Attention Deficits Predict Pain Improvement Following Lumbar Fusion Surgery:

A Case for Pre-Surgical Screening

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Abstract

Despite advances in surgical techniques, nearly half of all patients undergoing lumbar fusion surgery (LFS) for chronic low back pain (LBP) do not experience a meaningful level of improvement. In this study, pain is understood as a multifaceted phenomenon involving subjective and objective entities. Therefore, a biopsychosocial perspective of pain is introduced, suggesting that cognitive and behavioural factors may interfere with surgical outcomes. More studies have found an association between chronic pain and neurodevelopmental traits, such as Attention Deficit Hyperactivity Disorder (ADHD). However, this association remains unstudied in a treatment context. Thus, this study aims to investigate whether attention deficits, assessed by the Adult ADHD Self Report Scale (ASRS), are associated with treatment resistance following LFS. A retrospective database study of 270 former chronic LBP patients who had undergone LFS and completed a subsequent questionnaire, the ASRS, was conducted. Outcomes were assessed using the Oswestry Disability Index (ODI) as a measure of disability caused by back pain and the ASRS Screener (Section A) as a measure of attention deficits and a dichotomisation of the participants into four groups defining their risk of having ADHD. The statistical analysis of this study utilised both an ANCOVA test and a multiple linear regression, adjusted for the covariates sex, age at baseline, whether the patients took pain medication, walking distance at baseline, ODI baseline scores, and the total number of back surgeries received. The ANCOVA test revealed a significant group difference in pain improvement between participants at higher risk of having ADHD compared to those at lower risk. Additionally, the multiple linear regression confirmed a significant negative correlation between ASRS scores and pain improvement following LFS. Notably, the model can explain 25% of the variance in pain improvement scores, and the model includes a level of uncertainty, emphasising the need for future research. This study concludes that attention deficits are significantly associated with poorer postoperative outcomes following LFS and that the ASRS questionnaire could be beneficial for future screening and patient selection for LFS. These findings underscore the urgent need for more research into the relationship between cognitive and behavioural domains, such as attention deficits, and their effects on chronic pain disorders and treatment options for chronic pain patients.

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1. Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental condition that affects both children and adults, characterised by persistent patterns of inattention, hyperactivity, and impulsivity (Leffa et al., 2022, p. 2). The impact of ADHD influences various aspects of an individual's life (Leffa et al., 2022, p. 11), and research suggests that individuals with ADHD may experience heightened pain sensitivity (Bouchatta et al., 2022, p. 1; Ibrahim & Hefny, 2022, p. 3; Treister et al., 2013, p. 8). How individuals with ADHD perceive and react to pain could therefore affect their overall health and well-being (Kerekes et al., 2021, p. 5). This underscores the essential need to understand the broader implications of this disorder, especially in a context where pain disorders and treatment outcomes are critical (Suto et al., 2023, p. 9).

Chronic pain, and particularly chronic low back pain (LBP), is prevalent in many countries (Andrews et al., 2017, p. 5; Freburger et al., 2009, p. 251; Wu et al., 2020, p. 2). It often leads to significant disability (Freburger et al., 2009, p. 251), decreased quality of life (Andrews et al., 2017, p. 6; Poder et al., 2020, p. 1), and complex management challenges, especially when surgical interventions are considered (Freburger et al., 2009, p. 251). One of the most common surgical treatments for chronic LBP is lumbar fusion surgery (LFS). However, the efficacy of this treatment varies greatly, and many patients do not benefit from this procedure (Mino et al., 2017, p. 142).

The research investigating the relationship between ADHD and chronic pain suggests that the cognitive and behavioural characteristics of ADHD may influence how individuals experience and cope with pain (Kerekes et al., 2021, p. 5). In patients with ADHD, the interplay between core symptoms and chronic pain can further complicate the outcomes of surgical treatments. Understanding the underlying factors that contribute to the success or failure of these surgical interventions is, therefore, critical. This is not only important for improving surgical outcomes but also for tailoring future rehabilitation and pain management strategies.

This thesis is an extension of a semester project (in the master's program's 3rd semester course 'Teori, praksis og videnskabelig metode'), which was handed in in December 2024 and orally defended in January 2025. The project investigated a population of chronic LBP patients who had received LFS and how they had improved following this procedure (Mouritzen, 2024, p. 20). The project also investigated the covariates, which were gathered as part of the preliminary screening process for LFS to investigate their predictive effect on surgical outcomes (Mouritzen, 2024, p. 25). The project showed that only 50.21% benefited from LFS (Mouritzen, 2024, p. 20) and that the covariates used to screen and predict surgical outcomes could only explain 3.2% of the variance of the disability improvement one year after surgery (Mouritzen, 2024, p. 25). The study, therefore, emphasised the need to investigate additional factors that could help predict surgical outcomes and put forth attention deficits as a possible factor that could better predict surgical outcomes (Mouritzen, 2024, p. 35). This master's thesis aims to explore the intersection between ADHD and chronic LBP, focusing on the impact that attention deficits may have on surgical treatment responses. By investigating how attention-related cognitive and behavioural factors influence pain perception and treatment response, this study seeks to provide insights into how an ADHD screening could be a predictive factor for surgical outcomes.

1.1 Attention-Deficit Hyperactivity Disorder

ADHD is a neurodevelopmental condition characterised by frequent, pervasive, and impairing symptoms of inattention and/or hyperactivity/impulsivity. The diagnosis of ADHD relies on clinical assessment and is performed based on a diagnostic classification system (Leffa et al., 2022, p. 2f; Thomsen & Simonsen, 2010, p. 402), being ICD-10 in Denmark (Mouritzen, 2024, p. 8).

The ICD classification of ADHD mostly relies on a description of the most common presentations of ADHD (Leffa et al., 2022, p. 3), and the diagnosis is performed based on a clinical history of diagnostic criteria. Symptoms of inattention are seen as lacking attention to detail, sloppiness, problems with sustained attention, lack of awareness of direct speech, trouble organising activities, a tendency to lose objects, distractibility, and forgetfulness. Symptoms of hyperactivity are seen as both a feeling of and a bodily restlessness, trouble staying seated when expected, and a tendency to talk too much. Symptoms of impulsivity are seen as a tendency to answer questions before they are finished being asked, a tendency to interrupt, and trouble waiting their turn (Thomsen & Simonsen, 2010, p. 401). For the diagnosis of ADHD, several of these symptoms must be present in more than one environment, clearly interfering with social, academic, or occupational functioning. Furthermore, these symptoms should not be better explained by other mental disorders (Leffa et al., 2022, p. 4).

The evaluation should include a clinical interview with the patient and other relevant informants (e.g. parents or teachers) (Thomsen & Simonsen, 2010, p. 402). In addition, a complete physical examination should be performed to exclude other clinical conditions that might cause symptoms of inattention, hyperactivity, or impulsivity. A diagnosis of ADHD can therefore not be conducted on rating scales, neuropsychological testing, or neuroimaging exams alone. There are yet no biomarkers with sufficient predictive power to confirm or exclude a diagnosis of ADHD (Leffa et al., 2022, p. 4f).

Attention deficits are usually more prominent when an individual with ADHD is assigned boring, repetitive tasks, and inattention symptoms can increase when the individual is working on demanding tasks that challenge their cognitive processing abilities. Motivation, relevance, and attractiveness to the task can influence the manifestation of symptoms. Poor sustained attention often results in difficulties with following instructions and organising tasks, distractibility, and failure to give close attention to details. Hyperactivity can be observed as fidgeting with hands or feet, often leaving one's seat in situations where one is not supposed to and acting as if driven by an inner motor (Leffa et al., 2022, p. 4).

According to Psykiatrifonden (Psykiatrifonden), 4-5% of children in Denmark have a diagnosis of ADHD. In general, more boys than girls have a diagnosis of ADHD, but studies show that ADHD in girls is underdiagnosed and that the actual prevalence is higher (Leffa et al., 2022, p. 10). In Denmark, 1-3% of adults have ADHD (ADHD). Approximately 15% of childhood cases present full diagnostic criteria into adulthood, while 65% persist with symptoms causing impairment, but not with full diagnostic criteria, and 20% have no symptoms or impairment in adulthood at all (Leffa et al., 2022, p. 10).

1.1.1 ADHD and comorbidities

ADHD is a diagnosis with a large representation of comorbid disorders, and approximately 80-85% are also diagnosed with another condition (Psykiatrifonden; Stray et al., 2013, p. 1f). This is most often a psychiatric disorder like anxiety, depression, personality disorders, bipolar disorders, or schizophrenia, or substance abuse (Psykiatrifonden). But more studies have also documented an elevated risk of experiencing chronic pain when having a diagnosis of ADHD and an elevated risk of receiving a diagnosis of ADHD when already suffering from a pain disorder (Chruciel et al., 2023, p. 570; Meseguer-Beltrán et al., 2023, p. 2; Mouritzen, 2024, p. 9; Stickley et al., 2016, p. 326). This connection is shown in both clinical (Asztély et al., 2019, p. 2929; Treister et al., 2013, p. 8) and pre-clinical studies (Bouchatta et al., 2022, p. 9; Sifeddine et al., 2023, p. 352f; Suto et al., 2023, p. 6), which all found that subjects with ADHD showed hypersensitivity to pain stimuli or had a lower pain threshold and pain tolerance when compared to non-ADHD subjects.

1.2 Chronic pain

Pain is differentiated as either *acute pain* or *chronic pain* (Clark, 1999, p. 728; Goebel et al., 2010, p. 2). When pain is acute, it has a functional effect of drawing attention to injury or away from danger. However, if pain persists beyond the acute phase, it becomes dysfunctional and is considered chronic (Clark, 1999, p. 728; Kerekes et al., 2021, p. 2). Pain is considered chronic when the pain experience has lasted a minimum of three months, or the pain experience has lasted one month longer than expected if the cause of trauma is known (Frølich, 2010, p. 720; Mouritzen, 2024, p. 5). In Denmark, one in five adult Danes suffers from chronic pain (Sundhedsstyrelsen).

Chronic pain affects quality of life, mobility, and physical functioning. Living with chronic pain, therefore, has severe implications for the individual in terms of lost work, benefits, and medical costs. But chronic pain also has major implications for the health care system, as 1.5-3% of the annual gross domestic product (GDP) of most European countries is spent on chronic pain management (Andrews et al., 2017, p. 6).

1.2.1 Total Pain Theory

Pain is defined as "an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage" (IASP, 2011; Mouritzen, 2024, p. 5). This definition allows the conceptualisation of pain to include multiple domains and recognise its subjective nature (Frølich, 2010, p. 720; Goebel et al., 2010, p. 4). According to this definition, pain is acknowledged for its complexity and ability to affect both physical and psychosocial functioning. Therefore, pain cannot always be determined by the extent of tissue damage (Goebel et al., 2010, p. 4f). The first theory to include this multifaceted understanding of pain was by Dame Cicely

Saunders with her *Total Pain Theory* (Clark, 1999, p. 728; Goebel et al., 2010, p. 2). This theory of total pain describes the sum of suffering experienced by patients faced with advanced disease and terminal illness in four arenas; physical, spiritual, psychological, and social (Goebel et al., 2010, p. 2).

This theory of pain was made into a conceptual model by Ferrel et al. (1991), who emphasised how pain has the potential to overwhelm the individual and consume their entire life by impacting dimensions of quality of life. This model draws on Saunders' Total Pain Theory and the relationship between the four dimensions and how they influence and are influenced by pain perception. The first dimension in the model is physical well-being. Here, the functional ability identifies that pain and symptom management is a critical aspect in the improvement of a patient's physical well-being. These symptoms are not only pain symptoms but also other physical symptoms affecting pain perception, like fatigue or anxiety (Goebel et al., 2010, p. 4f).

The second dimension is spiritual/existential well-being, which refers to a range of beliefs that become more important as individuals face declining functionality. The existential well-being is defined as the propensity to make meaning through a sense of relatedness to dimensions that transcend the self. Saunders proposed that a feeling of meaninglessness or a lack of purpose is an indication of spiritual pain or lack of spiritual well-being. By helping the patient clarify personal goals, patients and their families may together discover a sense of meaning or purpose and improve their existential well-being (Goebel et al., 2010, p. 5).

The third dimension is psychological well-being, which influences and is influenced by pain perception because the psychological domain can influence physical function, pain, and quality of life. Cognitive therapies, like cognitive behavioural therapy, may help in this regard. The fourth and last dimension is social well-being, which refers to the level of comfort an individual feels about their relationship with friends, family, and significant others. A caregiver burden from these people can impact roles and relationships, affection, sexual function, and appearance, which are important aspects of social well-being. Social support is closely related to social well-being and is defined as the resources (both physical and psychological) that are provided by other individuals for the benefit of the pain patient (Goebel et al., 2010, p. 5f).

This study therefore not only investigates pain as a physical sensation but rather as a complex experience based on both the physical pain level experienced by the patient intertwined with the patient's existential, psychological, and social well-being as defined by the International Association for the Study of Pain (IASP) and the total pain theory by Cicely Saunders.

1.3 Theories of ADHD and chronic pain

The research field of ADHD and chronic pain is still relatively new and involves different possible explanations for why this association exists. The following sections will describe some of these theories on a neurobiological, cognitive, and behavioural level, as most seen in the research field's literature, before going into more detail about chronic low back pain and surgical treatment thereof.

1.3.1 Neurobiological mechanisms underlying ADHD and pain sensitisation

ADHD is a neurodevelopmental disorder (Leffa et al., 2022, p. 2), meaning that symptoms of ADHD present themselves during childhood and the neuroanatomical mechanisms underlying these symptoms manifest during early development (Friedman & Rapoport, 2014, p. 106). The underlying neurobiological mechanisms of ADHD are still not fully understood (Kerekes et al., 2021, p. 2), and more theories thereof co-exist.

1.3.1.1 The aetiology of ADHD

Symptoms of ADHD are associated with delayed brain maturation. Reduced volume and cortical thickness have been shown in children with ADHD (Jadidian et al., 2015, p. 174) in several frontal brain regions, in parietal-temporal areas, the basal ganglia, posterior cingulate cortex (PCC), the cerebellum, and corpus callosum (Cubillo et al., 2011, p. 195). This cortical thinning is also seen in adults with ADHD in frontal brain regions such as the right dorsolateral prefrontal cortex (DLPFC), the anterior cingulate cortex (ACC), and the inferior parietal cortex (IPC), which support attention and executive functions (Cubillo et al., 2011, p. 195; Friedman & Rapoport, 2014, p. 106f; Jadidian et al., 2015, p. 174). The lack of cortical thickness is associated with the severity of ADHD symptoms, and higher levels of inattention symptoms are associated with a slowing of cortical development and a higher rate of cortical thinning (Friedman & Rapoport, 2014, p. 106f). The peak of cortical thickness maturation in children with

ADHD is delayed, compared to controls, with an average of three years and four to five years in frontal and temporal brain areas (Cubillo et al., 2011, p. 195; Jadidian et al., 2015, p. 174).

The aetiology of ADHD is complex as both genetic and environmental factors play a role. Studies have shown that prenatal and perinatal factors, environmental toxins, and the maternal diet may be potential risk factors for ADHD. In-utero exposure to maternal stress, cigarettes, alcohol, prescribed drugs (e.g. paracetamol), and illegal drugs are also reported to be associated with ADHD (Song et al., 2020, p. 714f).

1.3.1.2 The neural pathways of pain

The sensations experienced by the body are known as *somatosensations,* and the system responsible for mediating these sensations is called the *somatosensory system*. This system comprises three distinct systems: *the proprioceptive system* (monitors information about the position of the body from muscles, joints, and organs), *the interoceptive system* (provides information about conditions within the body), and *the exteroceptive system* (senses external stimuli applied to the skin). The exteroceptive system is divided into three categories based on the stimuli that the different skin receptors perceive: mechanical stimuli (touch), thermal stimuli (temperature), and nociceptive stimuli (pain) (Pinel & Barnes, 2018, p. 200).

Somatosensory information ascends from the body to the brain over several pathways, with the two major ones being the *dorsal-column medial-lemniscus system* (carries information about touch and proprioception) and the *anterolateral system* (carries information about pain and temperature). Pain and temperature information reaches the thalamus through this system and is distributed to the somatosensory cortex and further to other parts of the brain (Pinel & Barnes, 2018, p. 201f). But when pain information reaches the cortex, it does not have a clear cortical representation; painful stimuli activate many different areas of the cortex, including the thalamus, the primary and secondary somatosensory cortices, the insula, and the ACC. The ACC is frequently linked to pain, as it is involved in the expectation of pain, the emotional reaction to pain, and in adaptive responses to minimise pain (Pinel & Barnes, 2018, p. 207).

Pain sensations are experienced through the somatosensory system, which provides information from the pain site to the thalamus in the brain, where it is distributed to the cortex and specifically the somatosensory cortex, the insula and the ACC.

1.3.1.3 The structural anatomy of pain and ADHD

A leading theory of ADHD is the *dopamine theory,* based on the theory that altered dopamine (DA) function fails to modulate signal transmission in either the mesostriatal or mesolimbocortical pathways (Oades et al., 2005, p. 123). The *mesostriatal pathway* and the *mesolimbocortical pathway* involve sets of dopaminergic axons arising from the midbrain to different parts of the cortex. The mesostriatal pathway is crucial for motor control and originates from the substantia nigra and ascends to different parts of the basal ganglia. The mesolimbocortical pathway originates from the ventral tegmental area (VTA), and projects to the limbic system (e.g. amygdala, nucleus accumbens, hippocampus) and the cortex (Breedlove & Watson, 2022, p. 103f), especially the prefrontal cortex (PFC), which is essential to attentional control, organisation, and planning (Solanto, 2002, p. 66). The PFC projects to many subcortical and limbic regions (Gade, 2021, p. 202), including the dorsal and ventral striatum, thalamus, amygdala, substantia nigra, back to the VTA (Solanto, 2002, p. 66), and the ACC (Cohen, 2014a, p. 354), why a dopaminergic dysregulation in PFC can cause dysregulations in these brain areas, that information from PFC ascends to (Solanto, 2002, p. 66).

