# Digital Back Care for Children

## Evaluating a Multidimensional Prevention Program for Primary School Children

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# Summary

Postural deviations are common in childhood (Batistão et al., 2016; Wilczyński et al., 2020; Yang et al., 2020) and continue to change significantly throughout various growth phases (Dolphens et al., 2012; Lafond et al., 2007). It is assumed that postural misalignments may place dysfunctional strain on the musculoskeletal system, potentially leading to chronic pain or functional impairments later in life (Sharma & Rawat, 2023). Although empirical findings on the direct relationship between posture and back pain remain inconclusive (Kamper et al., 2016), back pain is also recognized as a relevant health issue even in early developmental stages. It is highly prevalent across the population and is associated with considerable costs for healthcare systems (WIdO, 2023). These complaints are already present in childhood, with prevalence increasing with age (Greiner et al., 2018; Krause et al., 2019).

Building on this background, the present thesis examines body posture and back pain in middle childhood, while also exploring the relevane of the diagnostic tool (Study 1) and their connections to other physical and psychological health dimensions during this important developmental period (Study 2 and 3).

Study 1 focused on comparing two commonly used diagnostic tools for posture assessment in children: a visual orthopedic examination and a rasterstereographic scan conducted with the DIERS formetric system. While both methods identified a high prevalence of postural deviations in the third-grade sample, the technical scan detected significantly more abnormalities, particularly in spinal curvature. These discrepancies highlight methodological differences in detection thresholds and raise important questions regarding the cost-benefit ratio and accessibility of different tools in the context of postural assessment.

Studies 2 and 3 examined children’s body posture in relation to additional physical and psychological factors. While Study 2 focused on identifying correlations between these variables, Study 3 employed a longitudinal design to explore potential causal relationships. Both studies were conducted as part of the project “BackFit – From the Very Beginning – For a Lifetime”. Study 2 focused on the associations between body posture, muscular fitness, psychological well-being, self-compassion, and physical self-concept, based on data collected during the pretesting of the intervention. The results revealed associations within the physical and within the psychological dimensions, but no significant connections were found between any physical and psychological variables. Study 3 evaluated the feasibility and effectiveness of a digital back-care program designed for children aged 7 to 11 years. The 12-week intervention combined physical exercises with educational content aimed at improving knowledge about the structure and function of the back, as well as postural awareness. Delivered through an interactive, web-based platform, the program targeted improvements in posture, muscular fitness, and psychological well-being, including self-compassion and physical self-concept. The active control group followed a parallel 12-week program delivered through the same platform, consisting of weekly educational videos on general health promotion topics without a specific focus on back health. While the program led to improvements in back-related knowledge and self-compassion, no significant effects were observed in the other assessed domains.

Taken together, the three studies contribute to a more differentiated understanding of postural health in middle childhood and highlight the importance of better understanding psychophysical development and its trajectories during this critical period.

# 1 Theoretical Background and State of Research

This chapter outlines the theoretical foundations and empirical evidence surrounding posture as a multidimensional construct in childhood. It begins by defining posture and highlighting its developmental relevance, before discussing its diagnostic assessment, physical correlates, and psychological connections. Finally, it introduces preventive perspectives and sets the stage for the empirical studies presented in this dissertation.

## 1.1 Posture as a Multidimensional Construct

Various definitions and perspectives exist regarding human posture. Massion et al. (2004) distinguish three principal conceptualizations. The first principal conceptualisation, originally proposed by Thomas (1940), defines posture as the configuration of body segments at a given moment in time. The second perspective emphasizes the supportive role of proximal body segments and their corresponding musculature in facilitating goal-directed movements of distal segments. The third conceptualization focusses on maintenance of posture as the stabilization of body segments relative to one another or within space, particularly in response to external disturbances. Beyond these principal conceptualisations, posture can also be viewed more broadly as a psychomotor habit that is closely connected to somatic development, body composition, and neuromuscular coordination (Wilczyński et al., 2020). Proper posture relies on symmetrical body alignment, supported by a well-functioning nervous system, musculature, and motor skills (Grabara et al., 2017). Conroy et al. (2022) emphasize in their definition of good posture that it serves to protect the body's supportive structures from injury or long-term deformation, regardless of the body's position.

During childhood and adolescence, posture plays a crucial role in overall health, as rapid physical growth increases the risk of postural defects (Brzęk et al., 2017). Posture adapts to the ongoing process of musculoskeletal maturation with the goal of preserving a stable alignment in the sagittal plane and ensuring a load distribution that supports healthy spinal curvature development (Lafond et al., 2007). Within this process of postural development, school age and puberty represent critical phases of change (Dolphens et al., 2012). Brzęk et al. (2017) additionally highlight that, alongside growth-related changes, the lifestyle shifts toward increased sedentariness, such as prolonged sitting in school, television viewing, and computer use. These changes typically occur with the onset of formal schooling, when children become increasingly bound to static daily routines. The authors state these factors as negative influences on the development of postural disorders. These imbalances may lead to chronic pain, functional impairments, and a diminished quality of life (Sharma & Rawat, 2023).

Postural control, defined as the ability to attain and maintain a desired body position during both static and dynamic conditions (Verbecque et al., 2016), undergoes significant developmental change between the ages of 7 and 9 (Roncesvalles et al., 2005). This developmental period is also marked by the formation of an internal representation of the body’s position and structure in space (Roncesvalles et al., 2005).

Given its close links to motor skills, neuromuscular coordination, and physical well-being, posture is regarded as a key factor in child development.

For example, good posture is vital for physical health. Back problems, such as musculoskeletal issues, are widespread, leading to substantial healthcare costs (WIdO, 2023). Among the younger population, this is already a significant concern. According to a survey by the German health insurance company DAK, 43% of students reported suffering from back pain, and 20% experienced it weekly (Greiner et al., 2018). Additionally, the second wave of the German Health Interview and Examination Survey for Children and Adolescents (KiGGs), conducted from 2014 to 2017, showed a significant increase in the three-month prevalence of back pain compared to the first wave of the survey from 2003 to 2006 (Krause et al., 2019). The prevalence of back pain increases as children grow older, reaching rates similar to those of adults (Greiner et al., 2021; MacDonald et al., 2017; WIdO, 2023). In adulthood, back pain remains one of the most common health complaints (Lippe et al., 2021).

Postural abnormalities are also frequent during childhood (Batistão et al., 2016; Weigel et al., 2024; Wilczyński et al., 2020; Yang et al., 2020). Studies indicate that children who do not participate in sports are more likely to exhibit postural abnormalities than physically active ones (Kratenová et al., 2007). While it is widely assumed that these abnormalities are connected to back pain, this has not been conclusively established (Kamper et al., 2016). Studies have yielded mixed results regarding the relationship between body posture and back or neck pain, with some literature stating no such connection (Kripa & Kaur, 2021; Martinez-Merinero et al., 2020). In children, poor posture was connected to headache and spinal pain in an observation in the Czech Republic (Kratenová et al., 2007). In adult females, pelvic position may contribute to the development of severe back pain (F. Araújo et al., 2014). In addition, poor postural patterns may lead to reduced strength and endurance in the muscles that stabilize the spine (Dima et al., 2022), which could be a predictor for low back pain, as suggested by various studies (Hamberg-van Reenen et al., 2006; Heneweer et al., 2012). Moreover, body posture has been found to predict hand, neck, and shoulder pain in a work setting (Arefian et al., 2023; Mahmoud et al., 2019), while forward head posture also connects to neck pain in adults (Mahmoud et al., 2019). In elderly populations, changed postural alignment has been associated with knee pain (Tsuji et al., 2002) and increased risk of falling in females (Balzini et al., 2003).

Although the mechanisms of these associations remain partly unclear, the relevance of postural analysis in both clinical and public health contexts is undisputed. Moreover, posture may not only reflect physical but also psychological states. According to embodiment theory, bodily states and mental processes are interrelated and influence each other bidirectionally (Niedenthal, 2007). Therefore, postural alignment can influence mood, self-perception, and general psychological functioning (Michalak et al., 2012). These theoretical and empirical connections between posture and psychological health will be further examined in Section 1.5.

Given that the primary school years represent a critical phase of postural and musculoskeletal development and considering the long-term health relevance of postural patterns established during this period, early preventive efforts become especially important. Addressing posture at this stage may not only support physical functioning but also contribute to the development of psychological resilience and self-related competencies.

Early identification of postural abnormalities is therefore essential to prevent potential issues arising from these defects (Liebenson, 2008; Wallden, 2009). Because adolescent spinal pain has been identified as a predictor of spinal pain in adulthood (Jeffries et al., 2007), early prevention programs are needed, as also highlighted by Yang et al. (2020). Preventive interventions may be particularly important when movement patterns and postural habits are established during primary school age (C. L. Araújo et al., 2023). Declining physical activity and increasing sedentary behavior, driven in part by technological change, further contribute to early risk factors for spinal health issues (Skoffer & Foldspang, 2008; Woessner et al., 2021). Therefore, targeting postural health early on may serve not only to improve physical outcomes but also to foster long-term resilience, well-being, and healthy development overall.

### 1.2 Assessment of Posture in Childhood

Building on the developmental relevance of posture outlined in Section 1.1, reliable assessment methods are essential for early detection of deviations and prevention. Various evaluation methods, including X-rays, 3D MRI, spine scans, mobile applications, and orthopedic examinations, assess posture and identify orthopedic abnormalities (Brzęk et al., 2019; Degenhardt et al., 2020; do Rosário, 2014a, 2014b; Moreira et al., 2020; Sukadarin et al., 2016). These technological assessment methods aim to reduce errors and optimize efficiency (Roggio et al., 2021). Due to their reproducibility and precision, such tools are suitable for both scientific and clinical application (do Rosário, 2014b).

One widely used non-invasive method for spinal scans is rasterstereography, which is often conducted with the Diers formetric system (DIERS International GmbH, 2024). In this approach, a light strip pattern is projected onto the back surface and captured by a camera. The software analyzes the line curvatures and employs photogrammetry to create a three-dimensional image of the back surface. Additionally, the 3D coordinates of the spine are calculated from specific landmarks using triangulation and are digitally displayed (Drerup, 2014). This static analysis of various postural parameters quantifies posture regarding angles and distances (Lason et al., 2015).

Despite technological advances, traditional clinical assessments remain widespread. In routine medical practice, initial assessments are conducted through visual evaluation, relying on the examiner’s experience (Ludwig et al., 2023). Musculoskeletal evaluations conducted by orthopedic specialists demonstrate high specificity for detecting early signs of dysfunction (Scaturro et al., 2021). These examinations assess many areas of the spine and lower extremities for their function, including spinal rotation, lateral inclination, and gait analysis. Such movements are integral to everyday life and allow the examiner to assess limitations in postural function. This is especially important as many back issues cannot be attributed to one specific anatomical abnormality in the spine (Don et al., 2012).

Rasterstereography presents a valid and reliable analysis method for assessing the back surface and spinal parameters (Guidetti et al., 2013). However, opinions are mixed regarding its potential to replace X-rays and reduce the need for repeated radiographs in high-precision posture analysis required to verify or monitor the progression of spinal deformities such as scoliosis (Bassani et al., 2019; Mohokum et al., 2015; Wanke-Jellinek et al., 2019). Measurement variability between sessions has been reported, possibly due to minor variations in body positioning, breathing patterns, or postural sway (Degenhardt et al., 2017; Guidetti et al., 2013; Lason et al., 2015; Schroeder et al., 2015). Moreover, soft tissue distribution may interfere with landmark identification, especially in the pelvic region (Degenhardt et al., 2017; Schroeder et al., 2015).

Manual assessments, particularly in pediatric orthopedics, are vulnerable to subjective influences. Lengthy orthopedic exams may suffer from rater fatigue or varying examiner consistency (Fortin et al., 2011). This suggests that factors influencing orthopedic assessments may affect the subject and the examiner. X. Liu et al. (2020) emphasize that while expert knowledge is essential for functional assessments, examiner bias remains a central challenge. Other studies confirm that professional judgment is influenced by contextual and cognitive factors over time (Eva, 2018; Hamers et al., 1994). However, manual posture assessments by the same evaluator have proved reliable (Takatalo et al., 2020). Repeated exams by the same specialist allow the use of knowledge gained in previous exams to identify causes or propose treatments for detected issues (Gross et al., 2016). In children, this could include knowledge about the patient's growth, which can influence posture due to changes in body proportions (Latalski et al., 2013).

Importantly objective methods like rasterstereography conducted with the DIERS formetric system limit potential sources of subjectivity in orthopedic assessments by capturing and analyzing the spinal curvatures automatically.

Although the higher objectivity of rasterstereography supports its use for posture analysis, its application in everyday clinical practice is limited. According to Ludwig et al. (2023), this method is rarely employed in many areas due to the high acquisition costs of the technological systems. Other research teams also scrutinize the benefit-cost relationship of rasterstereographical scans in everyday practice (Vendeuvre et al., 2023).

Additionally, in clinical practice, objectively measured data still need to be interpreted by a specialist, thereby raising the dependence on the examiner's experience and the potential for rater bias.

### 1.3 Muscular Fitness and Postural Control

Building on the preceding sections, this chapter examines how muscular fitness interacts with posture and highlights its broader significance within developmental health frameworks.

Stodden et al. (2008) proposed a conceptual model positing a relationship between motor skill competence and physical activity, mediated by perceived motor competence and health-related fitness. The model further suggests that all four factors are linked to weight status, with these associations strengthening throughout childhood. This framework contributed to a shift in motor development research toward public health relevance (Barnett et al., 2022). Building on a systematic review of studies testing the connections proposed in Stodden’s model, Lima et al. (2022) expanded the framework by incorporating additional child and adolescent health outcomes. These include metabolic health, mental health, cognition, and academic performance, each hypothesized to be directly linked to motor competence, physical activity, health-related fitness, and weight status. In light of this extended framework, a comprehensive evaluation of a broader range of components and their connections becomes essential.

In the proposed expansion, Lima et al. (2022) call for empirical testing of the model’s extended pathways. As motor competence and physical activity lie at the core of both the original and extended models, most existing studies have focused on this connection (Barnett et al., 2022). While this section emphasizes the physical dimension, namely the role of muscular fitness in supporting posture, the psychological constructs introduced in developmental models will be discussed in greater detail in the subsequent sections.

