed to health shocks. Similarly, Fadlon and Heien Nielsen (92) demonstrate that using not-yet-treated individuals as controls improves the parallel trend assumption and achieves better balance between treated and controls. In adopting this approach, the study also uses the not-yet-treated method to improve comparability between groups. While this strengthens the reliability of the findings, it requires a trade-off in the form of a shorter follow-up period.

9.2. Strength and limitations of the data

Register data

A significant strength of the studies in this thesis is the use of routinely collected data from national registers, which ensure high quality and precision, minimizing bias and providing a robust foundation for analysis, as outlined in the data section (Section 7). The longitudinal nature of the data in Paper I and Paper III further enhances their value by enabling the analysis of changes over time and reducing the risk of reverse causation (124, 125). Additionally, hospital-diagnosed data contribute to robust analyses due to their reliability and focus on more severe cases. However, there are some limitations. The reliance on hospital-diagnosed cases excludes less severe cases, potentially underestimating the overall burden of back disorders. Furthermore, the quality and completeness of data vary across sectors. Municipal rehabilitation data are often incomplete and less reliable compared to regional health data, limiting the ability to include detailed rehabilitation utilization patterns in Paper II (126). Data from primary healthcare and private insurance providers also lack sufficient detail, capturing referrals for private rehabilitation without specifying the conditions or services involved. The register data also exclude individuals who bypass GP referrals and directly access private care, introducing potential selection bias.

Age is an important factor when studying back disorders and focusing on younger workers has both strengths and weaknesses. While back disorders are most common in the 50–64 age group for both men and women (5), Papers I and III focus on younger cohorts. This choice is based on the fact that younger individuals face different challenges. Health problems at a young age can have greater long-term effects because they still have many working years ahead of them (20). Younger workers are also less likely to leave the workforce, which changes how health issues affect their careers (80).

One advantage of studying back disorders is their high prevalence, even in younger age groups. This makes it easier to study health shocks in a group where such events are otherwise rare, filling a gap in current research (20). However, focusing only on hospital-diagnosed cases can be a limitation, as it excludes milder cases. Despite this, the high prevalence of back disorders across all ages makes them a useful case for understanding the long-term effects of health problems on work and income.

Overall, this means that the results of the papers in this thesis are likely underestimated due to a reliance on hospital-diagnosed cases, which exclude milder conditions. While the high-quality and longitudinal nature of the register data provide robust insights, limitations in data completeness and the focus on severe cases suggest that the broader impact of back disorders, particularly among younger cohorts, may be greater than reported.

The lower body JEM

As discussed in Section 7, using JEM can lead to exposure misclassification. However, it provided a unique opportunity to examine occupational exposures in a large population. While the matrix includes multiple exposures, my supervisory group and I selected the three most strongly associated with back disorders based on evidence from prior studies on back disorders (22-25).

A limitation of the matrix is that it has not been specifically validated for studying back disorders. However, it has demonstrated strong predictive validity for other outcomes, such as the risk of total hip replacement and acute myocardial infarction (109, 110), underscoring its robustness. A notable strength of the matrix is the expertise of the team responsible for its development. Comprising five highly experienced experts in occupational exposure quantification, the team ensured a rigorous classification process. Although some variability may exist within specific job groups, group-based exposure assessments are generally resilient to error. According to Berkson and classical error theory, such assessments typically result in little to no attenuation of dose–response relationships, provided individuals are allocated to exposure groups with distinct differences in exposure levels (87, 88). In this study, the range of job-specific average exposures was relatively wide, minimising concerns about misclassification and enhancing the reliability of the results.

9.3. Policy implications

Double or triple penalty of physical demanding work?

The findings from the papers underscore the significant burden of physically demanding work on both health and economic outcomes. Workers in such roles face a substantially higher risk of hospital-diagnosed back disorders and, if affected, experience greater income losses compared to those in less demanding jobs. Despite evidence of pro-poor inequity in access to rehabilitation, there is no indication that individuals in physically demanding jobs are prioritised for these services. This suggests that workers in physically demanding roles may face not only a double penalty but potentially a triple penalty. This includes an increased risk of developing back disorders, long-term consequences for their labour market outcomes, and an additional "penalty" in the form of inequitable access to treatment, making it even harder to return to work. Policies could address this double or potentional triple penalty by improving workplace ergonomics, offering tailored rehabilitation, and helping workers move to less physically demanding roles when needed. Workplace assessments and early interventions could play a key role in reducing both the health and financial impacts of back disorders.

Gender differences: are women worse off?

The studies reveal clear gender differences. Men tend to experience large, immediate income losses after back disorders, especially in physically

demanding jobs. Women, on the other hand, face longer-term challenges such as reduced working hours, weaker labour market attachment, and higher reliance on welfare benefits like disability pensions. Policies could reflect these differences. For men, faster access to rehabilitation and help with re-entering the workforce could ease their financial burden. For women, support should focus on maintaining their labour market connection through flexible working arrangements or retraining opportunities. Special attention should be given to men in physically demanding jobs, who are particularly at risk.