Different areas of the brain involved in ADHD pathophysiology also influence the affectivity of pain processing. The cingulate cortex is often mentioned in the literature as central to both the sensory-discriminative and emotional components of pain (Kerekes et al., 2021, p. 3; Pinel & Barnes, 2018, p. 207), as well as sustained attention in ADHD (Kerekes et al., 2021, p. 3). The cingulate cortex is divided into the anterior cingulate cortex (ACC) and the posterior cingulate cortex (PCC), which have different structural and functional connectivity. The PCC receives input from and projects to the thalamus and many different cortical systems, and the ACC receives input from fewer cortical areas; the superior temporal sulcus and the frontal lobe, and projects most of its information to the limbic structures, including the nucleus accumbens and the amygdala (Cohen, 2014a, p. 354).

Various areas of the brain are involved in connecting circuits underlying both ADHD symptoms and pain processing. This is especially the area of ACC as a junction, which receives information from the frontal lobe (generally responsible for attention and executive functions) and projects to the limbic structures.

1.3.1.4 The biochemistry of ADHD and pain sensitisation

As stated, the mesolimbocortical pathway leads to the PFC, which is essential to attentional control, organisation, and planning. The PFC is sensitive to the neurochemical environment, meaning that both excessive DA-receptor stimulation as well as insufficient stimulation can lead to working memory deficits (Solanto, 2002, p. 66).

DA-levels, especially in the frontal and prefrontal cortices, are often associated with both pain sensitisation and ADHD (Kerekes et al., 2021, p. 3). These frontal areas are implicated in overlapping brain circuits responsible for both attention (Cubillo et al., 2011, p. 195; Friedman & Rapoport, 2014, p. 106f; Jadidian et al., 2015, p. 174; Solanto, 2002, p. 66; Uddin et al., 2008, p. 250) and pain processing (Ji et al., 2025, p. 8; Pinel & Barnes, 2018, p. 207). Furthermore, dysfunction of the DA system has been shown to contribute to the development of neuroinflammation (Kerekes et al., 2021, p. 4).

Neuroinflammation is a phenomenon following neural cell damage, but also a defence mechanism protecting and restoring the normal structure and function of the brain against infection or injury. Neuroinflammation contributes to the recovery of impaired neurons but also to the occurrence and aggravation of neurodegeneration. Persistent neuroinflammation plays an important role in central nervous system (CNS) disorders, including neuroimmune diseases, neurodegenerative diseases, other neuropsychiatric diseases, and chronic pain. The natural immune cells of the CNS, microglia and mast cells, are mainly involved in the occurrence of neuroinflammation. There is a close association between mast cells and glial cells. Mast cells are generally clustered near the glia in neuroinflammatory conditions to recruit and activate other inflammatory cells, where neuroinflammation already occurs in the brain. Mast cells interact with microglia and participate in the migration and activation of microglia, thereby affecting the release of inflammatory mediators (Song et al., 2020, p. 715f).

DA also affects the ability of microglia and their secretion of cytokines, which have a pro-inflammatory effect. This process also plays a role in hypersensitivity to pain and chronic pain conditions. DA-receptor activation can elicit the inflammatory process through specific microglia pro-inflammatory phenotypes. Evidence suggests that high DA levels stimulate low-affinity dopamine receptors, which induce an anti-inflammatory effect in microglia, while low dopamine levels selectively stimulate high-affinity DA-receptors, which trigger inflammation (Kerekes et al., 2021, p. 4).

Patients with ADHD are more likely than controls to suffer from inflammatory conditions such as asthma, allergic rhinitis, atopic dermatitis, and allergic conjunctivitis. Moreover, maternal inflammatory status (e.g. autoimmune diseases or infections) can trigger the incidence of neurodevelopmental diseases, including ADHD (Kerekes et al., 2021, p. 3; Meseguer-Beltrán et al., 2023, p. 2; Song et al., 2020, p. 718). Several studies have reported elevated levels of pro-inflammatory markers in the blood of children with ADHD, and adults displaying ADHD symptoms also have higher serum cytokine levels compared to controls (Song et al., 2020, p. 718f), why ADHD, by some, is suggested to be a neuroinflammatory disease (Song et al., 2020, p. 721).

Chronic neuroinflammation also alters the neural network and can trigger a general sensitisation, which may affect overlapping circuits that underlie different neurological functions in pain perception and ADHD. Especially because pain-related areas of the brain that are also implicated in ADHD, the cingulate cortex and nucleus accumbens, are most often altered by neuroinflammation (Kerekes et al., 2021, p. 4). The inflammatory effect of ACC on ADHD and pain is investigated in pre-clinical trials of mice that have received 6-hydroxydopamine (6-OHDA), which causes disturbances in the central DA-pathway, and is a validated ADHD model (Bouchatta et al., 2022, p. 1). The study by Bouchatta et al. (2022, p. 9) found that the ADHD symptoms were amplified under inflammatory conditions and that these physiological and behavioural alterations were correlated with ACC hyperactivity in the 6-OHDA mice. Furthermore, a similar study by Meseguer-Beltrán et al. (2023, p. 15) found that anti-inflammatory treatment reduced the inflammation in ACC, reduced pain hypersensitivity and hyperactive behaviour.

The biochemistry underlying ADHD and pain is, among other factors, mediated by the neurotransmitter dopamine (DA), and a deficiency in DA stimulation can lead to working memory deficits. DA also plays a role in neuroinflammation in collaboration with mast cells and microglia. Neuroinflammatory markers are present in both children and adults with ADHD, and perinatal and maternal neuroinflammatory conditions have been associated with the development of ADHD. Dysfunction in the DA-system can induce pro-inflammatory markers in the ACC, which sends information to the limbic structures. This has been shown to affect both ADHD symptoms and sensitisation to pain stimuli.

1.3.1.5 The functional connectivity of ADHD and pain

Functional MRI (fMRI) studies have shown that abnormalities in ADHD not only affect isolated brain regions but also the functional connectivity between brain regions (Cubillo et al., 2011, p. 196). This aligns with the *default mode network theory* of ADHD.

The default mode network (DMN) is composed of brain regions that are most active during resting conditions, with very little activity during task performance (Gade, 2021, p. 206f; Jadidian et al., 2015, p. 176). Brain regions included in the DMN are the IPC, the PCC and the medial prefrontal cortex (MPFC) (Jadidian et al., 2015, p. 176; Uddin et al., 2008, p. 250). Attentional lapses have been found to occur shortly after periods of decreased deactivation of posterior DMN regions (Uddin et al., 2008, p. 250) and are thought to arise from failures in suppressing these areas. fMRI studies of participants with ADHD have reported reduced connectivity within the DMN (Jadidian et al., 2015, p. 176; Ji et al., 2025, p. 7) and between the DMN and the frontoparietal and ventral attentional networks compared to controls. ADHD is also associated with reduced connection to the frontoinsular and ACC and reduced connection to DLPFC and IPC (Jadidian et al., 2015, p. 176).

The DMN theory of ADHD is based on fMRI studies that have demonstrated alterations in the functional connectivity both within brain regions as well as networks between brain regions. These studies describe abnormalities predominantly in the frontal and subcortical regions as responsible for ADHD symptoms. This decreased connectivity may be caused by either a delayed cortical maturation, an altered dopamine function, a triggered neuroinflammatory process or an interplay between these mechanisms, which underlie symptoms like inattention, deficits in executive functions, and, as other studies have investigated, also perception of pain.

1.3.2 Attention deficits interfere with pain perception

1.3.2.1 The components of attention

The term *attention* was previously understood as a single process that facilitated the filtering or reduction of stimuli for further cognitive processing. Today, attention no longer denotes a unitary process; rather, it encompasses a broader range of behavioural and cognitive processes that are distinct from other types of cognitive functions. The concept of attention now has many ways in which the term and concept can be understood, and it varies as a function of both behavioural, physical, and cognitive demands existing at a given time point within a given situation (Cohen, 2014c, pp. 4-6).

While there are many varieties of attentional experiences, there are four elements of attention that each facilitate attention and are a by-product of the multiple components process. These four components are 1) sensory selective attention, 2) executive attention, 3) focus and capacity, and 4) sustained attention. Selective attention occurs when certain stimuli are given preference over others for subsequent processing. It is generally considered to include processes by which stimuli are oriented to, selected and engaged, and resources are allocated for additional cognitive processing. Selective attention can occur both covertly, in a relatively automatic manner, or overtly, with active focusing and the development of cognitive resources in accordance with a particular task demand (Cohen, 2014d, p. 265f).

Attention is not only focused on sensory input but also on selecting the optimal response to achieve certain goals. This requires an intention to act, focusing on available response alternatives, and selecting the proper response from these alternatives. Even selecting stimuli from the environment occurs relative to goals and directing behaviour based on these goals, and response-based attentional operations involve control processes that facilitate response execution. The term executive attention is used to describe these processes, which include response intention, selection, facilitation, inhibition, and switching, which together provide the basis of behavioural control (Cohen, 2014d, p. 270).

For most complex cognitive functions, serial processing is necessary, requiring reducing information to relatively discrete units, which can be processed to achieve the correct solution. Attentional performance is determined by multiple interacting factors, which do not always function optimally. Attentional capacity is limited by characteristics inherent to the individual, e.g. cognitive resources, but also momentary disposition of the person, e.g. sleepiness. Because people differ in both inherent and momentary dispositions, a maximum attentional capacity is difficult to determine. Attentional capacity is not universal, and an individual’s limitation of capacity will also vary within types of tasks and situations. Energetic capacity limitations, such as arousal, motivation, and drive, also constrain attention and can affect the energetic capacity, reduce the capacity to focus, and contribute to variations in attention. Energetic factors are strongly determined by a person's current physiological state and extrinsic factors in the environment. A person's attentional capacity can also determine an individual's sensory threshold. This varies over repeated trials of the same stimulus as a representation becomes familiar and a strengthening in memory of the stimulus influences perceptual sensitivity (Cohen, 2014d, pp. 273-275).

Sustained attention requires the maintenance of sensory selection, capacity, and response selection over time. It is therefore vulnerable to factors that affect any of the other elements of attention (Cohen, 2014d, p. 278). At the same time, the attentional capacity in the processes of sensory selective attention, executive attention and attention capacity is also determined by sustained attention (Cohen, 2014d, p. 275). Therefore, attention cannot be attributed to a single bottleneck of the flow of informational processing, and it cannot be isolated to specific brain structures, even though certain attentional component processes are strongly influenced by specific brain areas. Attention involves multiple brain systems acting in an integrated fashion (Cohen, 2014d, p. 266).

1.3.2.2 Attention deficits and perception of pain

As previously stated, 15% of childhood cases of ADHD present full diagnostic criteria into adulthood. In adulthood, inattention deficits most often persist while hyperactive and impulsive symptoms improve (Leffa et al., 2022, p. 10).

When one suffers from ADHD, different manifestations of attention are affected. These are sustained attention (Cohen, 2014b, p. 592), which can manifest as excessive mind-wandering or mental restlessness (Leffa et al., 2022, p. 10f), but also executive-attention and behavioural inhibition (Cohen, 2014b, p. 592), which may present as dysfunctions in inhibitory control and working memory (Barkley, 1997, p. 72; Leffa et al., 2022, p. 10f). Lastly, the process of selective attention is also affected in ADHD (Cohen, 2014b, p. 592).

The process of selective attention involves the two phases of *sensation* (the process of detecting the presence of a stimulus) and *perception* (the higher-order process of integrating, recognising, and interpreting complete patterns of sensation). This process of perception happens through the sensory systems, which are all organised hierarchically from the detection of a sensation to the perception of the stimulus. These sensations are transmitted from the part of the body that detects them to the *primary sensory cortex* of that sensory system, further along to the *secondary sensory cortex* and the *association cortex*. Each level receives most of its input from a lower level and adds a layer of analysis before passing it up the hierarchy until the analysis of the sensation has become a perception of the initial sensation (Pinel & Barnes, 2018, p. 191f).

The literature suggests an association between abnormalities in perceptual functions and the dopaminergic system in several psychiatric and neurological disorders. It is therefore also plausible that individuals with ADHD may experience altered perceptual functions compared to typically developing individuals (Fuermaier et al., 2017, p. 22). In a systematic literature review by Fuermaier et al. (2017, p. 22) the perceptual functioning of children and adults with ADHD was investigated. The review included 36 studies (Fuermaier et al., 2017, p. 24) and showed a significant difference in tactile perception, where children with ADHD were less able to differentiate between painful and non-painful stimuli, compared to controls (Fuermaier et al., 2017, p. 32). Similar results were found in a study by Scherder et al. (2008, p. 462) who investigated tactile perception in children with ADHD, their non-affected siblings and a control group. They found a significant difference in tactile perception between children with ADHD and controls, as well as between non-affected siblings of children with ADHD and controls. Children with ADHD and their non-affected siblings generally made more tactile perception errors (Scherder et al., 2008, p. 464). This hypersensitivity to pain is also demonstrated in adults in a study by Treister et al. (2013, p. 8). Their study aimed to assess the sensitivity to pain in participants with ADHD compared to controls using a cold pressor test (Treister et al., 2013, p. 5) and found that participants with ADHD had a lower pain threshold and a shorter pain tolerance than controls. An explanation as to why individuals with ADHD are hypersensitive to pain (Treister et al., 2013, p. 8f) could be deficits in tactile perception (Fuermaier et al., 2017, p. 32) making the sensory selection process of attention harder and thereby resulting in resources being allocated to nociceptive stimuli (Cohen, 2014d, p. 266).

Central sensitisation to pain is also investigated in a study by Ibrahim & Hefny (2022, p. 2f) of university students, who were screened for musculoskeletal pain, central pain sensitisation, and ADHD symptoms using the Adult ADHD Self-Report Scale (ASRS) v.1.1. They found that 39.6% had chronic back pain and that these students had a significantly higher central sensitisation than students without back pain. They also found that there was a positive association between chronic back pain and ADHD and central sensitisation and ADHD. This could be because the attentional capacity is partly influenced by and influences the sensory threshold, where a stimulus representation becomes more familiar and strengthens the memory thereof, resulting in a perceptual sensitivity (Cohen, 2014d, p. 275).

Normally, pain perceived through the exteroceptive system is considered nociceptive. But pain can also be considered *idiopathic* if the pain experienced by the patient is without a documented cause of pain. At the same time, when prolonged acute pain sensitises the nervous system (Frølich, 2010, p. 720f) by increased responsiveness to nociceptive stimuli (Kerekes et al., 2021, p. 2) it is called *nociplastic* pain (Pinel & Barnes, 2018, p. 208), which arises from altered nociception without clear evidence of actual or threatened tissue damage. This sensitisation can persist long after the initial acute pain, and if it does not resolve, it can lead to chronic pain (Kerekes et al., 2021, p. 2) and deficits in tactile perception as seen in individuals with ADHD (Fuermaier et al., 2017, p. 32; Scherder et al., 2008, p. 464; Treister et al., 2013, p. 8) as well as patients suffering from chronic LBP (Ji et al., 2025, p. 8).

Nociplasticity of pain can be caused by attentional deficits in all four attention manifestations and the interplay between them. Nociplasticity could be caused by sensory selection deficits in tactile perception, making it harder to differentiate stimuli, which is seen in individuals with ADHD. Deficits in executive attention make it harder to select proper responses, diminishing future nociceptive stimuli. The attentional capacity can determine the sensory threshold, making sensory selection more difficult and diminishing the attentional capacity in the presence of painful stimuli. But painful stimuli can also diminish the attentional capacity and result in a strengthened memory thereof and a perceptual sensitivity towards the painful stimuli. Lastly, sustained attention can be diminished by deficits in the other manifestations of attention as well as the painful stimuli itself, making it harder to sustain attention to a task.

1.3.3 Behavioural deficits in ADHD induce risk of pain experiences

When ADHD persist into adulthood, symptoms of inattention often continue, but in a more heterogeneous manner than in childhood and adolescence. Therefore, inattention symptoms most often present themselves as distractibility, difficulty remembering appointments, or difficulty with time management. Where symptoms of hyperactivity and impulsivity also persist into adulthood, these symptoms present themselves as constant activity, overscheduling, or choosing a busy job, while impulsivity can manifest as problems like quitting jobs, ending relationships prematurely, or being unwilling to wait in line. Often, behavioural symptoms such as emotional dysregulation and dysfunction of executive control are present as well (Leffa et al., 2022, p. 10f).

1.3.3.1 Executive deficits in ADHD

The behavioural symptoms of emotional dysregulation and dysfunction of executive control are in line with the model of ADHD by Russell Barkley (1997, p. 66). This model emphasises ADHD symptoms as caused by a response inhibition based on deficits in four executive functions. These four executive functions are working memory, internalisation of speech, self-regulation of affect, motivation, and arousal, and reconstitution (Barkley, 1997, p. 72).

Working memory gives rise to hindsight, forethought, anticipatory behaviour, and goal-directed or purposive actions. This form of memory is, therefore, thought to be linked to the subjective sense of time and the future, as working memory also gives rise to the capacity of internal stimulation or potential behaviours of imagining and working towards hypothetical futures (Barkley, 1997, p. 72). Self-directed internalisation of speech is emphasised as important for the development of self-control. Self-directed speech is believed to provide a means for reflection, description, and self-questioning through language, creating an important source of problem-solving abilities as well as a means of formulating rules and plans. Eventually, rules about rules, *metarules*, can be generated into hierarchically arranged systems that resemble the concept of metacognition in developmental psychology (Barkley, 1997, p. 74).