Muscular fitness has been extensively studied for its health benefits and has been consistently situated within the health-related fitness component of Stodden's model (Barnett et al., 2022). Among children and adolescents, higher levels of muscular fitness have been associated with lower obesity risk, better cardiovascular health, and improved bone development (Smith et al., 2014). In light of declining fitness levels, Faigenbaum et al. (2020) emphasize the importance of prioritizing muscular fitness in physical activity guidelines to support long-term health outcomes. In our analysis, different components of muscular fitness, such as trunk flexor and extensor endurance as well as functional mobility, are considered. While these components show no clear associations in adult populations (Okada et al., 2011), weak correlations have been observed in children (Mitchell et al., 2015), suggesting that the relationships between different components of muscular fitness may vary by age.

Beyond these general health benefits, muscular fitness seems to be connected to body posture. Muscular strength and functional movement have been linked to improved postural alignment, particularly among overweight children (Molina-Garcia et al., 2020). Postural anomalies have also been associated with reduced trunk strength, suggesting that targeted core strengthening may contribute to correcting postural imbalances (Barczyk-Pawelec et al., 2015). Postural deviations have also been linked to weakened spinal muscles (Dima et al., 2022), which may serve as predictors for the development of low back pain (Heneweer et al., 2012).

## 1.4 Psychological Constructs Relevant to Child Health

Childhood is a pivotal period for shaping psychological development and self-related constructs, many of which have lasting effects across the lifespan (Schlack et al., 2021). Drawing on Stodden's conceptual framework and its subsequent extensions, this section outlines three psychological variables, which are among others relevant to child health and development: psychological well-being, self-compassion, and physical self-concept. Particular emphasis is placed on the developmental characteristics of these psychological constructs in childhood and their relevance to health-related behavior, before exploring their potential connections to body posture in Section 1.5.

### *1.4.1 Psychological Well-Being in Childhood*

Among the key domains is psychological well-being, which has been identified as one of five distinct dimensions of child well-being (Pollard & Lee, 2003). Psychological well-being is a multifaceted construct encompassing positive mental, psychological, and emotional states that foster personal growth and life satisfaction. Core components include resilience and self-concept, while factors such as loneliness, depression, and self-esteem are also frequently examined under this umbrella (Abed et al., 2016). Psychological well-being encompasses positive states that reflect the mental, emotional, and psychological dimensions of an individual's life, contributing to personal growth, flourishing, and a sense of thriving (Linley & Joseph, 2004).

This construct has also been specifically conceptualized for children. According to the National Health Service in England, children with high levels of psychological well-being demonstrate a broad range of developmental competencies. These include the ability to grow emotionally, intellectually, creatively, and spiritually; to form and maintain fulfilling interpersonal relationships; and to engage with solitude in a constructive manner. Furthermore, such children are capable of empathizing with others, participating in play and learning, developing a moral understanding, and coping with challenges in ways appropriate to their developmental stage (Dwivedi & Harper, 2004).

Psychological well-being in children has been linked to various life outcomes, including the likelihood of developing mental health disorders, educational achievement, and overall quality of life. Moreover, psychological well-being has been associated with school-related success and has garnered considerable interest within educational settings (Amholt et al., 2020). Research further shows that psychological well-being in adults is positively associated with higher levels of self-compassion (López et al., 2018).

In our studies, self-concept was selected as a central indicator of psychological well-being and is positioned within Stodden's model in the domain of mental health. Self-concept has been identified as a component of psychological well-being and has frequently been used as one of the representative constructs in various studies (Kroesbergen et al., 2016; Neihart, 1999). The self-concept undergoes notable changes during childhood, particularly with the introduction of external influences such as school. While most children enter school with a positive self-concept, the start of formal education brings more achievement-based evaluations and social comparisons. As cognitive abilities develop, children's self-assessments become more realistic and often less positive between the ages of 6 and 8, making this a critical period for assessing well-being (Kroesbergen et al., 2016). This developmental shift, influenced by social and cognitive maturation, illustrates the interdisciplinary relevance of self-concept research in childhood (Brummelman & Thomaes, 2017).

### *1.4.2 Self-Compassion in Child Development*

Self-compassion was examined as a distinct construct in Study 2. However, due to its strong theoretical and empirical association with psychological well-being, it was conceptually grouped with self-concept under the broader dimension of psychological well-being in Study 3. Self-compassion has been increasingly studied for its role in emotional regulation and the reduction of distress and it is often conceptualized as an attitude or coping style (Neff, 2003).

Neff (2023) defines self-compassion as a continuum with three core elements: mindfulness over over-identification, connection over isolation, and self-kindness over self-criticism. According to Neff (2023), these aspects are interrelated and mutually reinforcing. In research, alongside the six factors mentioned above, the negative and positive poles of self-compassion are often examined separately. Gilbert (2005) suggests that the two poles are based on distinct processes, the parasympathetic soothing system and the sympathetic threat system, and differ in their affective and physiological responses. They are also associated with different psychological outcomes, with the negative pole of self-compassion more strongly linked to emotional distress and indicators of psychopathology (Neuenschwander & Gunten, 2025).

In adolescents, self-compassion has been linked to improved psychological and physical well-being as well as reduced depression, anxiety, and stress (Egan et al., 2022; Marsh et al., 2018; Sutton et al., 2018). However, research on self-compassion in younger children remains limited (Sutton et al., 2018). Therefore, little is known about how self-compassion develops, how it manifests at different ages, and how it affects children's behavior and well-being (Neuenschwander & Gunten, 2025). Although interventions have been observed to effectively increase self-compassion, the underlying processes and specific components driving this effect are still unclear (Neuenschwander & Gunten, 2025). Neuenschwander and Gunten (2025) suggest that one possible reason for the limited investigation of self-compassion in childhood is that the necessary cognitive and emotional abilities are still developing at this age.

### *1.4.3 Physical Self-Concept*

Closely related to the physical dimensions observed in this work is the construct of physical self-concept, which plays a key role in shaping children's perceptions of their abilities. In the hierarchical model of self-concept proposed by Shavelson et al. (1976), physical self-concept is positioned within the non-academic domain, alongside the components of social and emotional self-concept. It is sometimes referred to as physical self-perceptions and encompasses perceptions of physical ability and appearance (Babic et al., 2014). The component assessing general athleticism has been further differentiated into strength, endurance, mobility, coordination, and speed (Stiller et al., 2004).

In some studies, the construct of perceived motor competence, as referenced in Stodden's model, has been used synonymously with physical self-concept (Utesch et al., 2018), while in others it has been narrowly defined as the evaluation of one's athletic abilities (Barnett et al., 2016). In the present work, we include all subscales of the physical self-concept and classify them under the umbrella of perceived motor competence.

Research suggests that physical self-concept influences physical activity, obesity, health-related fitness, and life satisfaction in children and adolescents (Dreiskämper et al., 2015). Furthermore, it is considered a key factor in the development of a healthy, active lifestyle through adolescence, although its exact role in this process remains unclear, as highlighted in a comprehensive meta-analysis (Babic et al., 2014).

Physical self-concept is also linked to other psychological constructs examined in this work. For instance, low physical self-concept has been associated with lower psychological well-being in children (Delgado-Floody et al., 2022). In comparison, a more positive physical self-concept is linked to higher psychological well-being in this age group (Dreiskämper et al., 2015). Furthermore, interventions aimed at enhancing self-compassion have been shown to reduce self-critical behavior (Wakelin et al., 2022), which may indirectly affect how children evaluate their physical self.

## 1.5 Posture, Muscular Fitness and Psychological Health in Children

Building on the psychological constructs discussed in the previous section, the following part integrates these variables with the physical domains of posture and muscular fitness. In doing so, it draws on the developmental health frameworks proposed by Stodden and Lima to explore how physical and psychological factors are interrelated during childhood.

### *1.5.1 Muscular Fitness and Psychological Constructs*

Beyond its physical health benefits, muscular fitness has also been associated with a range of psychological outcomes in children and adolescents. Studies have shown positive correlations between muscular fitness and psychological well-being, self-esteem, and physical self-perceptions in children and adolescents (Bermejo-Cantarero et al., 2021; Smith et al., 2014). Moreover, research suggests an indirect pathway between muscular fitness and self-compassion. For example, self-compassion has been found to correlate positively with physical activity in adolescents, which in turn is linked to higher muscular fitness levels (Barnett et al., 2022; Martínez-Gómez et al., 2011; Wong et al., 2021).

### *1.5.2 Embodiment: Connecting Posture and Psychological Aspects*

Posture is introduced here as an additional, theoretically and empirically relevant variable that has not yet been formally integrated into the described developmental models. Although not explicitly included in Stodden’s framework, posture shows associations with two of its key components: weight status and physical activity. For instance, physical activity level and body composition have been shown to influence posture (Wyszyńska et al., 2016). Moreover, Calcaterra et al. (2022) highlight that obesity may contribute to poor posture, which in turn can limit participation in physical activity. A meta-analysis by Salsali et al. (2023), reported a weak correlation between physical activity and posture. However, as regression analyses revealed no significant associations, the authors emphasize the need to further investigate the potential influence of additional biopsychosocial factors on postural development. These findings suggest that posture deserves closer examination within this framework, particularly given its potential bidirectional relationships with health-related behavior.

To understand how posture may relate to psychological functioning in children, the embodiment framework offers a promising theoretical perspective that links bodily states with emotional and cognitive processes. As mentioned in Section 1.1, embodiment theory posits that bodily states and mental processes are functionally connected and mutually influential (Michalak et al., 2012; Niedenthal, 2007). Sensorimotor, affective, and cognitive systems are considered dynamically intertwined, allowing bodily experiences to shape emotional and cognitive outcomes (Niedenthal, 2007). Building on this theoretical foundation, contemporary psychological models and empirical research underscore the bidirectional relationship between posture and emotion, showing that body positions not only reflect affective states but can also actively shape them (Michalak et al., 2014; Niedenthal, 2007; Riskind & Gotay, 1982). Research on the psychological effects of body posture typically focuses on two main approaches: one focusing on slumped versus upright sitting postures, and the other on expansive power poses (Lin & Broadbent, 2023). For instance, upright body posture has been linked to positive effects on affect and fatigue in individuals with mild-to-moderate depression (Wilkes et al., 2017). In contrast slumped posture is commonly observed in those with this clinical condition (Dehcheshmeh et al., 2024). Two recent meta-analyses highlight moderate psychological effects of body posture. The first, by Elkjær et al. (2022), found significant effects of posture on various affective and behavioral outcomes such as feelings of power, mood, and risk-taking. These effects were observed for expansive versus contracted and contracted versus neutral postures, but not for expansive versus neutral postures. Körner et al. (2022), in a more comprehensive analysis of 117 studies, found that significant effects were mainly driven by comparisons involving slumped or low-power postures, whereas upright or high-power poses showed weaker and more variable results. Both reviews observed effects primarily in self-report and behavioral outcomes, with little evidence for physiological changes, likely due to the small number of studies addressing such measures.

In children, upright posture has been found to acutely improve psychological state, suggesting a potential link between postural alignment and psychological well-being even in younger populations (Inagaki et al., 2018). In addition to these findings, Briñol et al. (2009) found that upright, confident posture influences self-evaluative confidence, potentially shaping how individuals assess their own bodies and thus impacting physical self-concept. Furthermore, mindfulness practices that incorporate focused body postures, such as in yoga exercises, have been shown to increase self-compassion, suggesting a possible link between posture and self-compassion (A. R. Beck et al., 2017).

In summary, embodiment theory provides a conceptual framework for understanding how posture may influence self-related psychological functioning in children. Beyond posture itself, body awareness has been linked to increased levels of physical activity (Kalkışım et al., 2023), and embodiment theory suggests that improvements in posture and bodily awareness can positively influence psychological well-being (Michalak et al., 2012). This aligns with broader findings on the link between physical activity and mental well-being in children (LaVigne et al., 2016).

While prior research has pointed to various associations between posture and psychological outcomes, the existing evidence remains inconsistent, particularly in younger populations. This highlights the need for more targeted research on these relationships. These interactions may be especially relevant during middle childhood, a phase characterized by marked development in motor skills, self-perception, and social awareness (DelGiudice, 2018).

## 1.6 Preventive Approaches to Postural Health

Following the outlined interactions between posture, muscular fitness, and psychological constructs, this section focuses on preventive strategies to promote postural health in childhood. Emphasis is placed on early intervention, evidence-based programs, and the growing role of digital formats. Considering the rapid development of posture, muscular fitness, and psychological health during middle childhood and their relevance for long term health (DelGiudice, 2018), early intervention appears crucial to support healthy development and prevent the consolidation of unfavorable patterns.

Exercise-based interventions have shown promising effects in reducing lower back pain among children (Michaleff et al., 2014). A review by Kamper et al. (2016) found that prevention programs combining physical exercise with educational content are more effective in reducing back pain in children and adolescents than home exercise alone or no intervention. However, the overall quality of evidence remains limited, primarily due to the small number of controlled studies in young populations.

Back-care interventions that include educational content have also been effective in improving back-related knowledge among school-aged children (Dullien et al., 2018). Additionally, a posture training program implemented in schools and involving parental engagement over a period of 9 to 10 months led to improvements in both postural alignment and postural behavior among children aged 7 to 9 years (Brzek & Plinta, 2016). Moreover, studies indicate that core conditioning programs can enhance trunk muscle endurance in school-aged children (Allen et al., 2014), while functional mobility has been associated with physical activity and core strength (Duncan & Stanley, 2012; Mitchell et al., 2015). This emphasizes the potential benefits of structured exercise interventions.

Although interventions aimed at reducing sedentary behavior and increasing physical activity have been shown to improve psychological well-being in children and adolescents, the effects appear more pronounced in adolescents (Rodriguez-Ayllon et al., 2019). This highlights the importance of age-appropriate interventions that address not only physical dimensions such as core strength and mobility, but also psychological aspects like self-concept and emotional well-being. Yet, programs that systematically combine physical and psychological components remain scarce, underscoring the need for multidimensional approaches such as the one examined in this research.

Program adherence and the development of sustainable habits are key determinants of effectiveness in child-focused back-care interventions (Hill & Keating, 2016). However, maintaining engagement, especially in younger children, remains a challenge. Hill & Keating (2016) highlight that long-term engagement is particularly difficult in younger populations and emphasize the need for more engaging approaches. To enable meaningful participation, the program content and the assessment procedures must be tailored to children’s developmental stage, age, and cognitive abilities (Mauthner, 1997). Addressing these challenges calls for innovative strategies to enhance the accessibility and effectiveness of preventive programs. One increasingly relevant strategy is digital health promotion.