Prevention: reducing the burden of back disorders

Preventing back disorders is crucial to reducing their impact on health and society. The recent Danish healthcare reform provides an opportunity to focus on preventing chronic back disorders. The reform introduces new rights for individuals eligible for chronic care packages, ensuring that they receive a personalised treatment plan within a specified timeframe, as well as timely initiation of treatment and patient-centred preventive care. This is aimed at providing coordinated, high-quality care while equipping individuals with the tools to manage their condition effectively and prevent it from worsening (127). As a result, it is likely that more individuals will seek hospital diagnoses to access the benefits of the chronic care package. However, it remains unclear in the reform how these chronic care packages will be initiated. If they require a hospital-diagnosed condition, this is likely

to further incentivize individuals to seek diagnosis and treatment through the hospital system.

Additionally, the reform proposes access to subsidised private physiotherapy without the need for a GP referral. From an economic perspective, this change may affect supply and demand dynamics by altering market mechanisms and increasing supplier-induced demand. It could also lead to higher healthcare costs, as GPs will no longer act as gatekeepers, reducing transaction costs for patients. On the other hand, this change could facilitate quicker access to treatment for more individuals, potentially preventing severe back disorders and reducing long-term societal and economic burdens. The ambiguity of the effects indicate that it may be important to carefully monitor and evaluate changes in behaviours after changing referral requirements.

Pension reforms: prioritising physically demanding jobs

Denmark's pension reforms from 2020, the 'Arne Pension' and 'Senior Pension' aim to assist workers with extensive years in the labour market or reduced work capacity the chance to retire earlier (128). The findings from the papers highlight the importance of including PJE in deciding who qualifies for early retirement. Workers with long-term exposure to physically demanding jobs could be prioritised, as their health and ability to remain in the workforce are often significantly impacted. However, those

who have managed to “survive” many years in such roles may represent the “healthy survivors” and may not necessarily be as affected as those who were forced to leave the labour market earlier due to poor health. This suggests that using years in the workforce as a measure of wear and tear may not be the most reliable approach. The report from the National Research Centre for the Working Environment supports this, showing that only about 20% of those receiving the ‘Arne Pension’ feel worn down, compared to up to 60% of those on the ‘Senior Pension’ (129). Instead, placing greater emphasis on rehabilitation and retraining could help older workers transition to less physically demanding roles, allowing them to remain in the workforce while protecting their health.

Another pension type in Denmark is the disability pension, which may be granted if a person’s health prevents them from supporting themselves. However, a reform implemented in 2013 significantly restricted access to disability pensions, aiming to encourage as many people as possible to enter the workforce and achieve self-sufficiency. Under the reform, individuals under the age of 40 were generally no longer eligible for a disability pension but were instead required to participate in job testing programmes lasting 1–5 years, with the possibility of extensions for those needing long-term support. For individuals over 40, at least one job testing programme became mandatory before being considered for a disability pension. These programmes provide benefits at the same level as social assistance, which is typically lower than the disability pension benefit. Data from Danmarks Statistik (64) show that disability pension awards increased steadily until the reform in 2013, after which they declined

sharply. This trend was also evident in musculoskeletal disorders, where disability pension awards initially decreased post-reform. However, by late 2015, numbers began to rise again. This pattern suggests that while the reform initially reduced the number of disability pensions granted, its long-term impact may have been less effective in achieving sustained reductions. Instead, the reform appears to have delayed outcomes by extending the time individuals spent in job testing programmes. This suggests that the reform may not have had the intended effect of reducing the number of people on disability pension in this area, but instead may have simply delayed the outcome by keeping individuals in job testing programmes (65). Further analysis of the reform's impact in Paper III, could provide valuable insights into whether its effects were primarily short-term or if they masked deeper structural challenges in addressing back disorders.

10. Conclusion

The findings of this PhD highlight the profound impact of back disorders on individuals' health and labour market outcomes, particularly in the context of socioeconomic disparities and physically demanding jobs. The overarching aim of the research was to understand the long-term consequences of inequity, including the role of physically demanding work, on back disorders and their effects on productivity.

The studies revealed that workers in physically demanding roles face a higher risk of back disorders, compounded by significant income losses if affected. This creates a double or triple penalty, especially as access to rehabilitation services appears inequitable. Gender disparities were also evident, with men facing immediate income shocks and women experiencing longer-term labour market detachment. These findings underscore the need for gender-sensitive policies and interventions that prioritise rehabilitation, workplace adjustments, and retraining.

Furthermore, the results of the analyses highlight potential limitations in current policies such as the Danish pension and healthcare reforms, suggesting the importance of integrating physical workload considerations and enhancing preventative strategies. Together, these results provide a foundation for addressing inequities and developing evidence-based approaches to improve occupational health, reduce socioeconomic disparities, and support workforce participation.

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Appendix

Paper I

Wiben, A., Skovsgaard, C., Søgaard, K., Schiøttz-Christensen, B., and Olsen, K. R., Tip of the iceberg: unveiling the impact on back disorders from cumulative physical job exposure and evaluating bias from the healthy worker effect using a nationwide longitudinal cohort study. *European Spine Journal*. DOI: 10.1007/s00586-024-08212-x

Paper II

Wiben, A., Skovsgaard, C., Søgaard, K., Schiøttz-Christensen, B., and Olsen, K. R., Assessing physician-driven equity in access to public, free of charge rehabilitation after back disorder. Under review in *The European Journal of Health Economics*.

Paper III

Wiben, A., Skovsgaard, C., Søgaard, K., Schiøttz-Christensen, B., and Olsen, K. R., Early career health shocks and long-run labour market outcomes. Under review in *Economics and Human Biology*.