The self-regulation of affect, motivation, and arousal builds on the idea that human emotions can be reduced into a two-dimensional model, in which one direction is motivation (reinforcement or punishment), and the other is arousal. The ability to self-regulate and induce emotional states as needed in the service of goal-directed behaviour may also involve the ability to regulate and induce motivation and arousal states in support of such behaviours (Barkley, 1997, p. 74). The last executive function in Barkley’s model of ADHD is reconstitution, which comprises two processes. The first is *analysis*, which is the decomposition of sequences of events or messages into their parts, allowing them to parallel information-processing systems of the brain. The second process is *synthesis*, where these parts can be manipulated and used to construct or reconstitute new messages or responses to others. In addition, because the units in such messages can represent and initiate units of behaviour, those behavioural units can also be reconstituted into entirely new behavioural structures (Barkley, 1997, p. 70).

Barkley's model states that the deficiency in behavioural inhibition characterising ADHD is caused by deficits in the four executive functions, subserving self-control and goal-directed behaviour. This inhibitory deficit thereby indirectly disrupts the control of goal-directed behaviour by the influence of these executive functions. Consequently, the behaviour of those with ADHD is controlled more by the immediate context and its consequences than is the behaviour of others (Barkley, 1997, p. 75).

1.3.3.2 Behavioural deficits in ADHD

In line with Barkley's model of executive functions and behavioural inhibition, ADHD in adulthood is associated with a wide range of negative outcomes. Adults with ADHD generally have a lower employment rate, reduced income, and a higher risk of receiving disability pension compared to adults without ADHD. ADHD is also associated with the risk of having a gambling problem and in general spending too much money, divorce and emotional loneliness, vehicular crashes and serious traffic accidents (Leffa et al., 2022, p. 11), convictions of crimes and incarceration, higher mortality rates, suicide attempts, and substance use disorders (Leffa et al., 2022, p. 11; Song et al., 2020, p. 714).

1.3.3.3 Induced risk of pain in ADHD

A diagnosis of ADHD often entails a range of behavioural deficits. When looking at ADHD and attention deficits regarding pain, it is therefore relevant to keep in mind that adults with ADHD are more often involved in crashes or traffic accidents (Leffa et al., 2022, p. 11). Children with ADHD also have an increased risk of being in an accident or having received medical procedures (Stickley et al., 2016, p. 326), making them more prone to experiencing painful events (Scherder et al., 2008, p. 462). This could be a reason why adults with ADHD are more prone to experiencing chronic pain and having multiple pain sites (Mundal et al., 2023, p. 5). This is shown in a register study by Mundal et al. (2023, p. 2) who analysed data from a health survey of adolescents and young adults in Norway and compared it to data received from a clinic, where only data from adolescents diagnosed with ADHD were included. They found that the prevalence of experiencing pain was higher in the group with ADHD compared to the general population, and that the mean number of pain sites was higher in the group with ADHD compared to the general population (Mundal et al., 2023, p. 4).

Behavioural deficits of ADHD, maybe as a cause of behavioural inhibition and deficits in executive functions (Barkley, 1997, p. 75), can also present themselves as difficulty in remembering appointments, difficulty with time management, constant activity, overscheduling, or choosing a busy job (Leffa et al., 2022, p. 11). This can make it harder for adults with ADHD to schedule or participate in activities, reducing levels of experienced pain. This could be physical exercise, especially weight training and training focusing on coordination and stability, which is shown to have a significant effect on chronic low back pain (LBP) (Sundhedsstyrelsen, 2018, p. 196) or appointments with different health professionals.

Symptoms of adult ADHD can present themselves in more heterogeneous ways than in childhood and adolescence. These symptoms can present themselves as behavioural deficits that promote a type of behaviour which makes painful experiences more likely to have happened or happen in the future, as well as making it harder to engage in activities, minimising pain experiences, like regular physical exercise.

ADHD is characterised by deficits in attention regulation, impulse control, and executive functioning. Research has suggested an association between ADHD and chronic pain, highlighting the need for an interdisciplinary understanding of this relationship. Chronic pain is a complex condition influenced by biological, psychological, and social factors. In this context, Saunders' Total Pain Theory provides a useful framework for understanding pain as a multidimensional experience encompassing physical, emotional, cognitive, and behavioural components.

Several theoretical perspectives can be used to explain the potential mechanisms linking ADHD to chronic pain. Neurobiological explanations emphasise dopamine dysregulation, neuroinflammation, and alterations in the DMN, suggesting that ADHD-related neurochemical imbalances may contribute to heightened pain sensitivity and altered pain processing. Cognitive models propose that deficits in attentional control and sensory processing, such as deficits in tactile stimuli, may influence pain perception in individuals with ADHD.

From a behavioural perspective, Barkley's theory of executive function deficits provides insights into how ADHD-related impairments in self-regulation and inhibitory control may affect pain management strategies. Difficulties in adhering to treatment regimens, engaging in maladaptive coping mechanisms, and responding to pain in a dysregulated manner may further complicate pain experiences in individuals with ADHD.

Together, these perspectives illustrate the multifaceted nature of the ADHD-chronic pain relationship and highlight the importance of considering both neurobiological and psychosocial factors when examining pain perception and treatment outcomes in patient populations with possible comorbid ADHD.

1.4 Chronic low back pain

This study specifically investigates patients suffering from chronic low back pain (LBP) (Mouritzen, 2024, p. 5). On a global scale, LBP is one of the most common musculoskeletal problems, and it is the leading cause of absenteeism from work and activity limitation (Wu et al., 2020, p. 2). Also in Denmark, LBP is the most common pain condition, with 35-50% experiencing acute or chronic LBP. LBP can have many causes. However, even after a thorough investigation, a specific diagnosis remains challenging to determine in 70-80% of cases (Mouritzen, 2024, p. 6; Sundhedsstyrelsen, 2018, p. 196f).

LBP is defined as pain that lasts for at least one day (with/without pain referred to one/both lower limbs) in the posterior aspect of the body from the lower margin of the 12^{th} ribs to the lower gluteal folds (Mouritzen, 2024, p. 5f; Wu et al., 2020, p. 2) (Figure 1, p. 24).

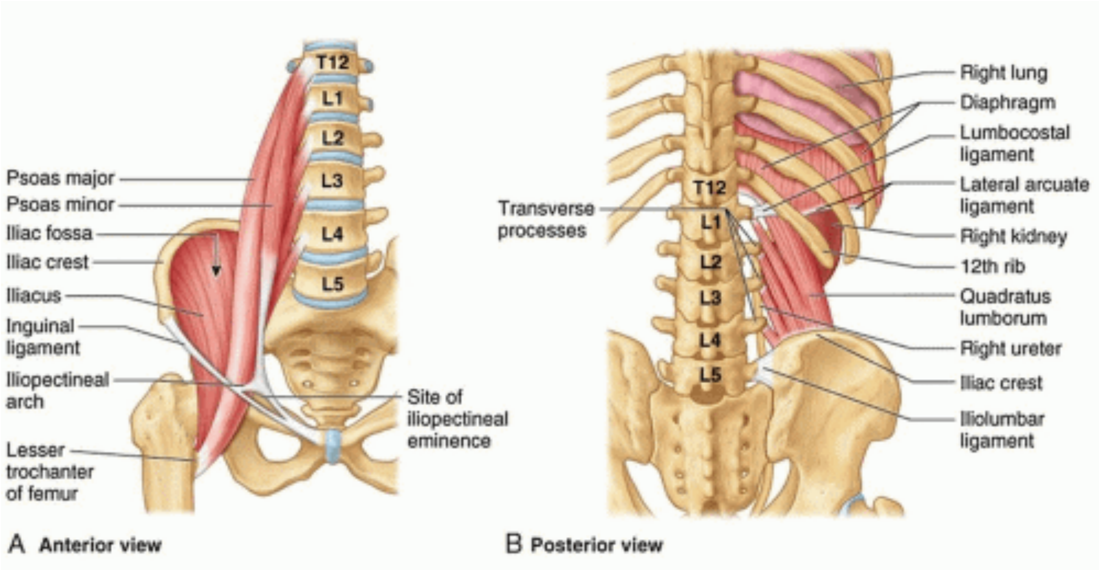

Figure 1: The anatomic structure of the anterior (A) and posterior (B) aspects of the body from the 12th rib to the lower gluteal fold (Made to Move, 2021)

1.4.1 Surgical treatment for chronic low back pain

The most used, last resort treatment for chronic LBP, is lumbar fusion surgery (LFS). This is despite the challenges of assessing an actual physiological cause of chronic LBP, and still, the use of LFS has increased 15-fold in the US between 2002-2007 (Mino et al., 2017, p. 142), and 3-fold in Denmark between 2009-2023 (Andersen et al., 2024, p. 9). This increased use of LFS is also problematic because the evidence for long-term pain relief or improved outcomes is conflicting (Mino et al., 2017, p. 142), with rates of success varying between 45-72% depending on the criterion of success (Mannion et al., 2007, p. 1102). According to a systematic review and meta-analysis by Yavin et al. (2017, p. 701f) on the safety and efficacy of LFS, decompression surgery, and non-operative care for degenerative diseases of the lumbar spine, an overuse of LFS can lead to complications and misallocations of resources. But at the same time, non-operative care can also lead to progressive spinal instability, intractable pain, and neurological impairment. Therefore, careful patient selection is required to avoid possible treatment-related adverse events following LFS for chronic LBP, as not all patients benefit equally from this procedure. Future efforts should therefore focus on identifying and guiding clinical decision making by identifying more predictors that can help ensure a positive surgical outcome (Mouritzen, 2024, p. 6f; Yavin et al., 2017, p. 711).

In the period from 2009-2023, there were 84,625 lumbar surgeries registered in DaneSpine (the Danish national clinical database for back surgery), which is 78% of all spinal surgeries registered in Denmark (Andersen et al., 2024, p. 6). Of these, approximately 1/3 received isolated decompression surgery, meaning that the remaining 2/3 received a form of fusion surgery (Andersen et al., 2024, p. 25). *Decompression surgery* treats neuropathic pain by freeing compressed nerves in the spine. During decompression surgery, one or both of the following procedures are used depending on the patient's needs; 1) a *laminectomy* where a section of or the entire vertebrae is removed to relieve pressure on the nerve, and/or 2) a *spinal fusion* where two or more vertebrae are fused with a bone graft to stabilise the spine (Borgwardt et al., 2012, p. 1164; Mouritzen, 2024, p. 7) (Figure 2).

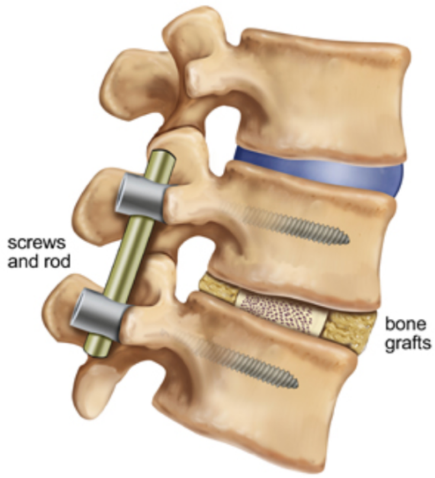

Figure 2: Spinal fusion of two vertebrae with a bone graft (Virginia Spine Specialists)

This study investigates patients suffering from chronic LBP, and more specifically, it studies patients with chronic LBP who have been treated with decompression surgery and a spinal fusion, namely lumbar fusion surgery.

1.5 ADHD and chronic low back pain

The relationship between ADHD and chronic pain is complex and multifaceted, involving neurobiological, cognitive, and behavioural mechanisms. Individuals with ADHD exhibit altered pain perception, potentially due to abnormalities in attentional stimulus selection, executive functioning, attentional capacity, and/or sensory processing. Neurobiological overlaps, particularly involving the frontal cortex, ACC, and dopamine dysregulation, may contribute to both heightened pain sensitivity and difficulties in modulating pain responses. Additionally, the presence of neuroinflammatory processes in ADHD further supports a shared mechanism with pain sensitisation.

According to the Total Pain Theory, pain cannot only be seen as based on physiological factors, and beyond this, cognitive deficits such as impaired attention, executive dysfunction, and difficulties with response inhibition may exacerbate the experience of pain in individuals with ADHD. Attentional bias towards nociceptive stimuli, a reduced ability to regulate pain perception, and difficulties with sustaining attention on treatment strategies may all contribute to a reduced ability to manage chronic pain.

Behavioural patterns associated with ADHD, including impulsivity and risk-seeking behaviour, may further increase the risk of pain-related complications, which may contribute to the presence and persistence of chronic pain and chronic LBP.

Given the rising prevalence of LFS as treatment for chronic LBP, it is crucial to consider attentional deficits as being able to influence surgical outcomes. Identifying attention deficits, as related to ADHD symptoms, in patients undergoing LFS could be essential for optimising post-operative pain levels, as individuals with ADHD may require a more individualised rehabilitation strategy to enhance compliance and long-term success.

ADHD is currently not listed as a risk factor for postsurgical pain, but it is recommended by more researchers (Kasahara et al., 2021, p. 305; Suto et al., 2023, p. 9) to integrate an ADHD screening into pre-surgical assessment to identify patients most likely either not to benefit from LFS or requiring an individualised treatment plan. It is therefore relevant to investigate whether this association between ADHD and chronic pain exists among patients suffering from chronic LBP. Furthermore, it is relevant to examine whether chronic LBP patients, who do not experience clinically relevant pain relief following LFS, have a higher prevalence of ADHD symptoms compared to patients who benefit from LFS. By identifying this potential connection between ADHD and post-surgical outcomes following LFS in chronic LBP patients, this study aims to contribute to a more nuanced understanding of patient management in chronic LBP, ultimately informing clinical decision-making and helping to develop a more targeted treatment intervention in chronic LBP patients (Mouritzen, 2024, p. 11).

1.6 Research question

As highlighted in the research presented above, a knowledge gap exists regarding the potential association between chronic LBP and attention deficits, and how this relationship may influence post-surgical outcomes following LFS. This association can have an impact on the future decision-making of chronic LBP patients and, therefore, better treatment outcomes, which leads to the following research question:

Is there an association between attention deficits and pain improvement following lumbar fusion surgery for chronic low back pain?

To answer this research question, the following hypotheses will be analysed:

1) *Patients with higher levels of attention deficits, investigated as ADHD symptom scores, display lower levels of improvement in pain, investigated as improvement in ODI score, compared to patients with lower levels of attention deficits.*
2) *Moreover, attention deficits correlate negatively with improvement in pain.*

2. Methodology

This study is a survey study, and the data is based on both sent-out questionnaires and data obtained as a data extract from a database. This section will present the database used for data extraction and the program used to send out questionnaires. This section will also present the different variables of this study, as well as the questionnaires used. Lastly, this section will describe the process of screening patients for possible participants and obtaining data.

2.1 DaneSpine

DaneSpine is a national database for all back surgical procedures in Denmark, containing patient-reported and surgeon-reported outcomes regarding a patient's surgical procedure and treatment. It is Denmark's biggest patient-reported outcome database and contains data from more than 100.000 surgical procedures. The data in DaneSpine is collected through validated, generic, and diagnosis-specific questionnaires and patient-reported demographic questionnaires relevant to treatment and follow-up. Registration in DaneSpine is important to ensure the value of the surgical procedures and to continuously validate which procedures can be optimised and how (Andersen et al., 2024, p. 2; Mouritzen, 2024, p. 12).

The data in this study partly consists of data from the DaneSpine database, which is compiled as an extract of patient- and surgeon-reported outcome data. The data provided through DaneSpine is accessible through employment at the Department of Back Surgery, Joint, and Tissue Disease at Rigshospitalet-Glostrup.

2.2 REDCap

REDCap is a secure web application for designing and managing online surveys, databases, or almost any other type of data collection (REDCap). Access to REDCap is granted through Region Hovedstaden. The questionnaire used in this project has been programmed into REDCap and sent to participants using e-Boks (Mouritzen, 2024, p. 13).

2.3 Data security

The DaneSpine data extract consists of data relevant to the patients' surgical procedures and follow-up, meaning that it involves personal data such as CPR numbers, names, addresses, etc. To secure the anonymity (Coolican, 2014b, p. 288) of the participants, all data extracted from DaneSpine is stored on a logged drive that can only be accessed through a personal work account on a computer at the Department of Back Surgery, Joint, and Tissue Disease at Rigshospitalet-Glostrup. The screening process of inclusion and exclusion criteria has taken place only on this drive, where the final participant cohort was selected, stored in a separate file, and uploaded directly from the logged drive and onto REDCap. REDCap is compliant with GDPR (REDCap) and can be used to send out questionnaires from Region Hovedstaden to the participants' e-Boks (Mouritzen, 2024, p. 13).

2.4 Measures

2.4.1 DaneSpine

Variables of this study were gathered through the DaneSpine database and consist of demographic and background variables, variables relevant to the patients' surgical procedure, including work- and health-related variables, and the questionnaires ODI and EQ-5D-3L. Some of these variables are also used in the screening process of including or excluding patients as possible participants.

2.4.1.1 Demographic variables and background information

The DaneSpine data extract contains personal information, which is essential for sending questionnaires to potential participants via e-Boks and for pairing the new data from the subsequent questionnaire with the existing data from the DaneSpine database. These variables include CPR numbers and names, which are removed to anonymise the dataset once all data is collected, paired, and prepared for analysis.

The DaneSpine data extract also includes demographic variables that were relevant to the patients' surgical procedures and have been shown to interfere with surgical outcomes. The first variable is the patients' sex, where female sex is associated with a worse postoperative outcome (Aalto et al., 2006, p. 651; Andrews et al., 2017, p. 9), but these results are inconclusive, as other studies find no significant association (Aalto et al., 2006, p. 651; 2012, p. 258; Mannion & Elfering, 2005, p. 98). The next variable included is age at surgery, where younger age is associated with better surgical outcomes (Aalto et al., 2012, p. 257), but these results are also inconclusive as studies have found no association or even that older age is associated with better postoperative outcome (Aalto et al., 2006, p. 651; Mannion & Elfering, 2005, p. 98; Sinikallio et al., 2009, p. 540).