The importance of digital health promotion is growing as a key strategy for engaging young people in preventive and health-promoting interventions (Ferretti et al., 2023). It offers several advantages, including broad accessibility, cost-effectiveness, and flexible personalization. Moreover, digital formats can foster social connections, which may serve as an additional source of motivation. However, it is essential that such programs are evidence-based and their effectiveness systematically evaluated (Koh et al., 2021). A further strength of digital health interventions is the opportunity to gamify health-related habits and content, which has been shown to increase engagement and adherence, particularly among younger populations (Suleiman-Martos et al., 2021). Adolescents and young adults are the primary users of digital health applications and are generally familiar with technological devices (Lupton, 2021). While most research has focused on these age groups, digital interventions have also been applied in younger populations. They demonstrated success in areas such as reducing sedentary behavior, increasing physical activity (Oh et al., 2022), and supporting the prevention and treatment of childhood overweight, including nutrition (Qiu et al., 2022; Suleiman-Martos et al., 2021).

### 1.7 Integrative Framework

Building on the previously outlined findings, this section synthesizes the physical, psychological, and preventive components of child development, with posture serving as a central integrating construct across all three studies.

Despite the recognition of posture as a relevant health indicator, research on preventive programs for children remains limited compared to adult populations (Foster et al., 2018; Kamper et al., 2016). Most existing approaches focus on physical parameters such as postural alignment and muscular endurance, while psychological constructs, such as self-concept and self-compassion, are rarely addressed in this context (Dugan, 2018). Given the influence of psychosocial factors on back pain (Kamper et al., 2016), a comprehensive, multidimensional framework is needed for effective early prevention.

To address this gap, the present dissertation combines three complementary studies that examine different layers of this multidimensional framework. The first study focused on the methodological comparison between visual and technical posture assessments in school-aged children, highlighting practical and diagnostic challenges in pediatric screening. The second study investigated the associations between physical factors, such as muscular fitness and posture, and psychological constructs, including psychological well-being, self-compassion, and physical self-concept. In doing so, it explored the theoretical foundations of embodiment and integrative health in middle childhood. The third study evaluated a digital back-care program designed to promote both physical and psychological health outcomes, testing the feasibility and effectiveness of a web-based, child-centered intervention. Together, these studies aim to contribute to the development of an integrative framework for child health promotion by combining empirical insights from diagnostics, cross-sectional associations, and intervention research. Based on this framework, the next chapter summarized the state of research before outlining the specific research questions and objectives of the dissertation.

# 2 Summary of the State of Research

Existing research recognizes posture as a complex, multidimensional construct influenced by physical, psychological, and behavioral factors. In childhood, posture is shaped by various developmental processes and undergoes continuous changes. Empirical evidence links poor posture to musculoskeletal complaints and reduced well-being, although findings on causal relationships remain inconclusive. While technological methods for assessing posture have advanced, their application in scientific, clinical, and educational settings remains challenging due to cost, interpretive complexity, and the wide variety of available methods. Muscular fitness has consistently been associated with postural control and broader health benefits, including psychological outcomes such as self-esteem and psychological well-being. Psychological constructs like self-compassion and physical self-concept are increasingly acknowledged as important within developmental frameworks but are still rarely examined in relation to postural health. Furthermore, preventive approaches that integrate physical and psychological components remain scarce, despite theoretical support and preliminary evidence suggesting their potential. These gaps emphasize the need for integrative, developmentally appropriate, and empirically grounded interventions targeting posture and related health outcomes in children. Based on this, the following thesis adresses posture in children from a comprehensive point of view, conducting three separate studies.

Study 1 aims to compare a commonly used visual clinical assessment with a rasterstereographic measurement of posture in primary school children.

Study 2 focuses on associations between posture, muscular fitness, and psychological constructs such as physical self-concept, psychological well-being and self-compassion in a sample of primary school children.

Building on Study 2, Study 3 evaluates the effectiveness of a digital back health program using the same sample. The study focuses on changes in posture, muscular fitness, back-related knowledge, as well as self-compassion and physical self-concept as indicators of psychological well-being.

# 3 First Study

## Comparison between rasterstereographic scan and orthopedic examination for posture assessment [1]

### 3.1 Goals and Hypotheses

There has been no direct comparison of postural assessment between visual orthopedic examinations and more technical diagnostic instruments, especially in young subjects. Therefore, this study aims to compare the postural assessment conducted by an orthopedic specialist with that provided by a rasterstereographical spine scan in elementary school children. Given the various factors that could influence the examiner's observations and the high objectivity of rasterstereographical scans, we anticipate differences in results, with the DIERS scan potentially identifying more orthopedic abnormalities.

### 3.2 Methods

#### *3.2.1 Participants*

The study was designed as an observational study. The study protocol was submitted in advance to the Ethics Committee of the University of Regensburg and received a favorable vote (No. 18-981-101). One hundred twenty children (the entire 3rd

[1] The results presented in this chapter were published in advance in: Weigel, S., Grifka, J. & Jansen, P. (2024). Comparison between rasterstereographic scan and orthopedic examination for posture assessment: an observational study. *Frontiers in Surgery, 11,* 1461569. https://doi.org/10.3389/fsurg.2024.1461569. The structure and order of content presented here may differ slightly from the published version.

grade of the local primary school) were invited to participate in the study. The school was chosen due to its proximity to the examination site. Due to logistical and staffing constraints, the number of cases was limited to 60 children. Therefore, only the third grade was invited to participate to get a more homogenous sample (120 children total). The study management contacted parents who returned the invitation section with contact details, and appointments were scheduled at the Orthopedic Outpatient Clinic. There was no further selection from the potential participants after the invitation.

In the end, 54 children were examined, comprising 28 girls and 26 boys. Demographic characteristics of the patients are presented in Table 1. Inclusion criteria were attendance in the third grade of the local primary school, absence of acute illnesses or pain on the day of the examination, and a completed and signed consent form. None of the 54 willing participants had to be excluded.

**Table 1**

*Demographic Characteristics of the Patients*

| | *N* | *Mean* | *SD* | *Range* |
|---|---|---|---|---|
| Male | 26 | | | |
| Female | 28 | | | |
| Age [years] | 54 | 9.4 | 0.4 | 8.7 – 10.4 |
| Height [m] | 54 | 1.38 | 0.05 | 1.28 – 1.49 |
| Bodyweight [kg] | 54 | 32.3 | 5.8 | 21.8 – 54.5 |
| BMI [kg/m$^2$] | 54 | 16.8 | 2.3 | 12.2 – 24.7 |

**Note.** BMI = Body Mass Index. Values are presented as means and standard deviations.

### *3.2.2 Examination of the Posture*

The examination took place at the Orthopedic Outpatient Clinic. Upon arrival, parents were greeted with the information sheet and consent form. The medical examination and spinal measurements were conducted following the initial administrative steps.

#### 3.2.2.1 Orthopedic Examination

The visual orthopedic examination, conducted by a specialist physician in orthopedics and traumatology and a senior physician in pediatric orthopedics, encompassed various assessments. From behind, the specialist inspected the back for abnormalities such as shoulder tilt, scapula winging, waist triangles, rib protrusion, possible lumbar bulge assessed through Adam´s forward bend test, leg position including the measurement of the intercondylar and intermalleolar distances, foot position, and other irregularities. The sagittal view allowed documentation of the curvatures of the cervical, thoracic, and lumbar spine; frontal inspection involved assessing the shape of the thorax and gait. In the standing position, the physical examination covered single-leg stance, toe walk, heel walk, spinal tapping pain, kidney tapping pain, sacroiliac joint pressure pain, pelvic position, paravertebral muscle tone increase, muscle tone increases in the musculus trapezius, functionality of spinal rotation, lateral flexion of the spine and spinal extension, plumb line deviation, shoulder mobility, and finger-to-floor distance. The latter was measured as the distance between the floor, and fingertips were measured during maximum forward bending, with the knees kept straight. Therefore, no negative score was possible even with good flexibility, as the minimal score was zero. In the supine position, assessments included hip mobility, popliteal angle, which is a measure of the elasticity of the ischiocrural muscle (K. M. Lee et al., 2011), difference in leg length, muscle shortening of the musculus quadrizeps femoris, its strength capabilities, and the Lasègue test (van den Hoogen et al., 1996).

After the examination, the doctor inquired about the presence of pain, its localization, if applicable, pain intensity (classified on a visual analogue scale), and its triggers.

#### 3.2.2.2 Examination by Video Rasterstereography

The back scan was conducted using the DIERS formetric system (Wiesbaden, Germany), which employs video rasterstereography for postural analysis. This system has been scientifically validated and is often used for postural analysis (Degenhardt et al., 2017; Lason et al., 2015; Schülein et al., 2013; Terheyden et al., 2018)

Five retroreflective adhesive markers (diameter 6 mm) were affixed to the children's unclothed backs to perform the back measurement, ensuring clear visibility of the course of the spinous processes. The posture was then measured in a relaxed, familiar position. The software utilizes various back and pelvis landmarks, along with these markers, to calculate parameters that quantify the posture and course of the spine. Parameters such as trunk inclination, trunk imbalance, pelvic tilt, pelvic torsion, kyphotic and lordotic angles, surface rotation, and lateral deviation were of particular interest. The postural parameters assessed with the DIERS formetric scan are described in detail in Table 2.

**Table 2**

*Description of the Parameters Assessed in the DIERS-Scan*

| | |
|---|---|
| Trunk Inclination (VP-DM) | Angle in degrees between the plumb line of the vertebra prominens (VP) and the line connecting the VP to the center of the lumbar dimples (DM). Negative values indicate trunk backward inclination, positive values indicate trunk forward inclination. |
| Trunk imbalance (VP-DM) | Lateral distance of the plumb line (positioned at VP) to the center of the dimples, positive value means VP is shifted to the right. |
| Kyphotic Angle (ICT-ITL) | Angle between the surface tangent at the cervico-thoracic inflection point (ICT) and the surface tangent at the thoracic-lumbar inflection point (ITL) in degrees. |
| Lordotic Angle (ITL-ILS) | Angle between the surface tangent at the thoracic-lumbar inflection point (ITL) and the surface tangent at the lumbar-sacral inflection point (ILS) in degrees. |
| Pelvic Tilt (DL-DR) | Height difference of the lumbar dimples (DL & DR), positive values mean the right side is higher. |
| Pelvic Torsion (DL-DR) | Reciprocal torsion of the surface normals on the two lumbar dimples (DL & DR), positive values mean right side is twisted forward. |
| Surface Rotation (rms) | The root mean square of the horizontal component of surface normals on the symmetry line. Notation: A positive value of surface rotation describes rotation to the right (spinous process points to the right). |
| Surface Rotation (Amplitude) | This value describes the maximum twist of the spine and is calculated as the sum of the magnitudes from the rotation to the left and right. |
| Lateral Deviation (max) (VP-DM) | The maximum deviation of the midline of the spine from the direct connection VP-DM in the frontal plane. |
| Lateral Deviation (rms) (VP-DM) | The root mean square of the deviation of the midline of the spine from the direct connection VP-DM in the frontal plane. |

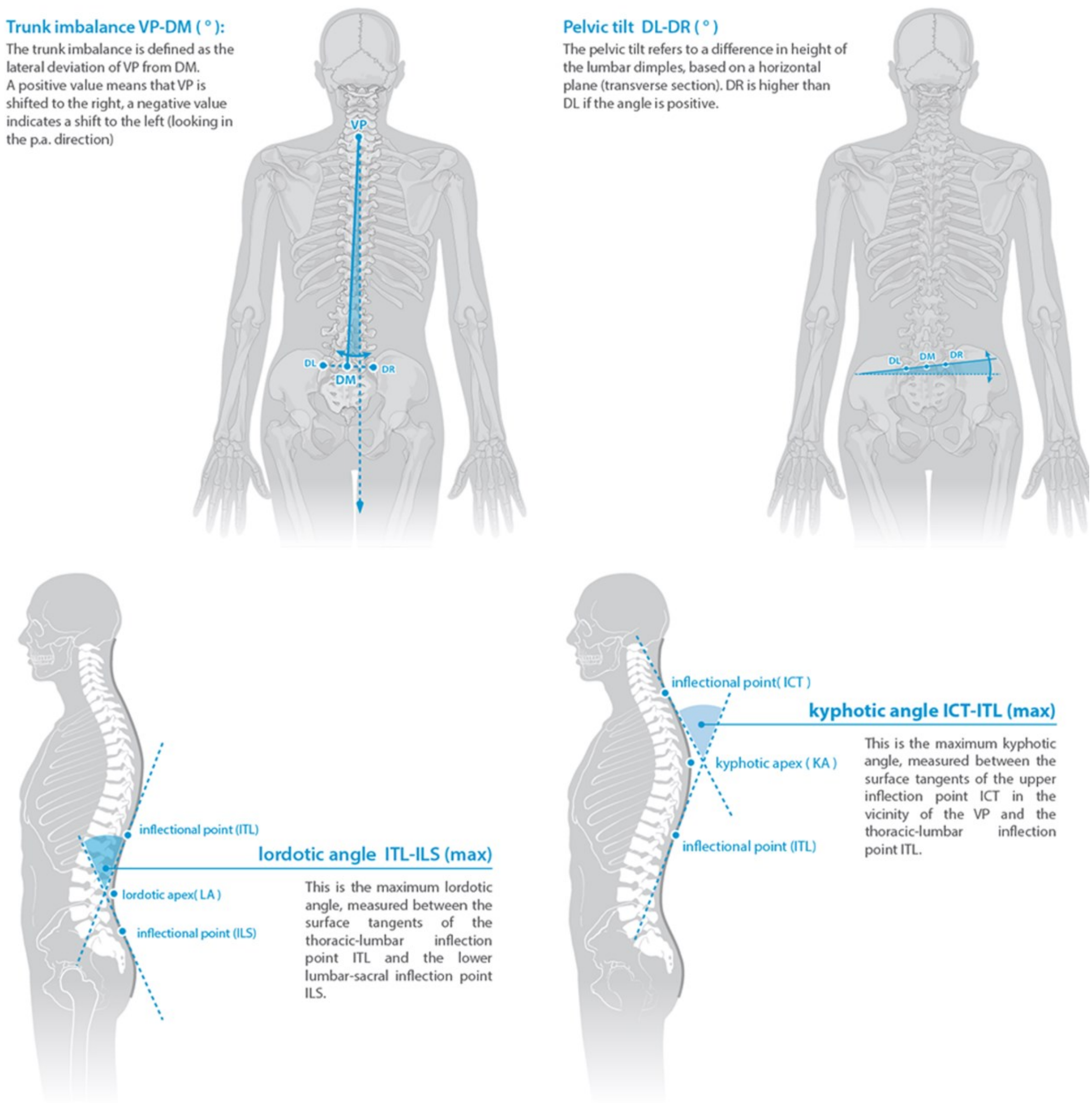
The postural measurements were then compared with reference values (Harzmann, 2000) to distinguish between normal and abnormal postural parameters. These values were derived from a study that conducted spinal scans with the formetric system in 497 fifth-grade school children in Germany. While alternative reference values for postural parameters exist (Heckmann et al., 2008; Schroeder et al., 2011), these were assessed in adolescent and adult samples. Given that some posture parameters change with age (Gong et al., 2019), these references were not chosen for comparison in our young sample. Other existing reference values do not distinguish between normal and abnormal values; they provide only mean values for the measured postural parameters (Furian et al., 2013). Furthermore, the chosen values are cross-referenced within the software and manual of the DIERS system employed in this study, highlighting their suitability for comparison.