2.4.1.2 Work-related variables

Work-related variables are also included as possible predictors for surgical outcomes. Some studies have shown that receiving cash benefits has a negative influence on post-surgical outcomes, why this is included as a predictive variable in this study. However, other studies have shown that cash benefits have had no effect. Longer pre-operative sick leave has also been shown to have a negative influence on surgery (Mannion & Elfering, 2005, p. 101), which is also included as a variable.

2.4.1.3 Health-related variables

Health-related variables are also included in the study. These comprise whether the patient took pain medication in the period before surgery, as a longer duration of analgesic use is associated with poorer surgical outcomes (Aalto et al., 2012, p. 257). Lower self-reported walking distance before surgery has also been shown to negatively predict surgical outcomes (Aalto et al., 2006, p. 651; Sinikallio et al., 2009, p. 540), why pre-operative walking distance is also included. Whether the patients had undergone previous back surgeries was also included as a variable, as it has been shown to negatively predict the outcome of the current back surgery (Aalto et al., 2012, p. 257).

Smoking status of the patients is also gathered in the DaneSpine data extract as it is shown to negatively influence post-surgical outcomes (Aalto et al., 2012, p. 257; Glassman et al., 2000, p. 2610f; Sandén et al., 2011, p. 1061). Smoking status is therefore also included as a variable.

2.4.1.4 The Oswestry Disability Index

The Oswestry Disability Index (ODI) is a questionnaire designed to assess functional impairment caused by chronic LBP. ODI consists of ten questions assessing different categories; pain, personal care, lifting, walking distance, sitting ability/functionality, standing functionality, difficulty sleeping, sexual function, social life, and ability to travel, which are measured on a scale from 0 to 5 points. The total score of this scale is multiplied by 2, which generates a score from 0-100, where a score of ≤ 20 indicates no or very little back trouble, and a score of ≥ 80 indicates that the patient is disabled to a degree where they are bed-bound (Andersen et al., 2024, p. 8; Mouritzen, 2024, p. 14).

When working with patient-reported outcomes, it can be challenging to interpret the meaning of an improvement because the extent of a change in a numerical score lacks a direct meaning of clinical significance. The concept of *minimum clinically important difference* (MCID) is therefore used to assess the smallest improvement in the patient-reported outcomes needed to achieve a level of clinical importance (Asher et al., 2018, p. 2). According to Asher et al. (2018, p. 4), the MCID value score for ODI is 14.3, meaning that a patient's ODI score should improve at least 14.3 points between baseline and follow-up for the surgical procedure to be considered to have made a clinically relevant change in the patient's pain level. Accordingly, the MCID level is set as a 15-point improvement in a patient's ODI score in this present study (Mouritzen, 2024, p. 14).

ODI is one of the primary measures of this study. The difference between the baseline and one-year follow-up ODI scores will be used to assess the patients' level of improvement following LFS. In instances where patients have undergone multiple back surgeries, the ODI improvement score is calculated as the difference between the patient's initial ODI baseline score and the most recent ODI one-year follow-up score (Mouritzen, 2024, p. 14).

The patients' ODI score at baseline is also included in the study as a covariate, as studies have documented an association between higher ODI baseline scores and poorer surgery outcomes (Sinikallio et al., 2009, p. 540).

2.4.1.5 EQ-5D-3L

The EQ-5D is used to measure health-related quality of life (HRQoL) (van Hout & Shaw, 2021, p. 1285) and the EQ-5D-3L includes five dimensions (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression) which are all scored on a 3-point scale ranging from 'none' through 'moderate' to 'extreme'. These five dimensions create 243 unique health states (van Hout & Shaw, 2021, p. 1285), ranging from 11111 (full health) to 33333 (worst health) (van Hout et al., 2012, p. 709). These health states are calculated into utility scores, which range from -0.594 to 1, where 1 indicates 'full health' and ≤ 0 indicates a condition responding to 'death' or 'worse than death'. An improvement of 0.12 in utility score is considered a clinically relevant level of improvement in HRQoL (Andersen et al., 2024, p. 7).

Chronic LBP is shown to influence HRQoL, which is why the baseline utility score is included as a predictive value in this study (Asztély et al., 2019, p. 2926; Poder et al., 2020, p. 1). Improvement in HRQoL between baseline and one-year follow-up is also included as a secondary measure of treatment outcome.

2.4.2 REDCap

While the DaneSpine data extract provides baseline and one-year follow-up data relevant to the participants' surgical procedures, information regarding potential attention deficits is gathered through a subsequent questionnaire, the ASRS, sent out using REDCap.

2.4.2.1 The Adult ADHD Self Report Scale v1.1

The Adult ADHD Self Report Scale v.1.1 (ASRS) is a symptom checklist of ADHD. The ASRS Screener (Section A) consists of six questions that assess all DSM-IV Criterion A symptoms (Kessler et al., 2005, p. 246). This checklist is validated for identifying adults at risk of having ADHD (Adler et al., 2018, p. 3). Section B consists of a further twelve questions, which give a more detailed evaluation of the patient's symptom severity (Kessler et al., 2005, p. 253). The entire ASRS, therefore, consist of 18 items. Every question asks how often an ADHD symptom has occurred during the last six months on a scale from 0-4 points (from 'never' to 'very often'). The results are scored by summing the answers on the response scale of each question (Kessler et al., 2007, p. 56; Mouritzen, 2024, p. 15).

When scoring the ASRS Screener (Section A), the results can be divided into a four-stratum classification of the possibility of having ADHD made up of scores ranging from 0-9 (very low risk of an ADHD diagnosis), 10-13 (a low risk of an ADHD diagnosis), 14-17 (a high risk of an ADHD diagnosis), and 18-24 (a very high risk of an ADHD diagnosis) (Kessler et al., 2007, p. 61; National Comorbidity Survey, 2024). Results on the ASRS Screener range from 0-24, and a score of ≥ 14 points is considered compatible with an ADHD diagnosis. The full ASRS (involving both Section A and Section B) is scored similarly, with all answers summed. Results range from 0-72 and show the severity of the symptom burden (Kessler et al., 2005, p. 252; Mouritzen, 2024, p. 15).

As stated in a previous section, a diagnosis such as ADHD can only be evaluated through a clinical interview and not just based on neuropsychological tests or rating scales. However, because of limitations in the required experience to conduct such an interview, as well as it being a burden for the possible participants, this study cannot be conducted in a way where an actual diagnosis of ADHD can be assessed. This study is designed as a questionnaire with self-report measures. It can therefore only assess whether participants express symptoms resembling those of a diagnosis of ADHD, and if so, if the participant expresses those symptoms to an extent that would suffice for a threshold for an ADHD diagnosis. Previous studies have investigated the connection between ADHD and chronic pain by using rating scales to assess symptoms of ADHD without stating an actual diagnosis hereof (Ibrahim & Hefny, 2022, p. 2; Kasahara et al., 2021, p. 300; Stickley et al., 2016, p. 327), why this study will do the same (Mouritzen, 2024, p. 9).

The results of the ASRS Screener (Section A) will be used as a primary measure in this study to assess the presence of ADHD symptoms and the risk of having ADHD. This study will use a Danish translation of the ASRS v1.1 created by Obel et al. (2009).

2.5 Inclusion and exclusion criteria

The participant group of this study are former chronic LBP patients who have received LFS. These former patients are registered in DaneSpine with all data relevant to their surgical procedure and follow-up. A data extract of all back surgical patients operated at Glostrup Hospital from 2011-2024 was retrieved, and this data extract comprised 17.704 admissions for back surgery, which underwent inclusion and exclusion criteria screening (Mouritzen, 2024, p. 16).

The inclusion criteria were that patients must have received decompression surgery with LFS, have completed baseline and one-year follow-up ODI in DaneSpine and have stated their LBP as having persisted for long enough to be considered chronic (Mouritzen, 2024, p. 16).

Patients were excluded if they had received previous unknown back surgeries, e.g. from other hospitals where data is not included in this data extract. Patients were also excluded if they had other comorbid conditions affecting their pain experience (e.g. cancer, neurological conditions, heart disease, or other diseases affecting pain or walking ability). These comorbid pain conditions are listed as exclusion criteria since they have been shown to negatively predict the results of surgery (Aalto et al., 2006, p. 651), which would interfere with the results of this study (Mouritzen, 2024, p. 16).

2.5.1 Sample size

Before the patients in DaneSpine were screened for possible participation, the required sample size was calculated, using G*Power, to state how large the required sample size would have to be to achieve the necessary level of power (Faul et al., 2007, p. 176; 2009, p. 1149). This is done twice, as this study's hypotheses are answered using both an ANCOVA test and a multiple linear regression, as to why a sample size is required for both.

The sample size for the ANCOVA test is computed using the *F* test family. The effect size, *f*, is set at a medium effect of 0.25, as no previous studies have been made investigating attention deficits in a surgery population to draw knowledge from. The alpha level is set at 0.05 (Field, 2018f, p .136), and the power level is set at 0.8, indicating an 80% chance of detecting an effect if one exists (Field, 2018f, p. 138). The ANCOVA analysis includes four groups, so the numerator degrees of freedom (df) are set at 3, and the number of groups is set at 4. The analysis will include six covariates. According to G*Power, the required sample size to perform an ANCOVA analysis is 179 participants.

The required sample size for a multiple linear regression is also computed using the *F*-test family and multiple linear regression as a fixed model where R^2 deviates from zero. The effect size, f^2, is again set at a medium effect, here of 0.15. The alpha level is also set at 0.05, and the power level is set at 0.8. The multiple linear regression includes seven independent predictors. According to G*Power, the required sample size to perform a multiple linear regression is 103 participants.

Based on the G*Power calculations, the required sample size of this study is 179 participants for the ANCOVA analysis and 103 participants for the multiple linear regression, respectively. The required sample size to achieve the necessary level of power is, therefore, 179 participants to investigate the association between attention deficits and improvement in pain following lumbar fusion surgery.

2.5.2 Screening for participants

The DaneSpine data extract comprised 17,704 individual surgery admissions for back surgical procedures at Glostrup Hospital from 2011-2024. These surgery admissions were all screened based on the stated inclusion and exclusion criteria (Figure 3, p. 36). First, surgery admissions were removed if the baseline or follow-up data did not include answers on the ODI questionnaire. 4,121 surgery admissions were hence removed because they did not include ODI baseline scores, and a further 6,667 surgery admissions were removed because they did not include ODI one-year follow-up scores (Mouritzen, 2024, p. 17f).

Then, 2,165 surgery admissions were removed because the patients stated having comorbid conditions affecting their level of pain (632 surgery admissions were removed because of heart disease, 312 surgery admissions were removed because of neurological conditions, 142 surgery admissions were removed because of cancer, 627 surgery admissions were removed because of ‘other stated disease affecting walking ability’, and 452 surgery admissions were removed because of ‘other stated disease affecting pain condition’) (Mouritzen, 2024, p. 18).

331 surgery admissions were removed because the patient had passed away since registration in DaneSpine. 217 surgery admissions were removed because the patient’s LBP was not stated as chronic. 2,549 surgery admissions were removed because the patients had received other back surgical procedures than LFS, and 177 surgery admissions were removed because the surgical procedure was not specified (Mouritzen, 2024, p. 18).

A further 207 surgery admissions were removed because they included patients who had received multiple surgeries, none of which were LFS. Then, 481 surgery admissions were removed because the patient stated having received other back surgical procedures before their first scheduled procedure at the Department of Back Surgery, Joint, and Tissue Disease at Rigshospitalet-Glostrup (Mouritzen, 2024, p. 18). Lastly, 78 surgery admissions were removed because they consisted of multiple surgery admissions of 72 patients (11 surgery admissions were duplicates due to surgery complications, and 67 surgery admissions were multiple surgery admissions due to multiple back surgical procedures received, where one of them was LFS) (Mouritzen, 2024, p. 18).

The final list of former chronic LBP patients, and possible participants for this study, consisted of 711 patients. To take non-responders into account, all patients will be contacted and requested to participate through a letter sent to their e-Boks using REDCap (Mouritzen, 2024, p. 18).

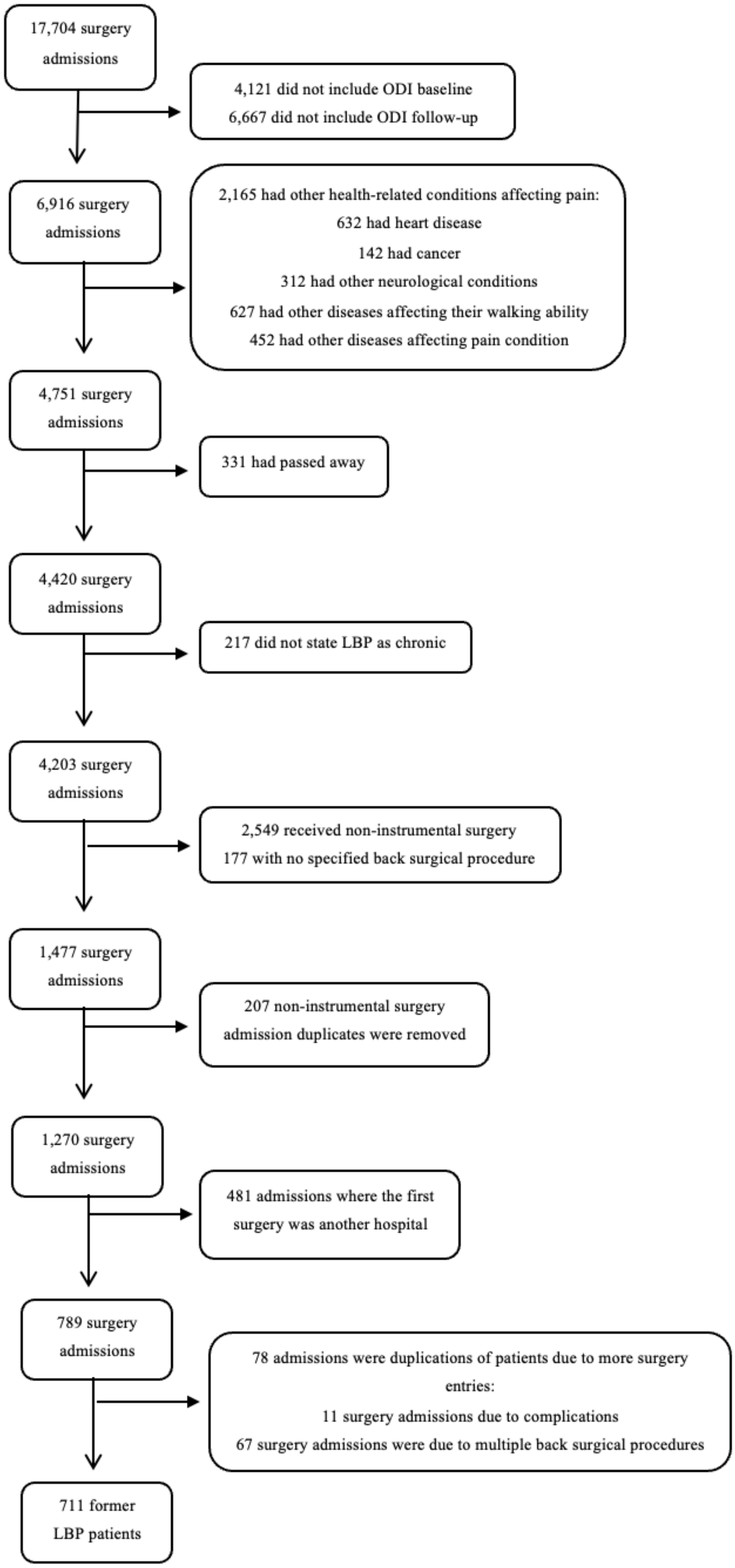

Figure 3: Flowchart of participant screening

2.6 Data collection

The data collection for this project has been completed in two parts. First, a data extract was conducted from DaneSpine in October 2024, and the former patients in the data extract were screened as presented. Second, the patients fulfilling the inclusion and exclusion criteria were all contacted in December 2024 and asked if they wished to participate in this study by answering a series of questionnaires (Mouritzen, 2024, p. 20). This data collection process happened through REDCap and consisted of questionnaires not only relevant to this project but also for future research projects at the Department of Back Surgery, Joint, and Tissue Disease at Rigshospitalet-Glostrup. The data collection process ran until March 2025, when the REDCap project was closed, and a total of 452 participants had responded.

After the data collection had ended, a mistake in the screening process was found. This study has previously excluded 2,549 patients who had received non-instrumental surgery and a further 177 patients with no specified surgical procedure. These surgical procedures are marked in the DaneSpine data extract with a coding system ranging from 1-10, where only codes 8 and 10 represent LFS. This study has also included patients with a code 9, who have, therefore, also received the subsequent questionnaires. These patients comprised 182 individuals who were removed from the data extract before their data were paired with the questionnaire data from REDCap. The final participant group, therefore, comprises 270 participants, and the following data analysis will consist of the presented variables from the DaneSpine data extract and the questionnaires sent out using REDCap from the 270 participants who have responded.

3. Statistical analysis

The statistical analysis of this project is based on data from the 270 participants who answered the subsequent questionnaire, the ASRS. The data consists of their background information from the DaneSpine data extract and their questionnaire answers. First, the participant group is presented through descriptive statistics. Then, the data is investigated through assumption tests to determine whether the study's hypotheses can be analysed using parametric tests. Afterwards, the hypotheses are tested using an ANCOVA test and a multiple linear regression.

3.1 Descriptive statistics

The data in this project consists of data from 270 former LBP patients who have received LFS. These participants have answered several questions regarding their treatment at baseline, just before surgery, and one year later. Furthermore, they completed a subsequent questionnaire for this project.