#### 3.2.2.3 Comparison Between both Examinations

Various posture parameters were examined in orthopedic evaluations and spine scan using the DIERS formetric system. The examination results for trunk imbalance and pelvic tilt can be directly compared in this process. Additionally, parameters providing information about the kyphosis and lordosis curvature of the spine are examined in both assessments. Figure 1 depicts which postural parameters were compared in the supplementary material. The shown figures are taken from the DIERS formetric 4D website with permission (DIERS International GmbH, 2024). The orthopedic specialist also assessed the same postural parameters.

**Figure 1**

*The four postural parameters compared between the two assessment methods.*




**Note.** Reprinted from the DIERS formetric 4D website with permission (DIERS International GmbH, 2024)

### *3.2.3 Statistical Analysis*

The statistical analysis was conducted using IBM SPSS Statistics 29 (IBM Inc., Chicago, IL, USA). Descriptive analyses were performed to determine incidences, mean values, standard deviations (*SD*), and range. The level of significance was set at $p < .05$.

McNemar tests were conducted for each of the compared parameters to analyze the divergent evaluations made by the orthopedist and the DIERS-scan. This test is widely used to compare different diagnostic methods in paired samples with dichotomous observations, such as normal versus abnormal, as assessed in the conducted posture evaluations and also if there is a relationship between the variable of interest (Lachenbruch & Lynch, 1998). The examining orthopedic directly recorded the results of the assessments on an anonymized pen-and-paper examination form. These data were then compiled into an SPSS spreadsheet, along with the data exported from the formetric system.

## 3.3 Results

### *3.3.1 Abnormalities Diagnosed by the Orthopedic*

The prevalence of different orthopedic abnormalities observed in the visual orthopedic examination is shown in Table 3.

**Table 3**

*Prevalence of Orthopedic Abnormalities in the Visual Orthopedic Assessment*

| | Yes *(N =, % =)* | No *(N =, % =)* |
|---|---|---|
| Any orthopedic abnormality | 43 (79.6%) | 11 (20.4%) |
| Shoulder abnormalities | 14 (25.9%) | 40 (74.1%) |
| Upper body and spine abnormalities | 20 (37.0%) | 34 (63.0%) |
| Lower extremity abnormalities | 27 (50.0%) | 27 (50.0%) |
| Muscular abnormalities | 15 (27.8%) | 39 (72.2%) |
| Pain | 5 (9.3%) | 49 (90.7%) |

Eleven (20.4%) of the 54 examined children showed no postural abnormalities in the visual orthopedic exam. Among the remaining 43 (79.6%) children, at least one of the examined characteristics was noticeable. The orthopedic abnormalities were retrospectively categorized into different groups, depending on the affected body region (see Table 4).

**Table 4**

*Classification of the Observed Abnormalities in the Orthopedic Examination*

| Summarized concept | Included abnormalities |
|---|---|
| Shoulder abnormalities | Shoulder tilt |
| | Scapula alata |
| | Shoulder mobility |
| Upper body and spine abnormalities | Waist triangle |
| | Rib hump |
| | Lumbar roll |
| | Cervical lordosis |
| | Thoracic kyphosis |
| | Lumbar lordosis |
| | Thoracic shape |
| | Spinal rotation |
| | Spinal lateral tilt |
| | Spinal reclination |
| | Plumb line deviation |
| Lower extremity abnormalities | Leg axis |
| | Foot position |
| | Knee axis |
| | Gait pattern |
| | Single-leg stance |
| | Toe walking |
| | Heel walking |
| | Pelvic tilt |
| | Hip mobility |
| | Leg length discrepancy |
| Muscular abnormalities | Increased paravertebral muscle tone |
| | Trapezius muscle tone increase |
| | Quadriceps muscle shortening |
| | Hamstring muscle shortening |
| | Strength assessment |
| Pain | Spinal percussion tenderness |
| | Kidney percussion tenderness |
| | Sacroiliac joint tenderness |
| | Acute back pain |
| | Localization of back pain |
| | Triggers of back pain |
| | Positive Lasègue test |

Abnormalities in the lower extremities were the most frequently examined; half (50.0%) of the sample displayed abnormalities in this area, which includes all issues related to the hips, legs, or feet. The assessment of pelvic tilt is included in this section, with one child (1.9%) having a noticeable pelvic position.

The second most prominent area of issues was the upper body, with 20 children (37.0%) displaying abnormalities. Most observed characteristics in this category were related to the shape and functionality of the spine, as it is a crucial part of the upper body concerning posture. Among other things, abnormalities in the compared parameters included trunk imbalance (0 children, 0%), thoracic kyphosis (2 children, 3.7%), and lumbar lordosis (1 child, 1.9%).

Fifteen children (27.8%) exhibited muscular abnormalities related to tension and shortening during the assessment. Only five children (9.3%) reported pain in response to various percussion tests or acute back pain.

In the measured clinical-orthopedic parameters, the mean popliteal angle was 11.8° on the right and 11.7° on the left. The mean finger-to-floor distance was 3.8 cm. Abnormalities in the leg axis were detected in only seven children (13%). The mean intercondylar and intermalleolar distances were 0.1 cm and 0.4 cm, respectively.

### *3.3.2 Abnormalities Diagnosed by Rasterstereography*

The values assessed with the rasterstereography method are presented in Table 5. As the direction of a possible deviation is interesting for this study, the magnitude of variances is reported for parameters with negative and positive values. A zero value indicates a balanced posture and is the goal. Some children showed perfect or near-perfect values in trunk inclination, trunk imbalance, pelvic tilt, and pelvic torsion. The lowest assessed magnitude for maximum lateral deviation was 2.5 mm. There were also children with high values for each parameter, resulting in a broad range.

For surface rotation, the mean amplitude was 9.0°, and the mean rms surface rotation was 4.3°. The mean values for the kyphotic and lordotic angles, describing the spinal curvature, were 42.2° and 36.8°, respectively. The mean rms lateral deviation was 4.0 mm.

**Table 5**

*Measured Parameters in the DIERS Scan*

| | *Mean* | *SD* | *Range* |
|---|---|---|---|
| Trunk inclination [°] | 1.1 | 3.0 | -6.4 – 8.8 |
| Trunk imbalance [mm] | -5.0 | 8.3 | -23.4 – 17.1 |
| Pelvic tilt [mm] | 0.2 | 4.6 | -9.0 – 15.0 |
| Pelvic torsion [°] | 0.8 | 2.9 | -6.3 – 5.4 |
| Kyphotic angle [°] | 42.2 | 9.1 | 22.4 – 63.0 |
| Lordotic angle [°] | 36.8 | 7.5 | 23.8 – 57.2 |
| RMS Surface rotation [°] | 4.3 | 3.0 | 1.0 – 15.6 |
| Surface rotation amplitude [°] | 9.0 | 3.8 | 2.9 – 22.8 |
| RMS lateral deviation [mm] | 4.0 | 2.1 | 1.2 – 11.8 |
| Maximum lateral deviation [mm] | -0.8 | 7.9 | -18.1 – 14.2 |

Table 6 displays the count of identified abnormalities in the postural measurements, assessed by the reference values. One (1.9%) child showed no postural abnormality in the rasterstereographical scan.

**Table 6**

*Posture Rating According to Reference Values (Harzmann, 2000)*

| | Reference Value | Abnormality assessed | No abnormality assessed |
|---|---|---|---|
| Trunk inclination [°] | 0 – 3 | 9 (16.7 %) | 45 (83.3 %) |
| Trunk imbalance [mm] | -10 – 10 | 17 (31.5 %) | 37 (68.5 %) |
| Pelvic tilt [mm] | -10 – 10 | 1 (1.9 %) | 53 (98.1 %) |
| Pelvic torsion [°] | -3 – 3 | 18 (33.3 %) | 36 (66.7 %) |
| Kyphotic angle [°] | 45 – 55 | 43 (79.6 %) | 11 (20.4 %) |
| Lordotic angle [°] | Boys: 32 – 37<br>Girls: 40 – 45 | 42 (77.8 %) | 12 (22.2 %) |
| RMS surface rotation [°] | 0 – 5 | 15 (27.8 %) | 39 (72.2 %) |
| Surface rotation amplitude [°] | -8 – 8 | 30 (55.6 %) | 24 (44.4 %) |
| RMS lateral deviation [mm] | 0 – 5 | 4 (7.4 %) | 50 (92.6 %) |
| Maximum lateral deviation [mm] | -10 – 10 | 6 (11.1 %) | 48 (88.9 %) |

### *3.3.3 Comparison Between both Measurements*

Table 7 depicts the different ratings of the compared postural parameters. The percentage refers to the share of the whole sample in which the ratings differed or only one assessment method found an abnormality. The statistical power and the effect size are also presented. The effect size *w* was calculated according to Steyn (2020).

**Table 7**

*Difference in Postural Assessments between Orthopedic Assessment and Rasterstereographical Scan*

| Postural parameter | Diverging Ratings *(N =, % =)* | Abnormality Only in Orthopedic Assessment *(N =, % =)* | Abnormality Only in Rasterstereographical Scan *(N =, % =)* | Significance Level of Difference | Effect Size ($w$ = ) | Statistical Power |
|---|---|---|---|---|---|---|
| Trunk imbalance | 17 (31.5%) | 0 (0%) | 17 (31.5%) | $p < .001$ | 0.94[a] | .79 |
| Pelvic tilt | 2 (3.7%) | 1 (1.9%) | 1 (1.9%) | $p = 1.00$ | 0 | 0 |
| Thoracic kyphosis | 41 (75.9%) | 2 (3.7%) | 39 (72.2%) | $p < .001$ | 0.88[a] | > .99 |
| Lumbar lordosis | 38 (70.4%) | 1 (1.9%) | 37 (68.5%) | $p < .001$ | 0.94[a] | .99 |

**Note.** [a] This indicates a large effect according to (Steyn, 2020).

## 3.4 Discussion

### *3.4.1 Differences in Postural Assessment*

Assessing the mentioned postural abnormalities with different methods resulted in divergent results. We can only speculate about the reasons. One reason might be the influence of posture during the test. The orthopedic examination was done by two senior orthopedic practitioners, whose experience reduces a possible variability in the examination. However, the rasterstereography was interpreted by a sports scientist with less experience than the orthopedic examiner. In the study with adults, the reliability of the DIERS System is good (Degenhardt et al., 2020).

The diverse assessment criteria restrict the direct comparison to only a few parameters. The assessment of spinal curvature revealed the highest difference in ratings, with over 60% differences in the evaluation of kyphosis and lordosis. This dissimilarity can be attributed to the distinct nature of each assessment method. Studies indicate that lumbar angles vary in different positions (Misir et al., 2019). This phenomenon was also noted in various postural parameters when transitioning from a habitual to an active posture in a sample of male adolescents (Ludwig et al., 2016). In both assessments in our study, participants were instructed to assume a relaxed, normal standing position. However, slight variations in posture could lead to different measurements and ratings, potentially contributing to the high rate of disagreement in these assessments.

Furthermore, the importance of precise placement and correct positioning in examinations using the DIERS formetric system is emphasized (Lason et al., 2015) to obtain accurately and correctly measured postural parameters. Slightly differing placements could also account for some differing measurements. For this, it is important to implement quality control. The DIERS system's scientists must establish a learning curve while performing the diagnostic, which has shown to reduce variances between repeated raterstereographic scans (Lason et al., 2015). This learning curve must be monitored. For this, a longer practice with rasterstereography is necessary, especially in pediatric orthopedics, where the children might show more variability. Only a few studies support the validity of rasterstereography in detecting spinal disorders. A small number of participants limits most and focuses only on adolescent idiopathic scoliosis, neglecting other abnormalities (Wanke-Jellinek et al., 2019). Some research teams believe that, when executed with precision, this method facilitates rapid and non-invasive data collection, making it appropriate for the initial assessment of postural abnormalities (Lason et al., 2015; Roggio et al., 2021). A meta-analysis demonstrated high validity and reliability for the postural parameters of lumbar lordosis and thoracic kyphosis, both assessed and compared in our study, when comparing a DIERS scan to the gold X-ray standard (Krott et al., 2020). The rasterstereographic scan using the formetric system demonstrated high sensitivity and good specificity in assessing postural abnormalities when applying the reference values described in the study conducted by Harzmann (2000), which emphasized the importance of having an experienced diagnostician conduct the scan. However, since no comparison was made with the gold standard of X-rays, it was impossible to calculate sensitivity and specificity in our study. In contrast, other authors have described these reference intervals as too narrow, suggesting a broader spectrum of values should be considered normal, particularly regarding kyphotic and lordotic angles (Willner & Johnson, 1983; Wohlfarth, 2018). This strict classification could potentially result in healthy children being diagnosed with postural abnormalities, leading to false positives in the rasterstereographic scan.