At baseline, the participant group had a mean ODI score of 37.9 (*SD* = 14.38) (Table 1, p. 39). 84.44% reported taking analgesics due to LBP, 64.81% were unable to walk more than one kilometre because of back or leg pain, and 25.19% were on sick leave due to LBP. This study also planned to include how many participants received cash benefits and were on sick leave before surgery. However, 71.48% have not answered whether they receive cash benefits, and 83.33% have not answered how long they have been on sick leave, even though they stated whether they were on sick leave at the time of the baseline questionnaire. These variables are, therefore, excluded from further analysis.

Also, this study should have included smoking status as a covariate. However, the non-union rate following surgery is not significantly affected by either the quantity a patient smoked before surgery or the duration of preoperative smoking abatement. Rather, surgery outcome is altered by postoperative smoking cessation (Glassman et al., 2000, p. 2611). As the DaneSpine data extract only includes whether the patient is smoking or not at baseline, but without further details, smoking is also not included in the following analysis.

Baseline	Total (N = 270)	
Variable	**Response (N)**	**%**
Sex	Female (177)	65.56
Smoking	Yes (42)	15.56
Analgesic use because of LBP	Yes (228)	84.44
Active in sports	Not active (90)	33.33
Sick leave because of LBP	Yes (68)	25.19
Walking distance	Less than 100 meters (43) 100 - 500 meters (82) 0.5 - 1 km (47) More than 1 km (95)	15.93 30.37 17.41 35.19
Variable	**Mean**	**SD**
Age at surgery	56.29	16.97
EQ-5D-3L	0.74	1.16
ODI	37.9	14.38

Table 1: Descriptive statistics (baseline)

One year after surgery, the participants' ODI score had improved to 22.92 (*SD* = 18.28) (Table 2, p. 40), and the mean improvement score (ΔODI) of the participant group was 14.98 (*SD* = 17.23). The MCID threshold for ODI is 14.3 points, meaning that the participant group just reached the threshold for improving their level of pain to a clinically relevant level. According to the ΔODI score, 51.48% of the participants were considered treatment-responsive following LFS, meaning that 48.52% were considered treatment-resistant.

One-year follow-up	Total ($N = 270$)	
Variable	**Response (*N*)**	**%**
Analgesic use because of LBP	Yes (162)	60
Walking distance	Less than 100 meters (17) 100 - 500 meters (35) 0.5 - 1 km (36) More than 1 km (182)	6.3 12.96 13.33 67.41
Active in sports	Not active (122)	45.19
Satisfaction with LFS	Satisfied (179) In doubt (60) Not satisfied (31)	66.3 22.22 11.48
Received more than one back surgery	42	15.56
Received more than one LFS	9	3.33
Experienced paralysis following surgery	49	18.15
Experienced incontinence following surgery	20	7.41
Variable	**Mean**	**SD**
EQ-5D-3L	0.74	0.22
ODI	22.92	18.28

Table 2: Descriptive statistics (one-year follow-up)

In the subsequent questionnaire, the ASRS, the participants had a mean score of 9.04 ($SD = 4.73$) on the ASRS Screener (Section A) and a score of 26.19 ($SD = 11.69$) on the total ASRS (Sections A and B) (Table 3). 17.41% of the participants reached the threshold of a 'high risk of having ADHD', and 8.89% reached the threshold of a 'very high risk of ADHD'.

Subsequent questionnaire	Total ($N = 270$)	
Variable	**Response (*N*)**	**%**
High risk of ADHD (ASRS > 14)	47	17.41
Very high risk of ADHD (ASRS > 17)	24	8.89
Variable	**Mean**	**SD**
ASRS Screener (Section A)	9.04	4.73
ASRS Total score	26.19	11.69

Table 3: Descriptive statistics (ASRS)

These preliminary results indicate that, among the 270 former LBP patients who received LFS, only 51.48% achieved a clinically relevant outcome following surgical treatment, and 66.3% reported satisfaction with the surgical outcome (Table 2, p. 40). 15.56% reported being more disabled one year after surgery, and 18.15% stated that they experienced a level of paralysis following surgery. Furthermore, 60% still took analgesics because of LBP one year after surgery, and the HRQoL of the participants had not changed. These results confirm the conflicting evidence of long-term pain relief following LFS (Mannion et al., 2007, p. 1102; Mino et al., 2017, p. 142) and that the screening process of surgical patients is not thorough enough. The preliminary results also demonstrated that 17.41% of the participants stated having symptoms corresponding to a diagnosis of ADHD, which is considerably higher than the Danish background population, where only 1-3% have a diagnosis of ADHD (ADHD). The following analysis will therefore investigate whether this increased level of ADHD symptoms interferes with the results of surgical treatment.

3.2 Assumption tests

Before testing the hypotheses of this study, various assumption tests were conducted to determine if the data could be treated as parametric. First, the questionnaires used in the study were assessed for internal reliability using Cronbach's alpha. Then, different assumption tests were performed to establish whether the hypotheses could be tested using parametric tests such as an ANCOVA and multiple linear regression tests. The preliminary assumption tests for both ANCOVA and multiple linear regression include linearity between the independent variables and the dependent variable, ΔODI, a test for normal distribution of variables, an investigation of possible outliers, and finally, a test for multicollinearity between variables. Assumption tests for the ANCOVA specifically are tests for homogeneity of the regression slope and homogeneity of variance.

3.2.1 Internal reliability of questionnaires

The questionnaires used in this study were tested for internal reliability using Cronbach's alpha (Coolican, 2014d, p. 217). This includes the questionnaires ODI and ASRS, as well as the EQ-5D-3L. The internal reliability for the ODI baseline was assessed to be good ($\alpha = 0.81$) and the internal reliability for the ODI one-year follow-up was assessed to be excellent (($\alpha = 0.93$), meaning that the items on the scale are highly intercorrelated (Clark & Watson, 1995, p. 315; 2019, p. 1421). The ASRS Screener (Section A) was also assessed to have good internal reliability ($\alpha = 0.81$), and the ASRS Total (Sections A and B) was assessed to have excellent reliability ($\alpha = 0.91$). The ASRS items are, therefore, also considered highly intercorrelated.

However, Cronbach's alpha showed that the internal reliability for the EQ-5D-3L baseline was problematic ($\alpha = 0.55$), but for the one-year follow-up, it was good ($\alpha = 0.8$). The scale consists of five items, why removing an item to increase the internal reliability of the EQ-5D-3L baseline score is impossible. Also, the Cronbach's alpha of the remaining four items would still range between 0.44-0.57, meaning that the questionnaire would still show a problematic level of internal reliability. This suggests that the items on the scale do not have internal consistency. The EQ-5D-3L baseline was therefore tested for homogeneity using the average interitem correlation (AIIC) to test whether the items of the scale assess the same underlying construct, in this case being HRQoL. The EQ-5D-3L baseline had an AIIC score of 0.19, which is within the limit of an acceptable level of homogeneity (0.15-0.5). Still, the EQ-5D-3L is removed from further analysis, as the α-level is much lower than the recommended threshold of 0.8 (Clark & Watson, 1995, p. 315f; 2019, p. 1421).

3.2.2 Linearity of variables

This study's primary independent variable is the score of the ASRS Screener (Section A). This was tested for linearity with the dependent variable (Coolican, 2014a, p. 528; Field, 2018a, p. 324), ΔODI, representing the improvement in disability one year after surgery. Figure 4 (p. 43) shows that there is linearity between the ASRS Screener (Section A) and ΔODI. The linearity of the continuous covariates was also investigated (see Attachment A, p. 2), and all covariates showed linearity with ΔODI.

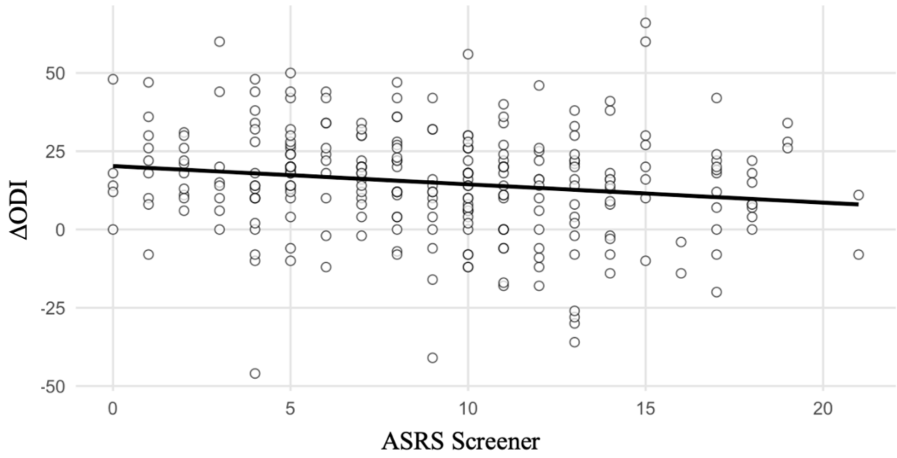

Figure 4: Scatterplot of ASRS Screener and ΔODI

3.2.3 Normal distribution of variables

The normal distribution of data was first tested on the primary variables of the study, the ODI baseline and one-year follow-up, and ΔODI, and the score of the ASRS Screener (Section A). Afterwards, the normal distribution was also investigated for all covariates. Normal distribution tests were conducted through visual investigation using histograms (Faraway, 2005c, p. 5f) and QQ-plots (Field, 2018a, p. 348).

3.2.3.1 ODI baseline

The participants' ODI baseline score was first tested for normal distribution using a Histogram (Figure 5) and a QQ-plot (Figure 6, p. 44). The visual presentations of the participants' ODI baseline scores show a distribution visually presented as normal.

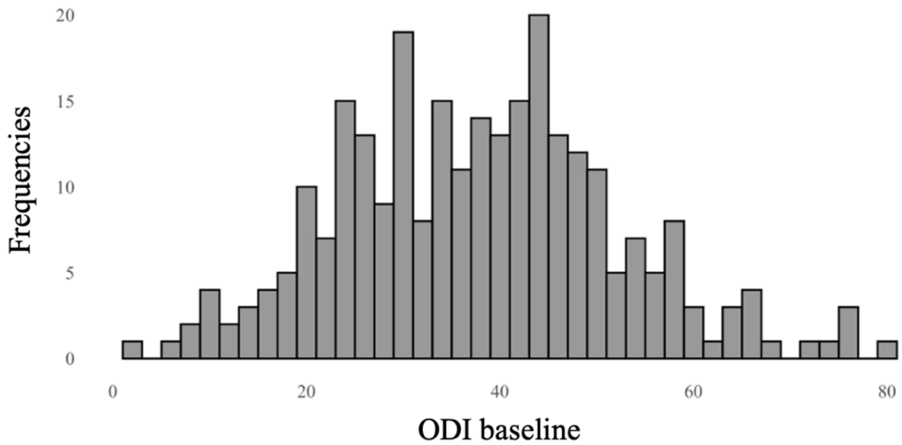

Figure 5: Histogram of ODI baseline

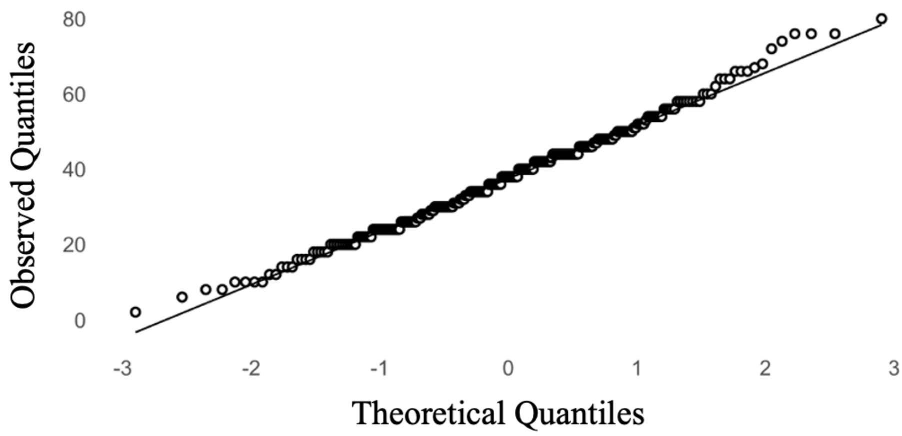

Figure 6: QQ-plot of ODI baseline

3.2.3.2 ODI one-year follow-up

The participants' ODI one-year follow-up scores were also tested for normal distribution. Visual presentations using a histogram (Figure 7) and QQ-plot (Figure 8, p. 45) were made, and they showed a distribution that does not present itself as normal. This was expected, since a lower score on the ODI one-year follow-up represents a lower level of disability and therefore a more successful outcome following surgical treatment.

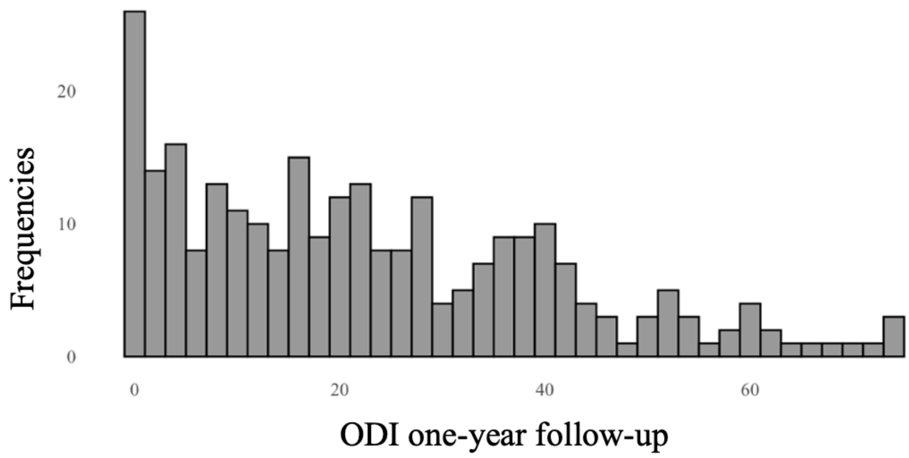

Figure 7: Histogram of ODI one-year follow-up

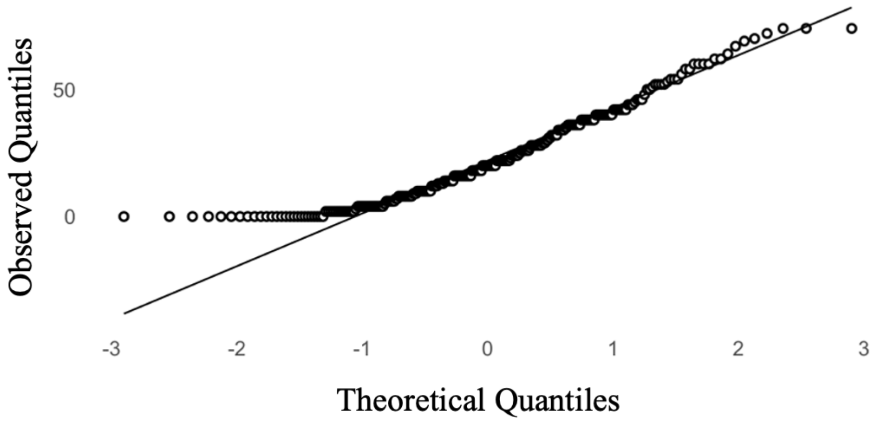

Figure 8: QQ-plot of ODI one-year follow-up

3.2.3.3 Delta ODI

Lastly, the ODI improvement score, ΔODI, was tested in the same manner as the ODI baseline and one-year follow-up. Figures 9 and 10 (p. 46) show the visual distribution of the data, which presents itself as normally distributed but with clear signs of outliers, which are investigated in the following assumption test.

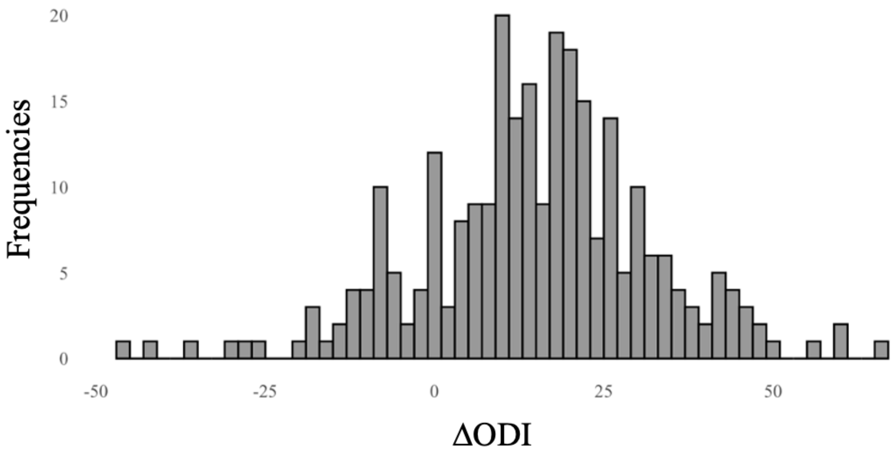

Figure 9: Histogram of ΔODI

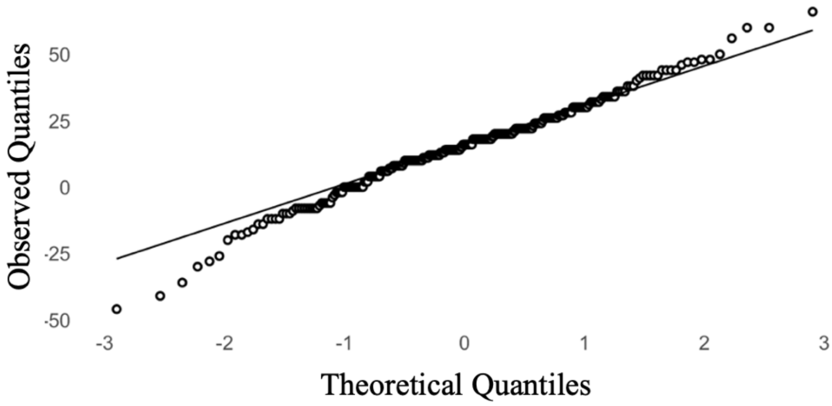

Figure 10: QQ-plot of ΔODI

3.2.3.4 ASRS Screener (Section A)

Like the scores from the ODI questionnaire, the data from the ASRS were also tested for normal distribution using visual presentations such as histograms and QQ-plots. The histogram (Figure 11) and QQ-plot (Figure 12, p. 47) of the ASRS Screener (Section A) show a normal distribution, but also with signs of outliers.

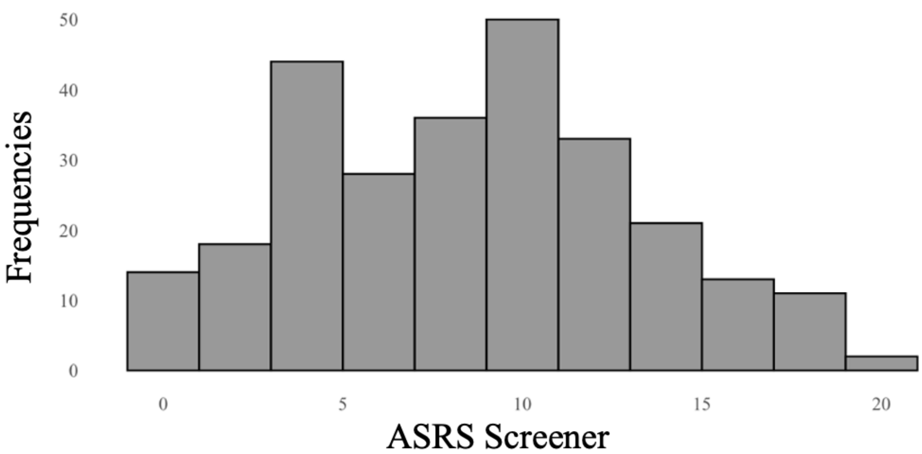

Figure 11: Histogram of ASRS Screener (Section A)

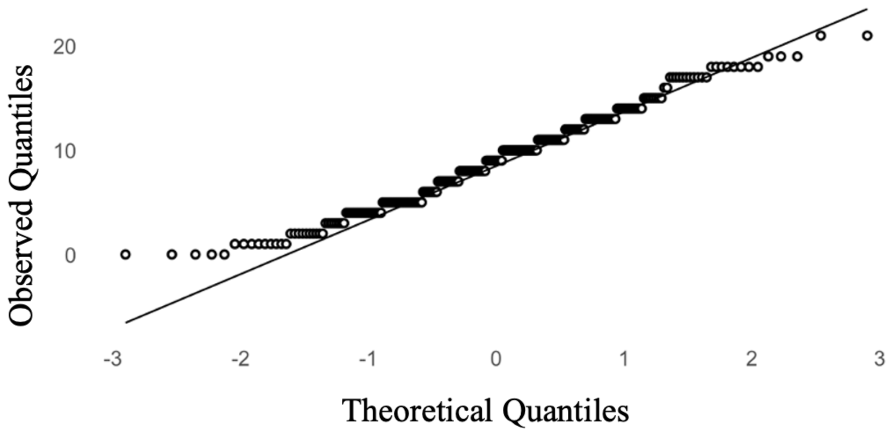

Figure 12: QQ-plot of ASRS Screener (Section A)

The tests of normal distribution show that the data of the primary variables, ΔODI and the ASRS Screener, represent themselves as normally distributed, but with signs of outliers, which will be investigated next. Age at baseline, the last continuous co-variate, was also investigated and showed a distribution which presented itself as normal, but also with signs of outliers (see Attachment A, p. 3).

3.2.4 Outliers

The variables ΔODI and the ASRS Screener score were investigated for outliers using boxplots (Field, 2018a, p. 337; Fox & Weisberg, 2019a, p. 199f). The boxplot of the ΔODI scores (Figure 13, p. 48) confirms that the data includes some outliers who have either extremely positive or negative ΔODI scores. The outliers were identified using the Interquartile Range (IQR) (Coolican, 2014e, p. 349; Field, 2018g, p. 68), showing that the outliers included three participants who had a ΔODI score above 56 points and six participants who had a ΔODI score below -24 points. These nine participants were removed from the dataset. Afterwards, the scores on the ASRS Screener (Section A) were investigated for outliers using boxplots (Figure 14, p. 48), which now showed no signs of outliers.

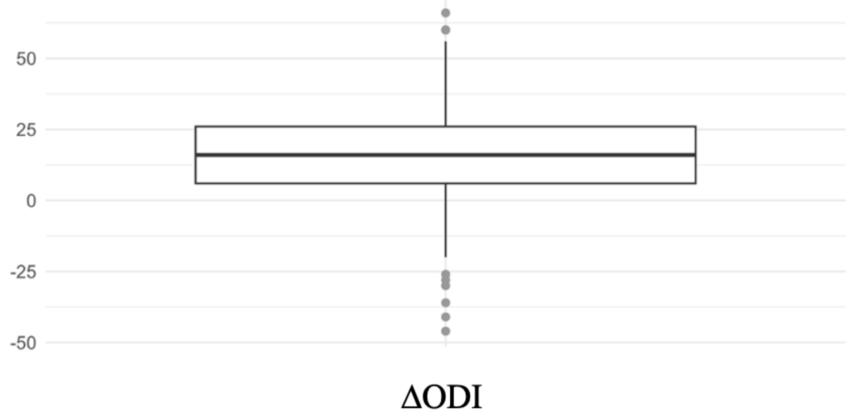

Figure 13: Boxplot of ΔODI

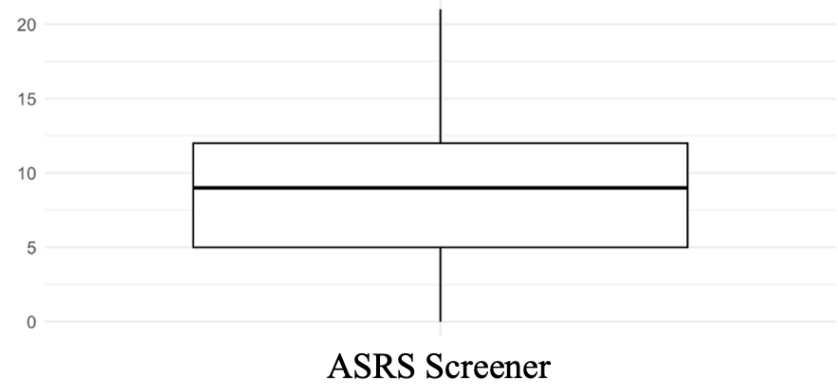

Figure 14: Boxplot of ASRS Screener (Section A)

The covariates were also tested for outliers using boxplots (see Attachment A, p. 4). The ODI baseline showed signs of outliers, which were identified using IQR. The outliers were four participants who had a baseline ODI score above 73 points. However, these participants are kept in the dataset, even though they have a high ODI baseline score, as their scores are used to calculate the ΔODI, which now presents itself without outliers.

3.2.5 Multicollinearity

Multicollinearity was tested with the Variance Inflation Factor (VIF) (Faraway, 2005e, p. 89f), and the test did not show any values above 10 (Field, 2018e, p. 534), indicating no multicollinearity in the model (Table 4, p. 49).

Variable	VIF
ASRS Screener	1.25
Sex	1.07
Age (baseline)	1.29
Pain medicine (baseline)	1.07
Walking distance (baseline)	1.5
ODI (baseline)	1.67
Back surgeries in total	1.07

Table 4: Variance Inflation Factor scores of independent variables

All assumption tests relevant to performing a multiple linear regression have been conducted, and data can now be considered parametric. However, two assumption tests are still needed to evaluate the use of an ANCOVA test, being homogeneity of regression slopes and homogeneity of variance, which will be tested next.

3.2.6 Homogeneity of regression slopes

Homogeneity of the regression slope evaluates the interaction between the independent variable, ΔODI, and the covariates (Field, 2018d, p. 777). The groups to be investigated in the ANCOVA test are dichotomised based on the ASRS Screener (Section A), which divides the respondents into four groups of risks of having ADHD. The interaction term between these groups and the different continuous covariates, age and ODI baseline, were investigated. The test revealed no significant interaction between the ADHD risk groups and age at baseline (p = 0.35), or between ADHD risk groups and ODI baseline scores (p = 0.68). Consequently, no interaction terms will be included in the ANCOVA test.

3.2.7 Homogeneity of variance

The last assumption tested is the homogeneity of variance to determine whether the population variance is the same across the groups being investigated. This assumption is tested using Levene's test (Coolican, 2014c, p. 578; Faraway, 2005d, p. 195), which was non-significant ($p = 0.64$), and homogeneity of variance can therefore be assumed.

All assumption tests relevant for performing an ANCOVA test and a multiple linear regression have now been performed. The EQ-5D-3L was removed from further analysis because it lacked internal reliability, and nine outliers were removed from the dataset, which ensured a normal distribution of the data. After these adjustments, all data can be treated as parametric in the following analysis.

3.3 Results

After all assumption tests were performed and data were considered parametric, the research question was investigated by analysis of the study's hypotheses. This study wishes to examine whether there is an association between attention deficits and pain improvement following LFS for chronic LBP. This is investigated through the two hypotheses; 1) that participants with higher levels of attention deficits display lower levels of pain improvement following LFS compared to participants with lower levels of attention deficits, and 2) that there is a negative correlation between attention deficits and improvement in pain. The first hypothesis is investigated using an ANCOVA test of four groups of participants with varying risk levels of having ADHD, to determine whether they exhibit different levels of ΔODI scores following LFS, while controlling for covariates. The second hypothesis is examined using a multiple linear regression between attention deficits, investigated through the ASRS Screener (Section A), and improvement in pain after surgery, represented as ΔODI, and the different covariates of this study.

3.3.1 Participants with higher levels of attention deficits display lower levels of pain improvement following surgery

The first hypothesis stated that participants with higher levels of attention deficits would display lower levels of pain improvement following LFS than participants with lower levels of attention deficits.

An Analysis of Covariance (ANCOVA) was conducted to test the hypothesised group difference in ΔODI when controlling for covariates. The ASRS Screener

(Section A) dichotomises respondents into four groups, stating their risk of having ADHD, ranging from a very low to a very high risk. These groups were used as the categorical variable of the ANCOVA analysis. The covariates included in the model were sex, age at baseline, whether the participant took pain medication because of back pain, walking distance at baseline, and the number of back surgeries received in total.

The results of the ANCOVA indicate that there is a significant main effect of ADHD risk group on ΔODI when controlling for covariates, $F(3, 247) = 4.13$, $p = 0.007$ (Table 5). This suggests that participants in the different ADHD risk groups show significantly different levels of ΔODI following LFS. This group difference was further investigated using a post-hoc test to identify where the difference is located. A Tukey's test revealed a significant group difference between the group with a 'very low risk of ADHD' and the group with a 'low risk of ADHD', where the ΔODI scores of the 'very low risk of ADHD' group were 6.47 points higher than the 'low risk of ADHD' group ($p = 0.005$) (Table 6, p. 52). The Tukey's test also revealed a significant group difference between the 'very low risk of ADHD' group and the 'high risk of ADHD' group, where the 'very low risk' group had a ΔODI score that was 12.92 points higher ($p < 0.001$).

Source	**df**	**Sum Sq**	**Mean Sq**	**F**	**p-value**
ADHD risk	3	2,105	702	4.13	0.007 *
Sex	1	389	389	2.29	0.13
Age (baseline)	1	31	31	0.18	0.67
Pain medicine (baseline)	1	89	89	0.52	0.47
Walking distance (baseline)	1	5,727	5,727	33.69	< 0.001 *
ODI (baseline)	1	3,953	3,953	23.26	< 0.001 *
Back surgeries in total	1	1,539	1,539	9.05	0.003 *
Residuals	247	41,989	170		

* = Source is significant at $p < 0.05$

Table 5: ANCOVA test of difference in ΔODI across ADHD risk groups adjusted for covariates

Contrast	Estimate	SE	df	95% CI	t	p-value
Very low risk – Low risk	6.47	1.93	247	[1.48, 11.45]	3.35	0.005*
Very low risk – High risk	12.92	2.79	247	[5.7, 20.14]	4.63	< 0.001*
Very low risk – Very high risk	8.9	4	247	[-1.33, 19.12]	2.25	0.113
Low risk – High risk	6.45	2.87	247	[-0.96, 13.87]	-2.25	0.113
Low risk – Very high risk	2.43	4	247	[-7.93, 12.78]	0.61	0.93
High risk – Very high risk	-4.03	4.36	247	[-15.31, 7.27]	-0.92	0.79

* = Contrast is significant at $p < 0.05$

Table 6: Tukey's post-hoc test and confidence intervals of ΔODI across ADHD risk groups

The difference in ΔODI across ADHD risk groups was examined visually using a bar chart (Figure 15) to illustrate the group differences. The chart shows clear group differences, with participant groups demonstrating lower risks of ADHD displaying higher ΔODI scores. However, the visual inspection also reveals that some participants in the 'very high risk of ADHD' group exceed the MCID threshold for ΔODI. This was unexpected and prompted further investigation of potentially influential cases that might affect model estimates.

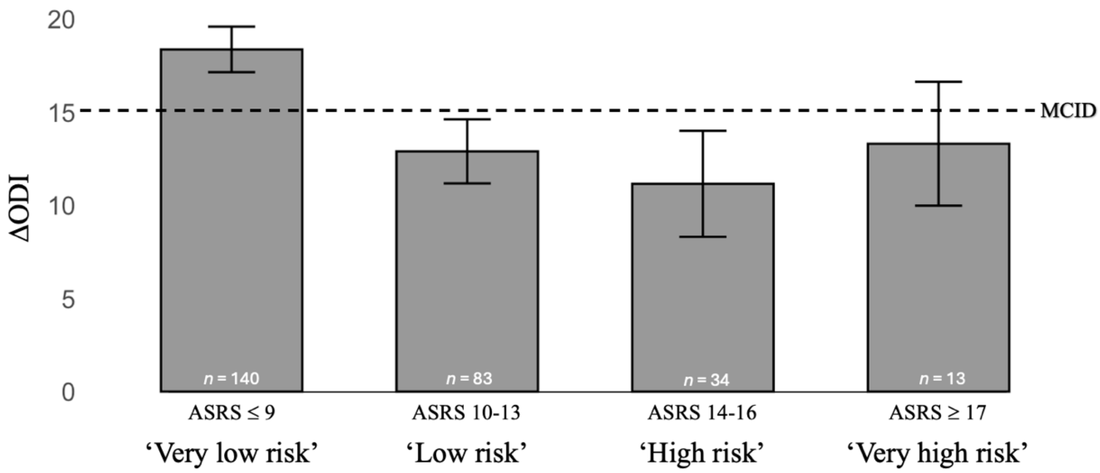

Figure 15: Bar chart of differences in ΔODI scores across ADHD risk groups

3.3.1.1 Assessment of influential observations

Potential influential observations were investigated using leverage and Cook's distance. Leverage was calculated for each observation based on the ANCOVA model, which included seven predictor variables and 261 observations. The threshold for a high leverage was set at $2\,x\,\frac{k+1}{n} = 0.061$, where k is the number of predictor variables and n is the sample size (Faraway, 2005a, p. 69; Field, 2018e, p. 511). Based on this threshold, 13 cases were flagged for elevated leverage. The participant with the highest leverage (L = 0.102) (Faraway, 2005a, p. 75f; Field, 2018e, p. 511) was investigated further. However, this participant did not account for the unexpected high ΔODI score in the 'very high risk of ADHD' group. While the participant did have a high ASRS Screener score of 21 points (placing them in the 'very high risk of ADHD' group), their ΔODI score was 11, which is below the MCID threshold.

Cook's distance was calculated for all 13 flagged participants, but none of them exceeded the threshold of 1, deeming an undue influence on the model (Field, 2018e, p. 558). However, the participant with the largest leverage also displayed the largest Cook's distance (D = 0.024) (Faraway, 2005a, p. 75f; Field, 2018e, p. 511). Due to the combination of a higher leverage and Cook's distance, a sensitivity analysis was conducted in which the participant was removed and the ANCOVA model re-estimated (Attachment B, p. 2). The results of this analysis showed only negligible differences in parameter estimates and p-values, and the overall conclusions of the analysis remain consistent. As a result, the participant was kept in the final model to preserve the integrity of the full dataset and avoid potential bias by exclusion.

Furthermore, six of the 13 flagged participants with elevated leverage had both high ASRS Screener scores (18-19 points, indicating a 'very high risk of ADHD') and ΔODI scores between 15-34 points, exceeding the MCID threshold. These cases likely contribute meaningfully to the group-level pattern observed in the bar chart and suggest that the group effect is not driven by a single outlier but rather reflects a subset of participants with consistent characteristics. This also highlights that some individuals with higher levels of attention deficits may still benefit substantially from LFS.

The ANCOVA test also showed that some of the covariates had a significant influence on ΔODI, independent of the ADHD risk groups (Table 5, p. 51). These were walking distance at baseline ($F(3, 247) = 33.69$, $p < 0.001$), ODI baseline ($F(3, 247) = 23.26$, $p < 0.001$), and the number of total back surgeries received ($F(3, 247) = 9.05$, $p = 0.003$). The covariates sex, age at baseline, and whether the patient took pain medication were not significant influencers of ΔODI ($p > 0.05$).

These findings suggest that participant groups with LBP and higher levels of attention deficits have lower pain improvement scores following LFS compared to the same patient population with lower levels of attention deficits.

3.3.2 A negative correlation between attention deficits and pain improvement

The second hypothesis states that there is a negative correlation between attention deficits, assessed as the scores of the ASRS Screener (Section A), and improvement in pain, assessed as ΔODI. The covariates corrected for in the model were sex, age at baseline, whether the patient took pain medicine because of back pain at baseline, walking distance at baseline, ODI baseline score, and how many back surgeries the participant had received in total. This hypothesis was tested using a multiple linear regression, and the overall regression model is significant, $F(7, 249) = 11.55$, $p < 0.001$, and can explain 25% of the variance of the ΔODI ($R^2 = 0.25$). The ASRS Screener (Section A) is a significant predictor of ΔODI, $b = -0.98$, $SE = 0.19$, $t = -5.09$, $p < 0.001$ (Table 7), indicating that a higher level of attention deficits is associated with a lower level of pain improvement following LFS.