Given that most of the abnormalities identified by the DIERS scan were close to the reference ranges, this could explain the high number of abnormalities detected by the formetric system. Expanding the reference frame by 50% of the original width in both directions reveals many elevated values within these extended boundary areas. For trunk imbalance, 14 of the 17 assessed abnormalities are within 10mm of the reference borders. Similar trends are observed for the lordotic and kyphotic angles, where 14 of 42 and 16 of 43 findings are relatively close outside the used reference values, respectively. When applying the widened reference interval for spinal angles, 13 children (24.1%) showed normal values, compared to only 2 children (3.7%) when classified using the narrower reference range. Many of these cases, with values near the border of the normal range, were simultaneously assessed as medically unremarkable by the orthopedic examiner. For trunk imbalance, this applies to all 14 children. For the lordotic angle in these border areas, 12 cases were not seen as striking in the visual observation, and for the kyphotic angle, 14 cases were not considered abnormal.

In contrast to the spine scan, orthopedic practitioners can integrate their knowledge about abnormal postural patterns during the assessment (Sweeting & Mock, 2007). This integration becomes evident in the form of rating abnormalities that might not be detected during the brief assessment in the scanner. Simulated postures can greatly impact the short observation duration in the rasterstereographical scan, even if they occur subconsciously. However, the child's genuine standing posture during the orthopedic visual assessment may be incorporated into the specialist's rating.

The question arises whether the application of rasterstereography in daily pediatric orthopedic practice is both practical and meaningful, or if the conventional approach of functionality-focused postural assessments conducted by orthopedic specialists or pediatricians suffices. Another method to analyze the posture more indirectly by load distribution on the feet and gait dynamics is the use of baropodometry. For example, in a pilot study with children suffering from scoliosis, it has been shown that they have different loading patterns than children from a healthy control group (Leblebici et al., 2023).

### *3.4.2 Found Orthopedic Abnormalities*

The elevated prevalence of orthopedic abnormalities identified through both assessment methods corresponds with findings from other studies, highlighting many postural issues in children (Batistão et al., 2016; Kratenová et al., 2007; Mahlknecht, 2007). The mean popliteal angle was lower in the observed sample compared to the results of other studies, which report mean values around 25° in children this age group. The observed children, therefore, showed a higher hamstring flexibility than the reference groups (Katz et al., 1992; Mudge et al., 2014). The measured intercondylar and intermalleolar distances are low, as the literature suggests a classification as abnormal when distances are more than 5cm and 7cm, respectively (P. Gupta et al., 2020).

However, challenges arise when interpreting identified abnormalities as reliable indicators of future issues. Various studies on changes in posture throughout childhood and adolescence present divergent results, indicating either preconditions for future postural problems or normal side effects of different growth phases (Batistão et al., 2016; Furian et al., 2013; Hagner et al., 2011; Ziętek et al., 2022).

### *3.4.3 Limitations*

One limitation of this study is the small sample size of 54 participants, due to logistical and personnel constraints. The non-mobile examination technique necessitated that the selected school be close to the examination site. Additionally, the limited number of postural parameters available for comparison is another constraint, arising from the differing focus points of the two evaluation methods. Specifically, the standard postural examination conducted by the orthopedic examiner at the clinic influenced the parameters available for comparison.

### *3.4.4 Conclusion*

Orthopedic, postural assessments and rasterstereographical spine scans presented divergent results, with spine scans identifying more postural abnormalities in the compared parameters. This raises questions about the choice of general practice and the cost-benefit ratio of different methods in pediatric postural assessment. Influencing factors can occur in both methods during observations or the interpretation of the results. Visual orthopedic assessments offer a quick and cost-efficient observation of posture. The reliance on the examiner can be positive, as experience-based evaluation can enhance the assessment. However, this also results in more subjective interpretations and potential rater bias. Conversely, even the objective data from spine scans are interpreted by human practitioners, introducing possible subjective influencing factors.

Regardless of the parameters compared, the prevalence of orthopedic abnormalities in children was high in both methods, consistent with existing literature. The interpretation of these findings remains disputed, whether as normal byproducts of growth phases or as indicators of future postural problems.

# 4 Second Study

## Exploring the links between bodily and psychological health dimensions in primary-aged school children[2]

### 4.1 Goals and Hypotheses

This study aimed to investigate the associations between bodily (posture and muscular fitness) and psychological health dimensions (psychological well-being, self-compassion, and physical self-concept) in children. These dimensions can be placed as influential factors in Stodden's model, and its subsequent extensions on the development of the relationship between motor competence and physical activity. In the present study, the associations between these peripheral factors are examined in more detail. Based on this aim, the following hypotheses were formulated:

1) We expect a positive association between muscular fitness and the ability to maintain an upright body posture (H1).
2) We hypothesize a positive relationship between posture and psychological well-being. Additionally, we expect posture to be positively associated with a better physical self-concept (H2).
3) We hypothesize that muscular fitness is positively associated with psychological well-being and higher self-compassion. Furthermore, we expect muscular fitness to be linked to a better physical self-concept (H3).

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[2] The corresponding paper to this study is currently under review: Weigel, S. & Jansen, P. Exploring the links between bodily and psychological health dimensions in primary school children. The structure and order of content presented here may differ slightly from the final published version.

4) We hypothesize positive associations between the physical self-concept and psychological well-being. Moreover, we expect psychological well-being to be related to self-compassion and self-compassion to be positively associated with the physical self-concept (H4).

Beyond these hypotheses, we also conducted exploratory analyses. Specifically, we investigated whether self-compassion is positively linked to the upright posture assessed in our study. Additionally, we explored the relationship between functional mobility and the two trunk-muscle endurance measures.

## 4.2 Method

### *4.2.1 Participants*

Their parents enrolled a total of 177 children to participate in a back pain prevention project. The current study was conducted as part of the pretesting phase of this intervention, which will be evaluated in Study 3. Participants were reached through pediatricians, youth centers, parishes, sports clubs, and the University's family service and media department. Local radio stations also promoted the back pain prevention study. Exclusion criteria included (a) structural diseases (e.g., scoliosis), (b) medical conditions restricting participation in strengthening exercises, (c) neurological disorders, (d) involvement in other scientific studies, and missing more than 10% of a questionnaire. Three children were excluded: one with scoliosis, one due to language barriers, and one for refusing to complete over 90% of some questionnaires.

The final sample consisted of 174 children ($M$ = 8.61, $SD$ = 1.33) aged 6 to 11. The age range was originally planned to be 7 – 11 years, but one 6-year-old was included as their seventh birthday was imminent. The sample comprised 77 girls (44.3%) and 97 boys (55.7%). Anthropometric data can be found in chapter 9.1, weight categorization followed BMI percentiles (Kromeyer-Hauschild et al., 2001).

Since the analysis method was adjusted during the review process, the a-priori power analysis (Faul et al., 2007) (assuming $d$ = 0.25, $\alpha$ = 0.0167, $\beta$ = 0.8; required $N$ = 135) no longer directly applies, as it was based on a different analytic approach involving multiple comparisons. Instead, the final analysis was based on a structural equation model that included only manifest variables and estimated bivariate correlations between them. Simulation studies by Wolf et al. (2013) demonstrated that sample size requirements in SEM vary substantially depending on model complexity, number of indicators, and magnitude of factor loadings. In their analyses, even models with latent variables and moderate to strong factor loadings required as few as 90–120 participants to achieve sufficient power and unbiased parameter estimates. The present model did not include latent constructs and is therefore structurally simpler. The excellent model fit suggests that the achieved sample size ($N$ = 174) was sufficient. Given that simpler models generally require fewer participants, the current sample size aligns with empirical recommendations for stable estimation in low-complexity SEMs.

### *4.2.2 Measurements*

#### 4.2.2.1 Muscular Fitness Assessment

Muscular fitness was assessed through three tests from two different test batteries, as functional mobility, trunk extensor endurance and trunk flexor endurance were evaluated. The individual scores were standardized as

$standardized\ value = \frac{value - mean}{SD}$, and the muscular fitness score was calculated as the mean of the three standardized scores.

*Functional mobility* was measured using the Functional Movement Screen (FMS) (Cook et al., 2014a, 2014b), which includes ten exercises: deep squat, hurdle step (left/right), inline lunge (left/right), shoulder mobility (left/right), shoulder clearing test (left/right), active straight leg raise (left/right), trunk stability pushup, extension clearing test, rotary stability (left/right), and flexion clearing test. Each exercise was scored from 0 to 3, with a maximum total score of 21. For bilateral exercises, only the lower score was included. Pain during exercises or clearing tests resulted in a score of zero.

Both tests evaluating trunk muscle endurance were taken from the McGill endurance tests (McGill et al., 1999) and slightly modified. For *trunk extensor endurance*, participants lay face-down cantilevered on a bench, arms crossed, with pelvis, knees, and hips secured by straps. A horizontal bar touching the shoulder blades ensured proper alignment. Time maintaining this position was recorded, with a maximum of 300 seconds. The test concluded after three losses of contact with the bar. For *trunk flexor endurance*, participants held a 50° sit-up position against a wedge, which was pulled 10 cm backward at the start of the test. Feet were strapped, hands crossed, and knees/hips flexed at 90°. The position was maintained without leaning back against the wedge or holding the knees, with a maximum of 300 seconds.

#### 4.2.2.2 Posture Assessment

Posture was evaluated using the Matthiass test, which is part of a German posture test for children (Tittlbach & Bös, 2002). Participants were scored based on the duration (in seconds) they could sustain an upright body posture with both arms held horizontally in front of a grid pattern with squares measuring 5x5 cm. The test was stopped when the participant's position varied by at least one square, the participant ended the test, or the maximum time was reached. The maximum achievable score was 120 seconds.

#### 4.2.2.3 Physical Self-Concept Assessment

The assessment of physical self-concept utilized the PSK-K questionnaire (Dreiskämper et al., 2015), which comprises 21 items distributed across seven subscales. Participants respond to each item on a 4-point Likert scale, ranging from "strongly disagree" (1) to "strongly agree" (4). The subscales include general athleticism, attractiveness, endurance, mobility, coordination, strength, and speed. Subscale scores for physical self-concept were derived by calculating the mean score of the three items within each subscale. We compared a one-factor model with a seven-factor model for our sample. In accordance with the original publication of the questionnaire, the seven-factor model showed notably better fit (CFI = .88, RMSEA = .09, SRMR = .07) compared to the one-factor model (CFI = .75, RMSEA = .12, SRMR = .08), suggesting a more adequate representation of the underlying structure. To analyze the internal reliability, Cronbach's Alpha and McDonald's Omega were calculated for every subscale. The subscales for general athleticism ($\alpha$ = .815, $\omega$ = .816), endurance ($\alpha$ = .712, $\omega$ = .721), mobility ($\alpha$ = .822, $\omega$ = .823), strength ($\alpha$ = .750, $\omega$ = .753) and speed ($\alpha$ = .780, $\omega$ = .787) showed good values, whereas attractiveness ($\alpha$ = .619, $\omega$ = .636) and coordination ($\alpha$ = .622, $\omega$ = .653) stay just below the 0.70 benchmark typically recommended for good reliability (Nunnally, 1978). The lower values for these two subscales are consistent with the original publication of the questionnaire (Dreiskämper et al., 2015), which suggested that these constructs may not yet be fully developed at this age.

#### 4.2.2.4 Psychological Well-Being Assessment

As self-concept was chosen as the primary representation of psychological well-being in this study, psychological well-being was assessed using the self-concept subscale of the German version of the “Beck Youth Inventories – 2nd edition” (J. S. Beck et al., 2018). It consists of 20 items that are answered on a 4-point Likert scale ranging from “never” (0) to “always” (3). The total score was calculated by summing up all scores with a maximum score of 60. Although the one-factor model demonstrated suboptimal fit (CFI = .80, RMSEA = .08, SRMR = .07), we followed the questionnaire manual’s recommendation to use a total score in the analyses. The internal reliability was assessed via Cronbach’s Alpha and McDonald’s Omega, where two participants had to be excluded due to a missing value. The results suggest a good internal consistency with $\alpha$ = .882 and $\omega$ = .879.

#### 4.2.2.5 Self-Compassion Assessment

Self-compassion was assessed with a German translation of the self-compassion scale short form adapted for children (Sutton et al., 2018). Two translators with a finished English degree translated the English questionnaire forward and backward. The scale comprises 12 items categorized into two subscales, each answered on a 5-point Likert scale ranging from “never” (1) to “always” (5). The subscales measure positive and negative self-compassion. To account for negatively framed items, reverse coding was applied. Subscale scores for self-compassion were obtained by calculating the mean score of the six items within the respective subscale. When comparing a one-factor with a two-factor model suggested in the original publication, the two-factor model demonstrated substantially better fit (CFI = .92, RMSEA = .05, SRMR = .07) compared to the one-factor model (CFI = .52, RMSEA = .13, SRMR = .13), indicating a more adequate representation of the underlying structure. To assess the internal reliability of the subscales as proposed by Sutton et al. (2018), Cronbach's Alpha and McDonald's Omega were computed. The analysis yielded $\alpha$ = .676 and $\omega$ = .674 for positive self-compassion, and $\alpha$ = .708 and $\omega$ = .719 for negative self-compassion. While these values suggest an acceptable internal consistency, values for positive self-compassion do not fully meet the .70 benchmark typically recommended for good reliability (Nunnally, 1978).

#### *4.2.3 Assessment of Parental Educational Level*

Due to the conceptual challenges associated with measuring socioeconomic status (Antonoplis, 2023), we focused on gathering more detailed information about the family situation by assessing the parents' educational level, as part of the SES measurement (Jöckel et al., 1998). The mother and father´s educational levels were rated from 1 to 8 on a scale. The classification was based on the German ersion of the ISCED-2011 framework by UNESCO, which was developed for national and international comparison in educational statistics (UNESCO Institute for Statistics, 2012). The higher of the two values was used to represent the family's education level.

#### *4.2.4 Procedure and Design*

The study was conducted as an observational study. The testing was carried out as part of the pretests for an intervention study to prevent back pain in children. Assessments took place at the Institute of Sport Science laboratories. Parents accompanied the children but remained outside their line of sight to minimize distractions. Each session lasted 60 to 90 minutes. After obtaining child and parental consent, testing began with a posture examination, a key component of the back prevention intervention, and the posture test. The SCS-C questionnaire and a brief warm-up preceded the motor tests, administered by a second tester in a new setting. The FMS was conducted first, followed by the back knowledge questionnaire for the intervention. Trunk flexor endurance was assessed next, followed by the BSCI-Y questionnaire. Trunk extensor endurance was then tested, with the PSK-K questionnaire concluding the session.

The study adhered to the ethical guidelines of the Helsinki Declaration and was approved by the Ethics Research Board of the University (Vote-no. 23-3522-101). The study was also preregistered on OSF[3].

#### *4.2.5 Statistical Analysis*

Descriptive statistics (including incidences, means, standard deviations, and ranges) were calculated. To examine the hypothesized correlations between the constructs, a structural equation model (SEM) was specified, including 12 manifest variables: two self-compassion subscales (positive and negative), seven physical self-concept subscales, the muscular fitness index, the posture score, and the psychological well-being score. All theoretically relevant correlations between these variables were freely estimated, except for the correlation between posture and self-compassion, which

[3] https://osf.io/2f4jq/?view_only=f81740d40a0b435e9d7e22378151a56

was fixed to zero due to a lack of theoretical justification. However, this association was explored separately outside the SEM framework. The model was estimated using the robust maximum likelihood estimator (MLR), which provides robust standard errors and fit indices corrected for non-normality, with confidence intervals calculated based on the robust sandwich standard errors. Model fit was evaluated using the robust $\chi^2$ test statistic, robust CFI, robust TLI, robust RMSEA with 90% confidence intervals, and SRMR. To account for differing measurement scales and ensure comparability of correlation coefficients, posture and psychological well-being were z-standardized before model estimation. Internal consistencies were assessed using Cronbach's alpha and McDonald's omega. Additionally, confirmatory factor analyses were conducted for the questionnaires, and for self-compassion and physical self-concept, a single-factor model was compared to a multifactor model, following the approaches used in the original publications. For exploratory analyses, Spearman's rank correlations were calculated to examine the explorative associations between non-normally distributed variables. All data preprocessing and analyses were conducted in R using the lavaan package (Rosseel, 2012) and IBM SPSS Statistics 29 (IBM Inc., Chicago, IL, USA).

## 4.3 Results

### *4.3.1 Descriptive Results*

The descriptive results of the measured variables are presented in Table 8.

**Table 8**

*Results of the Measured Variables*

| | *Mean* | *SD* | *Range* |
|---|---|---|---|
| Matthiass test [s] | 86.07 | 29.61 | 14 – 120 |
| FMS total score | 13.13 | 3.09 | 6 – 20 |
| Trunk flexor endurance [s] | 49.74 | 41.56 | 0 – 300 |
| Trunk extensor endurance [s] | 53.60 | 35.53 | 5 – 222 |
| Muscular fitness index | 0.00 | 0.75 | -1.41 – 3.04 |
| $\text{SCS-C}_{\text{Negative self-compassion}}$ | 3.34 | 0.79 | 1.17 – 4.83 |
| $\text{SCS-C}_{\text{Positive self-compassion}}$ | 3.44 | 0.75 | 1.17 – 5.00 |
| BSCI-Y score | 43.03 | 8.74 | 12 – 60 |
| $\text{PSK-K}_{\text{General Athleticism}}$ | 3.55 | 0.57 | 1.00 – 4.00 |
| $\text{PSK-K}_{\text{Attractiveness}}$ | 3.00 | 0.65 | 1.00 – 4.00 |
| $\text{PSK-K}_{\text{Endurance}}$ | 3.28 | 0.61 | 1.00 – 4.00 |
| $\text{PSK-K}_{\text{Mobility}}$ | 3.36 | 0.65 | 1.00 – 4.00 |
| $\text{PSK-K}_{\text{Coordination}}$ | 3.27 | 0.57 | 1.00 – 4.00 |
| $\text{PSK-K}_{\text{Strength}}$ | 3.19 | 0.59 | 1.00 – 4.00 |
| $\text{PSK-K}_{\text{Speed}}$ | 3.28 | 0.68 | 1.00 – 4.00 |

The collected values were briefly compared with available reference data. For the posture test, no normative data are published. The average FMS score in our study was 13.1 (boys: 12.6, girls: 13.8), slightly lower than those reported for Moldovan children (Mitchell et al., 2015), though the pattern of higher scores among girls was consistent. Since trunk muscle endurance norms exist only for children aged seven and older, the single six-year-old in our sample was excluded. Compared to Dejanovic et al. (2012), our sample showed lower endurance across all age groups and genders (details in Table 9).

**Table 9**

*Comparison of Trunk Muscle Endurance to Reference Values*

| | | 7 years | 8 years | 9 years | 10 years | 11 years |
|---|---|---|---|---|---|---|
| Trunk extensor | Boys | 37.3 ± 26.8 (110.8 ± 59.6) | 43.6 ± 19.8 (126.1 ± 67.9) | 58.5 ± 51.4 (150.7 ± 63.3) | 60.1 ± 26.8 (165.1 ± 68.6) | 75.7 ± 39.1 (160.2 ± 67.4) |
| | Girls | 6.9 ± 19.7 (111.0 ± 44.5) | 59.4 ± 35.2 (137.0 ± 64.6) | 51.5 ± 34.3 (191.6 ± 62.9) | 71.4 ± 28.0 (202.1 ± 65.6) | 84.0 ± 48.1 (182.0 ± 67.8) |
| Trunk flexor | Boys | 43.6±35.4 (76.0 ± 51.2) | 47.9±37.5 (140.6 ± 87.2) | 37.8±25.9 (147.8 ± 91.4) | 52.2±31.8 (137.9 ± 74.6) | 89.2±57.0 (129.2 ± 78.9) |
| | Girls | 35.7±28.8 (96.5 ± 75.8) | 52.7±38.3 (100.7 ± 80.9) | 62.6±56.9 (168.6 ± 95.2) | 45.1±27.6 (149.0 ± 81.4) | 76.5±79.0 (111.0 ± 69.2) |

**Note.** The values of the reference sample are provided in parentheses.

Self-compassion scores were slightly higher than those in a Canadian reference sample (Sutton et al., 2018), potentially due to cross-country differences (see Table 10).

**Table 10**

*Comparison of Self-Compassion to Reference Values*

| | Negative Self-Compassion | Positive Self-Compassion |
|---|---|---|
| Boys | 3.39 ± 0.80 (2.88 ± 0.72) | 3.29 ± 0.75 (3.07 ± 0.70) |
| Girls | 3.27 ± 0.78 (2.92 ± 0.68) | 3.61 ± 0.71 (3.26 ± 0.70) |

**Note.** The values of the reference sample are provided in parentheses.

Psychological well-being raw scores were converted to gender-specific T-scores provided in the test manual (J. S. Beck et al., 2018), yielding 24 children with significantly below-average, 25 with below-average, 76 with average, and 49 with above-average self-concept. Physical self-concept scores were similar to those reported in German third and fourth-graders (Dreiskämper et al., 2015). Detailed comparisons are also shown in Table 11.

**Table 11**

*Comparison of Physical Self-Concept with Reference Values*

| PSK-K Subscale | Score |
|---|---|
| General Athleticism | 3.27 ± 0.48 (3.51 ± 0.58) |
| Attractiveness | 3.00 ± 0.65 (3.23 ± 0.67) |
| Endurance | 3.28 ± 0.61 (3.27 ± 0.65) |
| Mobility | 3.36 ± 0.65 (3.22 ± 0.72) |
| Coordination | 3.27 ± 0.57 (3.28 ± 0.59) |
| Strength | 3.19 ± 0.59 (3.19 ± 0.66) |
| Speed | 3.28 ± 0.68 (3.27 ± 0.73) |

**Note.** The values of the reference sample are provided in parentheses.

### *4.3.2 Correlational Results*

The structural equation model showed excellent fit to the data, $\chi^2(2) = 2.26$, $p = .324$, robust CFI = 1.000, robust TLI = .989, robust RMSEA = .027 (90% CI [0.000, 0.163]), and SRMR = .020. All reported coefficients *r* are standardized estimates.

In line with H1, muscular fitness was strongly positively correlated with posture ($r = .48$, 95% CI [.260, .460], $p < .001$). Contrary to expectations (H2), posture was not significantly correlated with psychological well-being ($r = -.08$, 95% CI [−.199, .043], $p = .205$) or with any of the physical self-concept subscales ($r = -.07$ to .07, all $p > .05$, see chapter 9.1 for details). In contrast to H3, muscular fitness was not significantly correlated with psychological well-being ($r$ = −.04, 95% CI [−.155, .103], $p$ = .690), positive self-compassion ($r$ = .08, 95% CI [−.024, .116], $p$ = .199), negative self-compassion ($r$ = .05, 95% CI [−.051, .107], $p$ = .491), or any of the physical self-concept subscales ($r$ = .01 to .11, all $p$ > .05, see chapter 9.1 for details). In line with H4, psychological well-being was strongly positively correlated with positive self-compassion ($r$ = .47, 95% CI [.240, .458], $p$ < .001) and moderately positively with negative self-compassion ($r$ = .24, 95% CI [.061, .324], $p$ = .004). Moreover, physical self-concept subscales were significantly positively correlated with psychological well-being ($r$ = .35−.45, 95% CIs [.249, .540], all $p$ < .001) and with positive self-compassion ($r$ = .35−.44, all $p$ < .001). However, negative self-compassion showed no significant correlations with the physical self-concept subscales ($r$ = .03 to .13, $p$ = .055-.718). The correlations with the physical self-concept subscales are shown in detail in Table 12. Moreover, psychological well-being was strongly positively correlated with positive self-compassion ($r$ = .47, 95% CI [.240, .458] $p$ < .001) and moderately positively with negative self-compassion ($r$ = .24, 95% CI [.061, .324] $p$ = .004).

**Table 12**

*Correlations with the Physical Self-Concept Subscales*

| Observed Connection | | *r* | 95% CI | *p*-value |
|---|---|---|---|---|
| Psychological well-being | $PSK\text{-}K_{General\ Athleticism}$ | .45 | [.161, .352] | < .001 |
| | $PSK\text{-}K_{Attractiveness}$ | .40 | [.131, .390] | < .001 |
| | $PSK\text{-}K_{Endurance}$ | .41 | [.144, .354] | < .001 |
| | $PSK\text{-}K_{Mobility}$ | .45 | [.174, .377] | < .001 |
| | $PSK\text{-}K_{Coordination}$ | .54 | [.204, .409] | < .001 |
| | $PSK\text{-}K_{Strength}$ | .40 | [.142, .333] | < .001 |
| | $PSK\text{-}K_{Speed}$ | .42 | [.164, .404] | < .001 |
| Positive self-compassion | $PSK\text{-}K_{General\ Athleticism}$ | .25 | [.043, .168] | .001 |
| | $PSK\text{-}K_{Attractiveness}$ | .35 | [.094, .245] | < .001 |
| | $PSK\text{-}K_{Endurance}$ | .28 | [.061, .194] | < .001 |
| | $PSK\text{-}K_{Mobility}$ | .24 | [.047, .181] | .001 |
| | $PSK\text{-}K_{Coordination}$ | .44 | [.120, .250] | < .001 |
| | $PSK\text{-}K_{Strength}$ | .23 | [.034, .164] | .003 |
| | $PSK\text{-}K_{Speed}$ | .27 | [.056, .214] | .001 |
| Negative self-compassion | $PSK\text{-}K_{General\ Athleticism}$ | .09 | [-.021, .105] | .188 |
| | $PSK\text{-}K_{Attractiveness}$ | .06 | [-.062, .124] | .513 |
| | $PSK\text{-}K_{Endurance}$ | .08 | [-.029, .124] | .261 |
| | $PSK\text{-}K_{Mobility}$ | .13 | [-.002, -137] | .055 |
| | $PSK\text{-}K_{Coordination}$ | .03 | [-.057, .083] | .718 |
| | $PSK\text{-}K_{Strength}$ | .08 | [-.033, .103] | .318 |
| | $PSK\text{-}K_{Speed}$ | .12 | [-.014, .144] | .105 |

#### *4.3.3 Explorative Analyses*

There was no significant correlation between the posture score and self-compassion, $\rho$ = .083, $p$ = .137, 95% CI [-0.046, 1.000]. Functional mobility showed a low significant correlation with the muscular endurance of the trunk flexors, $\rho$ = .253, $p$ < .001, 95% CI [0.104, 0.391], and a medium-sized significant correlation with the trunk extensors, $\rho$ = .402, $p$ < .001, 95% CI [0.265, 0.523]. The values of the two trunk muscular endurance measurements were also moderately correlated, $\rho$ = .485, $p$ < .001, 95% CI [0.358, 0.594].

### 4.4 Discussion

Before addressing the hypotheses, key differences between our sample and reference samples are considered. The younger mean age in our study (8.61 ± 1.13) likely explains the lower FMS scores, supported by a significant positive correlation of FMS score with age ($\rho$ = .297, $p$ < .001, 95% CI [0.174, 1.000]). The observed trunk muscle endurance weakness may stem from the study's back prevention context, attracting parents concerned about posture-related motor deficiencies. Differences in self-compassion may reflect the national backgrounds of the compared samples, while the similarity in physical self-concept likely results from both samples being German.

#### *4.4.1 Relations Between Bodily and Psychological Well-Being*

The strong correlation between muscular fitness and posture confirms our hypothesis that these aspects of physical well-being are connected. This finding extends previous research, which primarily demonstrated this relationship in children with obesity (Molina-Garcia et al., 2020). The correlation between trunk muscle endurance tests and the FMS score aligns with Mitchell et al. (2015), who found a similar link between core strength and functional mobility in children. These observations differ from those of Okada et al. (2011), who observed no such relations in adults. While our study and the adult study used the same muscle endurance tests, the child study employed the prone plank test. Mitchell et al. (2015) suggest that differing methods may explain these inconsistencies. However, our results, using two tests also applied in the adult study, suggest that in children, the developmental stage leads to less differentiated motor skill domains compared to adults. As stated by Utesch et al. (2019), motor movements, such as those assessed by the FMS, require thousands of repetitions to be fully acquired and refined. At this young age, many specific movement patterns have simply not yet been consolidated. Therefore, general physical activity participation and overall sportiness are likely the primary determinants of performance, rather than specialized motor abilities (Malina, 2025).