Predictor	b	SE b	β	t	p-value
(Intercept)	28.86	7.58	NA	3.8	< 0.001 *
ASRS A	-0.98	0.19	-0.31	-5.09	< 0.001 *
Sex (M)	-1.92	1.77	-0.06	-1.09	0.28
Age (baseline)	-0.04	0.08	-0.03	-0.46	0.64
Pain medicine (baseline)	-4.45	2.32	-0.11	-1.92	0.06
Walking distance (baseline)	-2.13	0.9	-0.16	-2.35	0.02 *
ODI (baseline)	0.4	0.07	0.38	5.39	< 0.001 *
Back surgeries in total	-6.19	2.07	-0.17	-3	0.003 *

* = Predictor is significant at $p < 0.05$

Table 7: Multiple linear regression of ASRS Screener (Section A) and ΔODI, adjusting for covariates

This association was also investigated using a Pearson's correlation between the ASRS Screener (Section A) and ΔODI (Figure 16), without controlling for the covariates, which showed a weak, but significant, negative correlation between the ASRS Screener (Section A) and ΔODI, $r(259) = -0.18$, $p = 0.003$. To show the effect of the ASRS Screener more clearly, a partial correlation between the ASRS Screener (Section A) and ΔODI, adjusted for covariates, was also conducted. The partial correlation showed a significant negative correlation between the ASRS Screener (Section A) and the ΔODI scores adjusted for covariates, $r(249) = -0.31$, $p < 0.001$ (Figure 17).

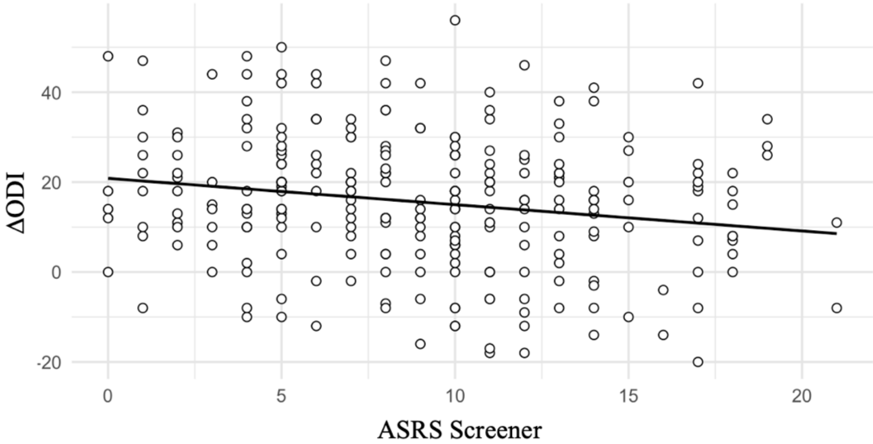

Figure 16: Pearson's correlation between ASRS Screener (Section A) and ΔODI

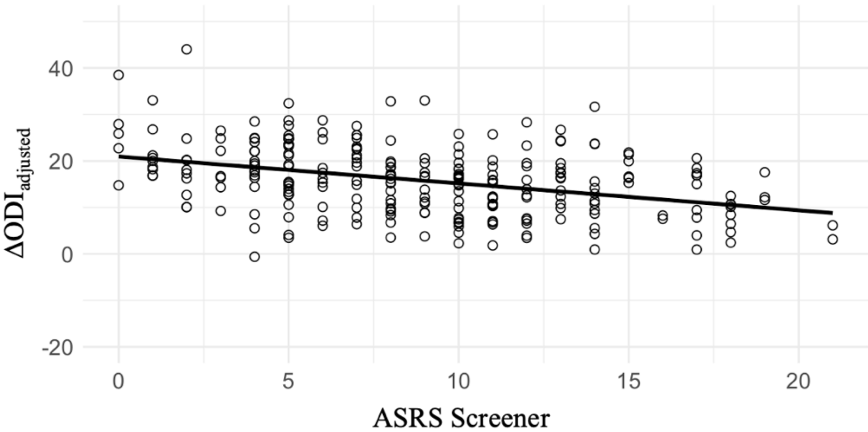

Figure 17: Partial correlation of ASRS Screener (Section A) and adjusted ΔODI

The multiple linear regression also revealed that some of the covariates had a significant effect on the ΔODI score (Table 7, p. 54). These were walking distance at baseline ($b = -2.13$, $SE = 0.9$, $t = -2.35$, $p = 0.02$) and the number of previous back surgeries received (b = -6.19, SE = 2.07, t = -3, p = 0.003), suggesting that these were also associated with poorer outcomes following LFS. ODI baseline (b = 0.4, SE = 0.07, t = 5.39, $p < 0.001$) was also a significant predictor of ΔODI and was associated with better outcomes following LFS. The covariates sex, age at baseline, and whether the participant took pain medication because of back pain were not statistically significant predictors of pain improvement following LFS ($p > 0.05$).

These findings suggest that there is a negative association between attention deficits and pain improvement following LFS.

3.3.2.1 The model fit

A predicted vs. observed values plot was generated to visually inspect the model fit. Figure 18 shows that the datapoints generally follow the tendency line, but some data points are still widely dispersed. This indicates that the model contains a degree of uncertainty, as it does not predict all outcomes of surgical treatment correctly.

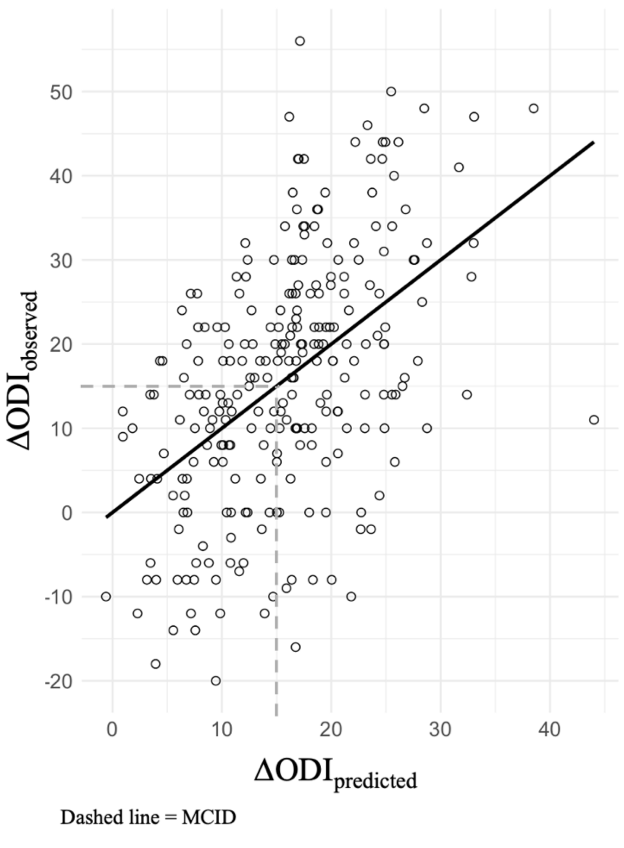

Figure 18: Plot of predicted ΔODI vs. observed ΔODI

The model fit was further investigated using the residuals of the model. But first, it was investigated whether the residuals could be considered normally distributed (Faraway, 2005b, p. 13f; Field, 2018a, p. 325), which was done through visual investigation using histograms (Faraway, 2005c, p. 5f) and QQ-plots (Field, 2018a, p. 348). The figures (see Attachment B, p. 3) showed that the residuals of the model were normally distributed.

Then, it was investigated whether the variance of the residuals was constant on all levels of the independent variable. Homoscedasticity was assessed visually using a residual vs. fitted values plot (Field, 2018a, pp. 333–335) of the predicted ΔODI scores (Figure 19), which showed that the data does visually present itself as homoscedastic. A Breusch-Pagan test was also conducted (Fox & Weisberg, 2019b, p. 571), which confirmed significant evidence of homoscedasticity (BP = 34.31, df = 8, p < 0.001). However, the residuals, which represent the difference between the predicted values of the model and the observed values (Wickham & Grolemund, 2017, p. 106), are quite large, underlining that the model's predictions still includes a degree of uncertainty.

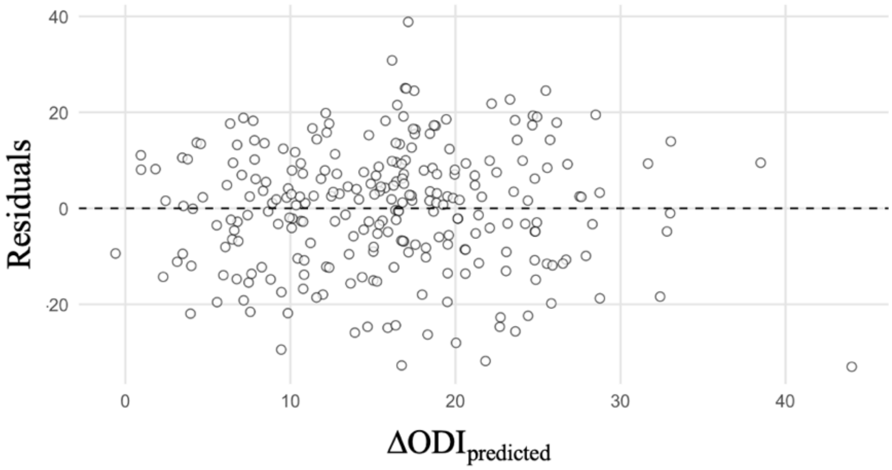

Figure 19: Residual plot of predicted ΔODI scores

This model does show an association between attention deficits and pain improvement following LFS, but it can, as of yet, only predict surgery outcomes on a group level, as the predictions of this model are not precise enough to predict surgical outcome on an individual level.

This study aimed to investigate whether there was an association between attention deficits and pain improvement following lumbar fusion surgery. This was investigated through two hypotheses. The first hypothesis stated that participants with higher levels of attention deficits would display lower levels of pain improvement following lumbar fusion surgery, compared to participants with lower levels of attention deficits. This was tested using an ANCOVA test, which showed that there was a significant difference in pain improvement across the groups with different risks of attention deficits.

The second hypothesis stated that there was a negative correlation between attention deficits and treatment outcome following lumbar fusion surgery. This hypothesis was investigated using a multiple linear regression, which showed a significant negative correlation between the ASRS Screener (Section A) score, representing attention deficits, and pain improvement when corrected for covariates.

4. Discussion

The purpose of this study was to investigate whether there was an association between attention deficits and pain improvement following lumbar fusion surgery for chronic low back pain. This was investigated through the analysis of two hypotheses, investigating a group difference and a correlation analysis. The following section will discuss the results of this study. The theoretical viewpoints of the study will be discussed, as well as different methodological considerations. Then, the clinical relevance of the results will be discussed, and, lastly, the limitations of this study will be presented.

4.1 Discussion of theory

The results of the analysis revealed that participants with higher levels of attention deficits displayed lower levels of pain improvement following LFS. This is in line with the previously presented theoretical causations of attention deficits and pain, stating that neurobiological mechanisms and cognitive and behavioural traits may influence treatment outcomes in this patient population.

First, the neurobiological framework offers potential mechanistic explanations for the demonstrated association. The ACC, which plays a central role in both attention control and pain processing, has been shown to exhibit structural and functional abnormalities in individuals with ADHD (Kerekes et al., 2021, p. 3). Dopaminergic dysregulation, which is often implicated in ADHD pathophysiology (Oades et al., 2005, p. 123), may impair top-down modulations of pain and increase vulnerability to central sensitisation (Kerekes et al., 2021, p. 3), which is seen in individuals with attention deficits (Ibrahim & Hefny, 2022, p. 3). Furthermore, chronic neuroinflammatory states, which have been proposed to underlie both ADHD and chronic pain conditions, may further disrupt neural circuits involved in pain regulation (Kerekes et al., 2021, p. 3; Meseguer-Beltrán et al., 2023, p. 2; Song et al., 2020, p. 718), resulting in surgical interventions being less effective in individuals with higher levels of attention deficits.

Secondly, these findings can also be understood through the cognitive theories of attention and perception. In ADHD, individuals often struggle with different aspects of attention, such as selection and sustained attention (Cohen, 2014b, p. 592), which are also important processes in modulating pain perception (Fuermaier et al., 2017, p. 22), and can result in tactile perception deficits (Scherder et al., 2008, p. 464; Treister et al., 2013, p. 8f). Attentional biases towards nociceptive stimuli, combined with a reduced attentional capacity and a reduced ability to shift attention away from sensations of pain, may result in heightened pain experiences and difficulty achieving symptom relief postoperatively, because of the development of nociplastic pain (Pinel & Barnes, 2018, p. 208). Furthermore, deficits in executive attention may limit the individual's ability to implement goal-directed strategies to manage discomfort (Barkley, 1997, p. 72; Cohen, 2014b, p. 592; Leffa et al., 2022, p. 10f), contributing to persistent functional limitations despite surgical interventions.

This is also in line with Barkley's theory of executive function deficits of ADHD, which provides further context for interpreting the results. Adults with ADHD frequently demonstrate difficulties in maintaining routines, following through on treatment plans, or engaging consistently in health-promoting behaviours (Barkley, 1997, p. 75; Leffa et al., 2022, p. 11). These deficits may compromise adherence to post-surgical rehabilitation procedures, which is relevant for achieving sustainable improvement goals. Thus, higher levels of attention deficits could contribute to lower levels of pain improvement through both cognitive and behavioural mechanisms.

However, it is also worth noting that some participants displaying higher levels of attention deficits did report a clinically meaningful level of improvement following surgery. This highlights the heterogeneity of attention deficits and suggests that this alone does not predict poorer surgery outcomes. As stated in Saunders' Total Pain Theory, other factors such as physical well-being, existential and psychological resilience, and social support may influence the individual trajectories of recovery (Goebel et al., 2010, pp. 4–6). This study aimed to highlight the importance of not just treating pain conditions as a somatic disorder but also assessing pain as subjective, where psychological factors interfere with pain experience and treatment outcomes (Frølich, 2010, p. 720; Goebel et al., 2010, p. 4). In this regard, the results of the study show that more psychological factors, like attention deficits, should be included in a future screening model to better predict surgical outcome on an individual level.

4.2 Discussion of methodology

This study has used the ODI questionnaire as a measure of disability caused by back pain, and an MCID cut-off of 15-point improvement between baseline and one-year follow-up. The ODI is currently the most widely implemented tool for assessing disability in patients with back pain, why the ODI facilitates consistency in outcome measurements and allows for meaningful comparisons across studies. Despite this, the use of the ODI questionnaire includes some concerns regarding the wording of the questionnaire and the contextual relevance of certain items. These concerns will be discussed in the following sections, as well as their implications for the results.

4.2.1 ODI as a measure of disability

This study uses the score of the ODI questionnaire as the primary measure of disability caused by chronic LBP. However, the introductory wording of the ODI states that the patient "must choose the statement that best describes them today". But even though a pain disorder is considered chronic, it does not mean that a patient always experiences the same level of pain. This also depends on the type of activity a patient has done during the day or the days before, or how they are feeling in general, as psychological factors can also influence the level of experienced pain (Frølich, 2010, p. 721). Therefore, a patient's answer on the ODI questionnaire can vary from day to day depending on how they are currently feeling. But even though this is a limitation of the use of the ODI, this is still the primary measure used in spinal surgery, why this is the only measure relevant to use to secure comparability with other studies (Mouritzen, 2024, p. 34).

The questions in the ODI questionnaire are designed to measure how a patient's level of pain affects their ability to handle tasks of daily life. But, as patients get older, their daily level of activity, or expected activity, declines, which could result in answering the questions on the ODI questionnaire with a lower score than would represent the patient's level of pain, if this activity was a part of their daily life. Some examples of this are questions 8: 'Sex life' and question 9: 'My social life', where 0-point answers would be: *"My sex/social life is normal and does not give me more pain"*. If a patient, for any other reason, did not have a rich sex or social life before suffering from a pain condition, then this answer would give a score of 0, even though this would be scenarios where the patient would have experienced pain, if this was a natural part of their daily life (Mouritzen, 2024, p. 32).

Despite these concerns regarding the wording and contextual relevance of certain items in the ODI questionnaire, its use remains methodologically appropriate. The ODI is currently the most widely implemented tool for assessing disability in patients with back pain. Therefore, despite some concerns, the use of the ODI questionnaire in this present study supports methodological consistency of research within this field.

4.2.2 Pain improvement of lumbar fusion surgery

4.2.2.1 MCID of ODI improvement

In this study, 51.48% had a ΔODI score ≥ of 15 points, exceeding the MCID threshold for a clinically relevant treatment response (Asher et al., 2018, p. 4). This corresponds with the results of the meta-analysis by Mannion et al. (2007, p. 1102), which showed that the success rate varies between 45-72% depending on the criterion of success. This variation in success rate suggests that the use of a different threshold level of ΔODI could potentially interfere with the results of the study, why the choice of using an MCID threshold of 15 points will be investigated.

According to Andersen et al. (2024, p. 8), DaneSpine uses an MCID threshold of ΔODI ≥ 12.8 points. If we had used this threshold instead, it would have resulted in 58.15% of the participants fulfilling the MCID criteria and being considered treatment responsive. This could have changed the results of the ANCOVA analysis, as the participant group with a 'high risk of ADHD' would have been the only group that had not reached this MCID cut-off of 12.8 points. However, the results of the multiple linear regression would be the same, as the negative association between the ASRS Screener and ΔODI is unaffected by the MCID cut-off.