With regard to the psychological variables, both hypotheses regarding the relationship between psychological and physical health aspects must ultimately be rejected, representing the main finding of this study. This absence of significant associations between posture, muscular fitness, and psychological variables challenges assumed psychophysical links in children and calls for a closer examination of possible developmental, theoretical, and methodological explanations.

Dreiskämper et al. (2015) stated, research findings vary regarding the age at which children can validly report or assess their global and domain-specific self-concept. As psychological well-being is also represented by self-concept in our study, this should also be considered when interpreting the current findings. Crone et al. (2022) also emphasize the numerous changes and influencing factors, such as social comparison, cognitive development, and the ability to adopt different perspectives, that shape the development of self-concept during childhood and adolescence. They argue that forming a stable self-concept is a primary developmental task of adolescence and, therefore, has not yet been fully achieved in childhood. The authors further note that, due to frequent and overly positive external feedback, children's self-perception tends to be excessively positive. This inflated self-view may also extend to physical self-perceptions, such as those reflected in the physical self-concept.

The third hypothesis was formulated based on two review studies that identified a connection between muscular fitness and psychological well-being (Bermejo-Cantarero et al., 2021; Smith et al., 2014). These reviews combined research on both children and adolescents, which suggest that older participants possess a more differentiated ability to self-assess psychological components, potentially influencing the observed relationships.

The indirect relationship between self-compassion and muscular fitness through physical activity could also not be replicated in children. One possible explanation is the significant difference in muscular fitness between childhood and adolescence (Beunen & Thomis, 2000), with notable increases during adolescence, particularly in boys. Similarly, the relationship between self-compassion and physical activity may also be less direct in children than in adolescents and adults (Wong et al., 2021). Another possible explanation is that the underlying factors may continue to develop throughout childhood and adolescence. Due to the limited number of studies on the development of self-compassion in children, these insights are often drawn from the broader field of compassion research. However, there is ongoing debate as to whether these two forms of compassion can be understood within the same overarching framework. While they may share many underlying structures, there are also notable differences (Neuenschwander & Gunten, 2025).

Recent research on the development of bodily self-consciousness suggests that while children as young as 6 or 7 years can self-identify with a body representation, the more complex integration of multisensory signals, such as touch referral and shifts in perceived self-location, develops only later in childhood or adolescence (Cowie et al., 2018). Moreover, as summarized by Gottwald et al. (2021), the sensory bases for perceiving one's own body characteristics are still immature in childhood, with proprioceptive estimates and the integration of visual and proprioceptive information remaining error-prone even at ages 8–10. This gradual developmental trajectory suggests that posture may not yet represent a salient or clearly differentiated construct in children's self-perception of well-being and health. A certain level of cognitive and physical maturation may be required before children are able to meaningfully recognize and relate postural aspects to their internal psychological states. Consequently, the assumed link between posture and psychological well-being as proposed by embodiment theory (Michalak et al., 2012), may not yet be functionally established in younger children, as the bodily cues required for such embodied self-evaluations are likely not fully accessible or integrated at this stage of development. Furthermore, studies that suggest a link between posture and psychological variables, such as mood, often examine the short-term effects of deliberately adopted postures on emotional states (Inagaki et al., 2018; Körner et al., 2020). These short-term effects do not necessarily imply the existence of stable, long-term associations or a consciously reflected perception of habitual posture. However, it is precisely this habitual or chronically maintained posture that is of greater relevance in the context of our posture assessment and hypotheses.

In the theoretical domain of physical self-concept and perceived motor competence, conceptual clarity remains lacking. Different terms are often used to refer to the same construct, while the same term may describe differing underlying concepts or definitions. Although this issue has been discussed in the literature for some time, no consistent terminology or shared definitions have yet been established (Dreiskämper et al., 2022).

A possible methodological explanation for our observations could lie in differing approaches to posture measurement. While the cited studies focused on subconsciously adopted long-term posture, our study examined the ability to consciously maintain an upright posture for an extended period, which is two postural states between which the posture differs (Ludwig et al., 2016). Although this ability to stay upright could help maintain an upright posture unconsciously over time, factors like habitual behaviors, extending beyond motor and physical abilities, play a significant role in sustaining unconscious posture (Clark et al., 2010). Additionally, 55 of the 174 participants (31.6%) achieved the maximum score by maintaining the required upright posture for 120 seconds. This high proportion suggests a potential ceiling effect, likely influencing posture correlations.

Moreover, the decision to use assessment instruments for measuring physical self-concept during childhood is a complex one, as outlined by Dreiskämper et al. (2022). This applies not only to the conceptual level, in choosing between unidimensional and multidimensional approaches, but also to the mode of assessment (e.g., questionnaires vs. pictorial scales), given the wide range of available measurement tools. More complex instruments may not be appropriate for younger children whose physical self-concept is still underdeveloped, while simpler instruments may fail to adequately reflect the more differentiated self-perceptions of older children. The hierarchical and multifaceted nature of the physical self-concept is closely tied to cognitive maturity and typically develops in middle to late childhood (Dreiskämper et al., 2022). Thus, given the relatively broad age and developmental range of our sample, it is plausible that for some children a unidimensional instrument might have been more appropriate than the domain-specific questionnaire employed in this study. Contrary to our study, previous research has primarily found associations between physical self-concept and physical fitness in primary school children when domain-specific fitness tests were employed that directly measured the physical abilities reflected in corresponding subdomains of the physical self-concept (Tietjens et al., 2020). However, even in that study, the associations within the domain of physical fitness were relatively weak, which the authors attributed to the possibility that such relationships may develop later in childhood or adolescence. Similarly, although the self-compassion questionnaire used in this study was originally developed for children in English-speaking contexts and showed valid associations with measures of mindfulness, self-concept, and psychological well-being during validation (Sutton et al., 2018), it remains unclear whether children, depending on their individual stage of development, are cognitively able to consciously understand and reflect on the abstract constructs involved in self-compassion.

Our results mostly support the fourth hypothesis, confirming significant positive associations between psychological well-being, positive self-compassion, and physical self-concept in children. The strong correlation between psychological well-being and physical self-concept aligns with previous findings linking a positive physical self-concept to improved well-being in this age group (Delgado-Floody et al., 2022; Dreiskämper et al., 2015). Similarly, the strong relationship between positive self-compassion and psychological well-being in this study mirrors observations in adults, where higher self-compassion was associated with reduced self-criticism and better psychological outcomes (López et al., 2018; Wakelin et al., 2022). Interestingly, the negative subscale of self-compassion was not related to physical self-concept dimensions, in contrast to the positive subscale. These differing associations between the two aspects of self-compassion may be explained by the distinct underlying systems on which they are based (Neuenschwander & Gunten, 2025). As these systems develop independently, they may show associations with other variables at different points in time. Future studies should consider longitudinal designs to explore causal pathways, as E. E. Lee et al. (2021) did in adults, to determine whether similar patterns emerge in childhood.

Taken together, the results do not support the assumption that the physical and psychological contextual factors proposed in Lima's extended model are strongly interconnected. While we did not examine links to the model's core components, such as physical activity and motor competence, our focus on more peripheral factors revealed no substantial associations. Although previous studies have demonstrated connections between the core constructs and both physical and psychological variables, our findings suggest that the broader network of peripheral influences may be less tightly connected than hypothesized.

#### *4.4.2 Limitations*

As outlined in the discussion, several limitations need to be considered when interpreting the results. First, while the study focused on key constructs such as self-compassion and physical self-concept, it remains unclear whether these constructs are fully developmentally appropriate and reliably measurable in children of this age, potentially limiting the interpretability of the findings. The relatively wide age range of our sample, which, particularly in the context of a childhood study, covers a broad span of developmental stages, must also be taken into consideration. Moreover, there may be a mismatch between some measurement instruments and the specific tests used. For example, stronger associations are typically found when skill-specific self-concept measures are paired with corresponding motor performance tasks, which was not the case here. Additionally, the suitability of the measurement instruments should be considered a limitation, as the multidimensional structure of the PSK-K may have exceeded the cognitive and reflective capacities of some younger participants. This potentially limits its validity in this age group. Similarly, the self-compassion scale, although adapted for children, may still rely on abstract self-reflective abilities that are not yet fully developed in all participants. This could have affected the reliability and interpretability of the responses. Additionally, the relatively homogeneous sample, particularly with respect to the high parental educational level, may have restricted variability, limiting the ability to detect associations that might emerge in more diverse populations. One further limitation of the present study concerns the relatively low participant-to-parameter ratio in the structural equation model. While traditional guidelines recommend larger samples the perfect model fit suggests that the parameter estimates are robust and the model is well specified. Nonetheless, future research should aim to replicate the findings with a larger and more diverse sample to ensure the generalizability and stability of the parameter estimates. Furthermore, recruitment through the back prevention project likely attracted families who were already highly engaged with their children's health and demonstrated strong research interest, further reducing the generalizability of the findings. Finally, the main limitation of the study lies in its cross-sectional design, which precludes conclusions about causal relationships or developmental trajectories over time.

#### *4.4.3 Conclusion*

The present findings offer important insights into the relationship between physical and psychological health in children. Notably, both hypotheses concerning psychophysical associations between posture, muscular fitness, and psychological outcomes had to be rejected, suggesting that such connections may not yet be established or measurable in this age group. These null findings highlight the importance of considering developmental, methodological, and theoretical factors when investigating embodied psychological processes in children. Given the cross-sectional design, no conclusions can be drawn about causal directions or developmental trajectories. Therefore, longitudinal research is urgently needed to examine how and when links between physical function and psychological well-being begin to emerge across childhood and adolescence.

### 4.5 Deviations from Preregistration

Several deviations from the preregistration plan were implemented during the study. First, the manuscript title differs from that in the preregistration. For the BSCI-Y questionnaire, the total score was used instead of the average score across all items, following the test manual. Additionally, due to the results of the factor analysis, no total scores were calculated or used for the PSK-K and SCS-C scales. The hypotheses were reorganized into four major categories to group thematically related analyses. Additionally, a preregistered hypothesis that predicted no relationship between core endurance and FMS was deemed inadmissible and reassigned to the exploratory analysis to investigate a possible link.

The power analysis from the preregistration was adjusted and recalculated for this study following the method of Faul et al. (2007). Since strong correlations were observed between psychological well-being, self-compassion subscales, and physical self-concept, a regression analysis using psychological well-being as an outcome variable was not conducted.

# 5 Third Study

# Evaluation of a web-based back prevention program for primary school children[4]

Study 2 was conducted as part of the pretest for Study 3, which will address the examined health dimensions from a longer-term perspective.

## 5.1 Goals and Hypotheses

The objective of Study 3 is to evaluate the effects of the 12-week web-based back prevention program BackFit on the health dimensions assessed in Study 2. Given that the BackFit program is designed to increase physical activity, strengthen trunk muscles, promote postural awareness, and enhance back-related knowledge, we expect corresponding improvements in these areas among participants. Based on these findings, the following hypotheses are proposed:

1) The intervention group will significantly reduce postural anomalies and reported back pain more than the control group (H1).

2) The intervention group will improve trunk muscle endurance and functional mobility more than the control group (H2).

[4] The corresponding paper to this study is currently under review: Weigel, S. & Jansen, P. Evaluation of a web-based back prevention program for primary school children: a randomized controlled trial. The structure and order of content presented here may differ slightly from the final published version.

3) Compared to the control group, the intervention group will show more significant improvements in psychological well-being, specifically in self-compassion and self-concept (H3).

4) The intervention group will increase back-related knowledge more than the control group (H4).

As Dullien et al. (2018) found that the ability to maintain an upright posture improved equally in both experimental and control groups over a period of 10 months among German fifth-grade students, we aimed to explore potential changes in postural endurance in both groups. We also explored changes in parent-reported daily sitting times to examine whether the intervention leads to a reduction in sedentary behavior. In addition, we investigated the potential influence of the demographic factors of sex and socioeconomic status on the observed changes in an exploratory manner. Furthermore, subgroup analyses within the intervention group were conducted to identify potential factors contributing to intervention responsiveness. We examined whether participants who showed improvements in back pain prevalence or motor performance differed from those who did not with respect to variables such as age, sex, baseline performance, postural assessment findings, or recent growth. Additionally, changes in motor performance were compared between the youngest and oldest participants to explore potential age-related effects of the program. Aiming at these items a principle limitation is that no usual medical examination of back muscles status and posture was performed. To further assess the suitability and implementation of the program, parents were briefly surveyed at the end of the project regarding their child's motivation, the appropriateness of the videos, and the ease of integrating the program into daily life.

## 5.2 Method

### *5.2.1 Participants*

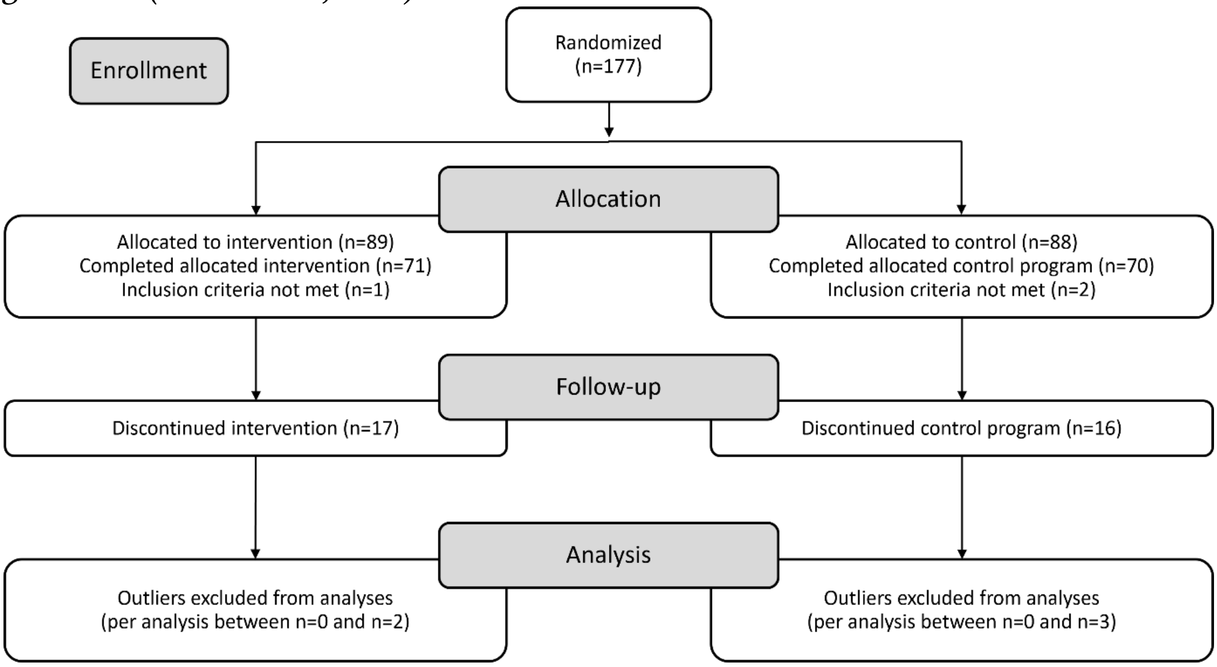
Between January 2023 and November 2024, participants were recruited through pediatric practices, youth organizations, religious communities, sports clubs, the university's family support services, and local media outlets. The project was also promoted via local radio broadcasts. A power analysis (Faul et al., 2007) with the parameters $d$ = 0.25, $\beta$ = 0.80, and $\alpha$ = .0125 indicated that a sample size of 182 children was required. To account for an anticipated dropout rate of approximately 10%, the initial target was increased to 200 participants. However, this preregistered target could not be achieved due to recruitment challenges during a limited 1.5-year recruitment period and a fixed project timeline. Recruitment concluded with a total of 177 children, with 89 allocated to the intervention group (IG) and 88 to the control group (CG).