Another study has used a different cut-off of ΔODI, defined as a ≥ 30% improvement between the ODI baseline and follow-up scores, which in their study corresponded to an 8–56-point improvement, dependent on ODI baseline. Their follow-up was measured after two years (Aalto et al., 2012, p. 257), and by using this cut-off, they found that 62.4% of their study population received a good outcome following surgery. If this current study had used the same MCID cut-off of ΔODI, it would have resulted in 64.44% of participants having received a good outcome following surgery, with a ΔODI score ranging from 4-60 points. This percentage rate is close to the results by Aalto et al. (2012). Therefore, the results of these studies, considering the pain improvement following LFS, do not seem to differ, but only the method of concluding the MCID.

4.2.2.2 MCID vs. surgery satisfaction

This study uses ΔODI as a measure of treatment response, but the patients were, as part of the DaneSpine questions, also asked whether they were satisfied with the treatment outcome, ranging from 1 ("I am satisfied"), through 2 ("I am in doubt") to 3 ("I am not satisfied"). Here, 66.3% stated that they were satisfied with the surgical outcome. Because of this discrepancy between treatment-response, measured as ΔODI and surgery satisfaction, the relationship between the objective and subjective surgical outcome measures was investigated.

The association between functional improvement, using ΔODI and patient-reported satisfaction with the surgical result was examined using a non-parametric correlation analysis, Spearman's rho, as the satisfaction score is ordinal (Field, 2018c, p. 472). This correlation analysis indicated a significant negative association between the two variables ($r_s = -0.52$, $p < 0.001$), which was further supported by an ordinal logistic regression (Field, 2018b, p. 1115), showing that a greater ΔODI score was associated with lower odds of patient satisfaction, when adjusting for covariates ($\beta = -0.1$, $SE = 0.01$, $p < 0.001$).

The association between these two measures of surgical outcome indicate that the patients' subjective experience of success may not fully align with the objective measures of functional improvement and that more patients are satisfied with the results of the surgical procedure than reach the more ‘objective’ criteria of MCID. It is likely that other factors, such as preoperative expectations, coping strategies, or psychological traits, play a role in patients’ perception of satisfaction, independent of the degree of functional improvement.

Another explanation of this discrepancy in surgical outcome can be the fact that old age is associated with higher satisfaction. A study by Cho & Cheon (2023, p. 2) investigated whether lifestyle affected the level of satisfaction in old age and stated that the only factor significantly affecting life satisfaction was age itself (Cho & Cheon, 2023, p. 6), meaning that the older a patient was, the higher their level of life satisfaction would be, independent of lifestyle and health. This could also be the reason why more participants are satisfied with the surgical outcome compared to the number of patients who can be considered treatment responsive, simply because older people are more satisfied. This finding is also in line with the study by Sinikallio et al. (2009, p. 540), which demonstrated that younger age was associated with higher dissatisfaction regarding surgical outcomes. Sinikallio et al. (2009, p. 541) speculate that this may be because the expectations of treatment outcomes for younger patients are higher compared to those for older patients.

4.2.3 Excluded variables

When designing this study, different covariates were chosen to be included in the analysis based on two criteria: 1) they were part of the DaneSpine database, and 2) they were, in previous studies, found to have a significant effect on pain improvement following LFS. However, some of the covariates presented in the methodological section have been removed from the final analysis, which can have influenced the level of variance of 25% that the model can explain of the ΔODI scores.

The final analysis should have included covariates such as smoking status, pre-operative sick leave, whether the patient received cash benefits, and how the patients rated their HRQoL through the EQ-5D-3L questionnaire. These covariates have all been shown to affect LFS outcomes (Aalto et al., 2012, p. 257; Asztély et al., 2019, p. 2926; Glassman et al., 2000, p. 2610f; Mannion et al., 2007, p. 101; Poder et al., 2020, p. 1; Sandén et al., 2011, p. 1061), why they could potentially have contributed to increasing the explained level of variance of the ΔODI scores as well as the accuracy of the model. However, these variables have not been included in the final analysis for various reasons. As stated previously, covariates like sick leave and cash benefits were removed from the analysis because of missing data. These questions were part of the DaneSpine database, but 71.48% of participants did not answer whether they received cash benefits, and 83.33% did not answer how long they had been on sick leave, if this was the case. These covariates were therefore removed because of missing data.

This study should also have included smoking status as a covariate, as postoperative smoking cessation significantly affects LFS surgery outcome (Glassman et al., 2000, p. 2611). However, this covariate was also removed from the analysis, as the DaneSpine database only states the smoking status of the participants at baseline, which, in itself, is shown not to affect LFS outcomes (Glassman et al., 2000, p. 2611).

Lastly, the EQ-5D-3L questionnaire was removed from the final analysis because of a lack of internal reliability. Chronic LBP is shown to affect HRQoL (Asztély et al., 2019, p. 2926; Poder et al., 2020, p. 1) and this measure was, therefore, supposed to have been included as a secondary measure of treatment outcomes as not to state improvement as just a somatic entity, but also highlight the multifaceted domains and subjective nature of pain disorders (Frølich, 2010, p. 720; Goebel et al., 2010, p. 4).

These excluded covariates could have contributed to elevating the level of variance that the model can explain, as well as maybe the degree of uncertainty surrounding the model estimates. The removal of these covariates limits the model's ability to capture parts of the multifactorial nature of surgical outcomes and may reduce the precision of the conclusions drawn from the presented analysis. It is likely that the inclusion of more psychological and behavioural covariates, e.g. smoking cessation, sick leave, cash benefits or HRQoL, could have strengthened the explanatory power of the model and provided a more comprehensive picture of the patient profiles that are most at risk of a poorer surgical outcome.

4.3 Discussion of results

The statistical analysis of this study has demonstrated that there is a negative association between attention deficits and improvement in pain following LFS. The following section will discuss the clinical relevance of these results as well as the effect of the covariates included in the final analysis.

4.3.1 Clinical relevance of results

The purpose of this study was to investigate whether the inclusion of an ADHD screening tool could improve patient selection for LFS surgery, as only between 45-72% benefit from surgery, depending on the criterion of success (Mannion et al., 2007, p. 1102), deeming a more thorough patient selection necessary.

The demonstrated association between attention deficits and pain improvement suggests that an ADHD screening tool could be beneficial in future patient selection for surgery. However, this model can only explain 25% of the variance of the participants' ΔODI scores and the model display a level of uncertainty in its predictions as seen in both the plot of the predicted ΔODI vs. observed ΔODI (Figure 18, p. 56) and the residual plot of ΔODI (Figure 19, p. 57). Therefore, this model can predict the outcome of LFS on a group level, but, as of yet, not on an individual level, where it would actually benefit the practitioner in their decision making and, in the end, the patient.

4.3.1.1 Multifactorial causations and patient selection

This study has documented that there is a negative association between attention deficits and LFS outcome, but it cannot state a causation. The theoretical background for this study presents some different possible causations, but none of them can, in this study, be either confirmed or rejected. This would require an investigation of this model in a prospective study, rather than a retrospective study, where data is collected with a hypothesis-driven purpose rather than through a preset database as DaneSpine. A prospective study would create the possibility to include more covariates that have not been possible in this project, e.g. missing data in DaneSpine or because the questions are not stated in a way where the results are associated with LFS outcome (e.g. smoking status at baseline vs. postsurgical smoking cessation).

It would also be possible to include other covariates in the model that could investigate some of the possible causations between attention deficits and LFS outcomes, not just to state whether there is an association, but also to understand the mechanisms thereof. A possible causation underlying the association between attention deficits and LFS outcomes is the anatomical brain structures which are involved in both attention deficits and pain processing. This is especially the area of the ACC (Kerekes et al., 2021, p. 3; Pinel & Barnes, 2018, p. 207), which receives information from the frontal lobe, processing attentional and executive information, and projects to the limbic structures (Cohen, 2014a, p. 354). Various fMRI studies have confirmed an alteration in functional connectivity regarding both attention deficits and pain processing (Cubillo et al., 2011, p. 196; Jadidian et al., 2015, p. 176). It would therefore be relevant to include an fMRI paradigm in a prospective study of the association between attention deficits and surgery outcome following LFS to investigate whether this anatomical overlap exists and to what extent. This could include cognitive tests like the n-back test or an emotional response test to investigate deficits in working memory or alterations in emotional processing.

In a prospective study, it would also be relevant to investigate the role of neuroinflammation, as this has been presented as an underlying causation in many studies (Kerekes et al., 2021, p. 3; Meseguer-Beltrán et al., 2023, p. 2; Song et al., 2020, p. 718). Neuroinflammatory markers could be collected through blood samples or dura puncture, as the dura mater is exposed during LFS. This would make it possible to investigate gene expressions of pro-inflammatory cytokine markers as seen in chronic pain patients and individuals with ADHD (Kerekes et al., 2021, p. 4; Song et al., 2020, p. 718f).

A prospective study would also involve a more thorough investigation of cognitive and behavioural manifestations of attention deficits to better evaluate if there is a difference in the attentional manifestations that may be affected by pain sensations (Ibrahim & Hefny, 2022, p. 3; Treister et al., 2013, p. 9). This would also include an investigation of executive functions, as these can also play a role in the cognitive and behavioural dimensions of attentional deficits (Barkley, 1997, p. 75) and pain processing (Mundal et al., 2023, p. 5). These aspects could, in a prospective study, be investigated through neuropsychological testing using validated tools like the D-KEFS test battery, Conner's Continuous Performance Test (CPT) and a more thorough screening using additional questionnaires like the Behaviour Rating Inventory of Executive Function (BRIEF), which all investigate executive functions, attention, and inhibition.

As of now, the results of this study do not demonstrate a precise enough model for screening patients for LFS. But the results do show a significant association that is relevant to investigate further to develop a more precise model for screening patients, so as to ensure that patient selection is not only based on somatic or health-related factors, but also psychosocial or behavioural factors, that would be relevant to consider to ensure treatment success.

4.3.2 The effect of covariates

The presented model has investigated the effect of ADHD symptom scores on ΔODI, including the effect of covariates, which have all previously been documented to affect the outcome of LFS. However, in this study, most of these covariates affected LFS differently than expected, except for the effect of the number of back surgeries received in total.

The total number of back surgeries a participant had received was included as a covariate, as it has been shown to negatively predict the outcome of the current back surgery (Aalto et al., 2012, p. 257). According to the results of both the ANCOVA test and the multiple linear regression, the results of this study were in line with previous studies, as it also showed that the total number of back surgeries received had a significant negative association with LFS outcome.

This study also included self-reported walking distance and ODI baseline, as these both have been shown to affect LFS outcome. A lower level of preoperative walking distance (Aalto et al., 2006, p. 651; Sinikallio et al., 2009, p. 540) and a higher ODI baseline score have been shown to predict poorer surgical outcomes (Sinikallio et al., 2009, p. 540). However, the results of this study found that a higher level of self-reported walking distance and a lower ODI baseline score predicted poorer outcomes following LFS. A study by Sinikallio et al. (2009, p. 540f) has documented that younger age was associated with higher dissatisfaction with surgical outcome, because their expectations of treatment outcome were higher. This could also be the case for patients with a higher functional baseline level, both measured as walking distance and ODI scores. The patients expect more of the postoperative surgical outcome, as their baseline level is higher, why they are more disappointed when they do not experience pain improvement to the extent they were hoping for (Sinikallio et al., 2009, p. 541).

In the study by Sinikallio et al. (2009, p. 539) surgery outcome is based on patient satisfaction assessed on a four-point Likert scale from 'very satisfied' to 'very dissatisfied'. As previously mentioned, a higher preoperative level of functionality could lead to higher unfulfilled expectations why Sinikallio et al. (2009, p. 540f) may have found that a higher ODI baseline score is associated with poorer surgical outcome, measured as patient satisfaction. However, in this current study, surgical improvement is measured as ΔODI, where a higher ODI baseline score leaves room for a larger improvement score independent of the level of satisfaction. In this study, these two measures of surgery outcome have also been shown to differ, as more participants are satisfied with the LFS outcome than have reached the MCID threshold. It was, therefore, investigated whether there was an association between ODI baseline and the level of satisfaction in this study population using Spearman's rho (Field, 2018c, p. 472), which showed that there was a weak, but significant, positive association between ODI baseline and postoperative level of satisfaction ($r_s = 0.24$, $p < 0.001$). This was also investigated using an ordinal logistic regression (Field, 2018b, p. 1115), including the covariates of the model, which showed no significant association between ODI baseline and postoperative level of satisfaction ($\beta = 0.02$, $SE = 0.01$, $p = 0.056$). Unlike the study by Sinikallio et al. (2009, p. 540), this study can document a positive significant association between ODI baseline and LFS outcome. However, this effect is no longer significant when adjusting for covariates.

According to the results of both the ANCOVA test and the multiple linear regression, the covariates sex, age at baseline, and pain medicine at baseline did not have a significant effect on ΔODI following LFS. Studies which have shown a significant effect of sex on LFS outcome have shown that the female sex is associated with a worse postoperative outcome (Aalto et al., 2006, p. 651; Andrews et al., 2017, p. 9). However, other studies have also found that sex has had no significant effect on postoperative outcome (Aalto et al., 2006, p. 651; 2012, p. 258; Mannion & Elfering, 2005, p. 98), and the result of this study is in line with these findings.

Previous studies also disagree on the effect of age on LFS, as one study has found that younger age is associated with better surgical outcomes (Aalto et al., 2012, p. 257) whereas other studies have found that older age is associated with better surgical outcomes (Aalto et al., 2006, p. 651; Mannion & Elfering, 2005, p. 98; Sinikallio et al., 2009, p. 540). It is uncertain why age at baseline does not have a significant effect on LFS in this study. But maybe patients in general do not get offered a procedure like LFS if they are either still quite young, as other non-invasive treatment options are preferred, or too old, as this is a very demanding type of surgery. Therefore, patients who are either very young or very old compared to the study group's mean age of 56.29 may have already been sorted out of the patient population before surgery, so the age of the remaining participants, who have received surgery, will not interfere with the results.

Lastly, this study also included whether the participants took pain medication at baseline as a covariate, as studies have shown that a longer duration of analgesic use is associated with poorer surgical outcomes (Aalto et al., 2012, p. 257). However, this study has only documented whether the participants took pain medication before surgery and not the duration of analgesic use, as this time frame is not included in the DaneSpine questions. As this covariate had no significant effect on postsurgical outcome, it could indicate that whether the patients take pain medication, without the time frame, is not associated with postsurgical outcome. This time frame of analgesic use would need to be included in a future analysis.

4.4 Limitations

This study has some limitations that are relevant to consider. First, there is a potential response bias in the patient cohort since approximately 49% (6,667 of 13,583) were excluded from the dataset because they did not have any follow-up data. There can be more reasons for this missing data: maybe data is collected but not uploaded to the DaneSpine database. But another possibility is that these patients have just not answered the follow-up questionnaires that were sent out as part of their surgical treatment plan. This could result in a bias where these patients could be significantly different from the patients who have answered the follow-up questionnaires. Maybe the patients who have answered the questionnaires are doing significantly better than the ones who have not answered the questionnaires, why they found the time and resources to do so. Or maybe, the ones who have not answered the questionnaires are doing significantly better than the ones who have answered, why they have not found it as important to do so. Because these excluded patients consist of 37.66% of the entire patient cohort, they could have substantially changed the results of this study, if they were significantly different, why they would have been relevant to include if this was a possibility (Mouritzen, 2024, p. 34). However, based on the available data, it is not possible to determine in what direction these 'missing' participants would drive the results of this study.

Another limitation of this study is that data is only collected from one hospital department, the Department of Back Surgery, Joint, and Tissue Disease at

Rigshospitalet-Glostrup. Expanding this study to include data from multiple hospitals across regions could validate the findings of this study and ensure the applicability to a broader population (Mouritzen, 2024, p. 34f).

5. Conclusion

This study aimed to investigate whether attention deficits, measured through the ASRS Screener (Section A), were associated with pain improvement following lumbar fusion surgery, measured as ΔODI, in patients with chronic low back pain. Pain is a multifaceted and subjective phenomenon; therefore, the inclusion of cognitive domains, such as attention deficits, is relevant to investigate in determining whether this should be included in a future screening process for patients undergoing lumbar fusion surgery.

To capture the complexity of pain disorders, the association between chronic pain and attention deficits have been theoretically investigated through both a neurobiological, a cognitive, and a behavioural perspective. These three domains all highlight intertwined causations and possible explanations as to why this association exists. However, the results of this study cannot state a causal relationship between these, and further studies are needed. Subsequent studies should include more factors that could highlight the effect of cognitive and psychological domains on pain disorders and pain treatments.

The final study population comprised 270 former chronic low back pain patients who had received lumbar fusion surgery. The results of this study highlight that there is a need for a more thorough screening process, as only 51.48% of participants reached the threshold for a minimum clinically important difference in disability following surgery. The results also show that 17.41% of the study population reached the threshold for a possible ADHD diagnosis, which is much higher than in the adult Danish background population, where only 1-3% have a diagnosis of ADHD. The statistical analysis of this study further demonstrated that there is a negative association between attention deficits and pain improvement following lumbar fusion surgery. This is shown both as a group difference between ADHD risk groups, dichotomised through the scores of the ASRS Screener (Section A), and as a correlation between ASRS scores and ΔODI. This study, therefore, concludes that the ASRS questionnaire would be a relevant additional screening tool in future screening and patient selection for lumbar fusion surgery.

However, the results of this study demonstrate a variance of 25% of the ΔODI and a level of uncertainty. This emphasises that even though this study has found a significant association between attention deficits and pain improvement, more studies are needed to validate these results. The inclusion of more variables investigating the cognitive, behavioural, and psychosocial domains of the pain patient, as stated in Saunders' Total Pain Theory, would be beneficial as to meet the future pain patient not just as a somatic patient, but with an understanding of all the facets of a patient's life that the pain disorder affects and how to best offer other or supplementary treatment options relevant for this patient group.

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