Exclusion criteria were as follows: (a) pre-existing structural conditions such as scoliosis, (b) medical restrictions preventing participation in strengthening exercises, (c) neurological disorders, (d) concurrent participation in other scientific intervention studies, (e) more than 10% missing responses in any administered questionnaire, (f) early program withdrawal, and (g) repeated delays making a completion of the program within 15 weeks impossible. Based on these criteria, 36 participants were excluded from the analysis: one due to a diagnosed scoliosis (IG), one due to significant language barriers that prevented standardized testing (CG), and one for failing to complete more than 90%

of several questionnaires (CG). The remaining excluded participants (17 IG, 16 CG) either withdrew from the program or could not complete it within 15 weeks due to repeated delays, as illustrated in Figure 2.

**Figure 2**

*Flowchart of patient enrollment and randomization according to the CONSORT 2010 guidelines (Moher et al., 2010).*




The final dataset comprised 141 children aged 6 to 11 years (M = 8.60, SD = 1.30). Although the intended age range was 7 to 11 years, one six-year-old was included, as the child was nearing their seventh birthday at the time of data collection. Of the total sample, 65 participants were girls (46.1%) and 76 were boys (53.9%). Group allocation was nearly balanced, with 71 children in the IG and 70 in the CG.

### *5.2.2 The BackFit Program*

The BackFit program was designed to run over 12 weeks, with distinct content tailored to each group. Weekly videos were unlocked sequentially, requiring participants to complete the prior week's content before accessing the next module. Unlocking occurred after seven days or immediately upon task completion if delayed beyond one week. While this flexible approach could extend the overall duration, it ensured thorough engagement with the material. The intervention was delivered via a web-based platform designed by the web development company Selbstdenker AG (Regensburg, Germany). As a website it was accessible remotely, and content was adapted to the specific needs of each group. To enhance motivation, participants could collect trophies and virtual coins by completing various tasks. These coins could be used to play games or customize a personal avatar, increasing engagement with the program.

#### 5.2.2.1 Intervention Group

The IG received two weekly videos: a 30-minute exercise video and a 5-minute knowledge video. The exercise videos focused on strengthening trunk muscles and were designed to be engaging and age-appropriate. To increase accessibility and appeal, each video was embedded in a storyline or included everyday household items such as towels, tennis balls, or toilet paper rolls. An adult, a mascot and a child demonstrated exercises to ensure easy imitation and understanding. The cartoon-style knowledge videos addressed educational topics related to the structure and function of the spine, sedentary behavior, proper lifting techniques, and general principles of back-care. Screenshots of the exercise and knowledge videos can be found in Section 9.2.

To further encourage healthy habits, the program included two optional daily components. First, participants could use a movement diary on the BackFit website to record their daily physical activity and sedentary behavior. Second, they were encouraged to integrate six simple daily habits into their routines, such as performing a wall push-up after washing hands. Small reminder cards were placed in relevant spots around the home to prompt the activities, and participants could track their frequency online to support self-monitoring and accountability.

#### 5.2.2.2 Control Group

The CG received one cartoon-style knowledge video per week, each lasting approximately five minutes. These videos focused on general health-related topics such as sleep hygiene and nutrition but did not include any back-specific content. The topics were inspired by the Klasse2000 health promotion and prevention program implemented in German primary schools (Verein Programm Klasse2000 e. V., 2025). A screenshot of the knowledge video can be found in Section 9.2.

### *5.2.3 Measurements*

#### 5.2.3.1 Posture Assessment

Before the posture assessment, participants' weight and height were measured. Postural abnormalities were evaluated using a slightly modified version of the visual assessment form used in Study 1. Modifications were necessary because, for ethical reasons, participants wore shorts and tight-fitting tops, which limited the visibility of certain anatomical landmarks. If a top was too loose, it was temporarily adjusted with clothespins to improve the visibility of body contours. Thus no usual medical examination was possible.

Participants were observed standing in a relaxed, upright position. Assessed features included shoulder tilt, plumb line deviations, leg alignment, foot positioning, and other visible irregularities. The sagittal view was used to evaluate the cervical, thoracic, and lumbar spine curvature while wearing the outer garments. Functional tests included single-leg stance, toe and heel walking, gait analysis, spinal rotation, lateral flexion, spinal extension, and finger-to-floor distance. The latter was measured while participants stood on a low stool, allowing the fingertips to extend below the level of the feet during maximal forward bending with knees fully extended. Following the physical examination, participants were asked about the presence of back pain and if applicable its location intensity (assessed using a visual analogue scale), and possible triggers.

To evaluate the ability to maintain an upright posture over time, the Matthiass test was administered (Tittlbach & Bös, 2002). Participants were instructed to stand upright and hold their arms extended horizontally in front of a vertical grid marked with 5 × 5 cm squares. The test measured the time (in seconds) participants could maintain the posture without deviating by more than one square. The test was terminated if posture shifted beyond one grid line, the participant stopped voluntarily, or the maximum test duration was reached. The maximum score was 120 seconds.

#### 5.2.3.2 Trunk Muscle Endurance Assessment

Trunk muscle endurance was assessed using two adapted McGill endurance tests (McGill et al., 1999). For trunk extensor endurance, participants lay prone on a bench with their legs secured by straps. The upper body extended horizontally beyond the bench with arms crossed over the chest, while a horizontal bar placed at the upper back served as a reference to monitor alignment. The position's duration was recorded, with a maximum limit of 300 seconds. The test was terminated after three instances of the back losing contact with the bar. For trunk flexor endurance, participants maintained a 50° sit-up position supported by a wedge, which was shifted 10 cm backward at the beginning of the test. Feet were strapped, hands rested across the chest, and both knees and hips were flexed at 90°. Participants were instructed to hold the position without leaning back onto the wedge, rounding the back forward, or using their hands for support. The maximum duration was again limited to 300 seconds.

#### 5.2.3.3 Functional Mobility Assessment

Functional mobility was assessed using the Functional Movement Screen (FMS) (Cook et al., 2014a, 2014b). It comprises 10 exercises or clearing exams: deep squat, hurdle step (left/right), inline lunge (left/right), shoulder mobility (left/right), shoulder clearing test (left/right), active straight leg raises (left/right), trunk stability push-up, extension clearing test, rotary stability (left/right), and flexion clearing test. Each exercise was scored on a scale from 0 to 3, with a maximum possible total score of 21. The lower score of the two sides was used for exercises performed bilaterally. Any occurrence of pain during the exercises or clearing tests resulted in an automatic score of zero.

#### 5.2.3.4 Psychological Well-Being Assessment

This study selected self-concept as an indicator of psychological well-being next to self-compassion. The self-concept subscale of the German version of the “Beck Youth Inventories – 2nd Edition” (J. S. Beck et al., 2018) was utilized to assess psychological well-being. This subscale comprises 20 items, each rated on a 4-point Likert scale ranging from “never” (0) to “always” (3). All item scores were summed up to determine the total score, with a maximum achievable score of 60.

Self-compassion was measured using a German adaptation of the self-compassion scale short form designed for children (Sutton et al., 2018). The adaptation process involved two translators with advanced English proficiency who independently translated the questionnaire forward and backward. The scale consists of 12 items divided into two subscales, with responses recorded on a 5-point Likert scale ranging from 'never' (1) to 'always' (5). The two subscales assess self-judgment and isolation (negative self-compassion), and self-kindness and acceptance (positive self-compassion). Negatively phrased items were reverse-coded to ensure consistent scoring. Subscale scores were calculated as the mean of the six items within each respective subscale.

The internal consistency of the subscales was assessed using post-test data with Cronbach's Alpha and McDonald's Omega. For positive self-compassion, values of $\alpha$ = .752 and $\omega$ = .749 were obtained, while for negative self-compassion, both $\alpha$ and $\omega$ were .715. These values fall within the acceptable range, exceeding the .70 threshold for internal consistency (Nunnally, 1978).

#### 5.2.3.5 Back-Knowledge Assessment

Back-related knowledge was assessed using a test consisting of nine questions, covering back-care-related content presented in the program's educational videos. Each correct answer was awarded one point, and the individual scores were summed to generate a total score, ranging from 0 to 9.

#### 5.2.3.6 Assessment of Parental Background Information

Additional background information was collected through a parental questionnaire at both testing sessions. This included a brief health history, past posture-related problems, physical activity and sitting behavior, as well as the parents' educational background. Parental education was assessed using a scale based on the ISCED 2011 framework (UNESCO Institute for Statistics, 2012) ranging from 1 to 8. Due to conceptual challenges associated with this construct (Antonoplis, 2023), the higher of the two parental education levels was used to represent the SES. According to Huebener (2020), parental education can be seen as a key indicator for the describing the socio-economic background of children. For the second testing session, a shortened version of the parental questionnaire was used, focusing solely on sitting and physical activity behavior, as well as back-related complaints.

### *5.2.4 Procedure and Design*

The study followed a 2 (group) × 2 (time) factorial design and adhered to CONSORT guidelines for randomized controlled trials (Moher et al., 2010). Testing sessions took place at the laboratories of the Institute of Sport Science. Children attended the sessions accompanied by a parent, who remained outside the child's visual field to minimize distraction and external influence. While testing was underway, parents completed a questionnaire providing additional background information. Each session lasted approximately 60 to 90 minutes. Informed consent was obtained from both children and their parents prior to testing.

The posture examination was conducted first, followed by the postural endurance test. Before the motor tests, participants completed the SCS-C questionnaire and a brief warm-up. Motor testing was conducted by a second examiner in a separate room, beginning with the FMS, followed by the back knowledge questionnaire. Trunk flexor endurance was then assessed, followed by the BSCI-Y questionnaire and, subsequently, trunk extensor endurance. The session concluded with the PSK-K (Dreiskämper et al., 2015), a physical self-concept questionnaire used to explore relationships in Study 2. At the end of the pretest, group allocation was determined by simple randomization using a draw from a box containing an equal number of lots for each group (100 per group), prepared by the study coordinator at the outset of the study. Group assignment and explanation of the program were provided by the same person who conducted the motor tests. Participants in the IG also received habit cards for use during the intervention.

The posttest was conducted within two weeks of program completion and followed the same structure, omitting the initial administrative procedures. The PSK-K questionnaire was not administered at posttest, as it was used only for pretest correlations. Upon completing the study, each child received a €15 voucher as compensation. After data collection, children in the CG were offered the habit cards and introduced to the intervention program, which they were invited to complete. The study was registered retrospectively in the German Clinical Trial Register (DRKS)[5] on April 1, 2025 and preregistered on OSF[6].

### 5.2.5 *Statistical Analysis*

Statistical analyses were performed using IBM SPSS Statistics 29 (IBM Inc., Chicago, IL, USA). Descriptive statistics were used to calculate frequencies, means,

[5] https://www.drks.de/DRKS00036556
[6] https://osf.io/3t67m/?view_only=2cf0b6189281440d8302a01497521a0f

standard deviations (*SD*), and ranges. Group differences in demographic variables were analyzed using the Chi-square test, Fisher's exact test, Mann–Whitney U test, or t-test for independent samples, depending on the distribution. Only daily sitting time was normally distributed. The Wilcoxon test was used to assess changes in the number of postural abnormalities within each group, while a Chi-square test evaluated differences in the one-month back pain prevalence between groups. Two-factorial analyses of variance (ANOVAs) were conducted for the dependent variables FMS total score, back knowledge, self-compassion, self-concept, postural endurance, and daily sitting time (the last two exploratory), with test time as the within-subject factor and group as the between-subject factor. Assumptions of homoscedasticity and homogeneity of covariance matrices were tested using Levene's and Box's M tests, respectively, and were met. For the two trunk endurance variables, one-way ANOVAs were calculated using the difference between pre- and post-test scores, as the assumption of homoscedasticity was violated, and two-factorial ANOVAs could therefore not be applied. To examine the influence of sex and SES on intervention effects, one-way ANOVAs with these fixed factors were conducted for the difference scores of the dependent variables previously analyzed via ANOVA in the IG. SES was dichotomized via median split to allow categorical analysis.

Bonferroni correction was applied separately for each hypothesis to account for multiple testing, resulting in adjusted significance thresholds ranging from $p = .05$ to $p = .0167$. The specific threshold used for each hypothesis is reported in the results section. Outliers were defined as values falling outside the range of mean ± 3 *SD*.

## 5.3 Results

### *5.3.1 Demographic Data*

Demographic data for both groups are presented in Table 13. The only significant difference between the groups was found in parental educational level. However, in both groups, most parents held a bachelor's degree or higher, corresponding to the top three categories of the classification. One parent did not provide information on educational level. For daily sitting time, the values of two participants were excluded, as the reported values exceeded 24 hours per day.

**Table 13**

*Group Comparison of Demographic Data*

| | | IG | CG | Group Difference |
|---|---|---|---|---|
| Age M (SD) | | 8.52 (1.34) | 8.67 (1.26) | *p* = .455[a] |
| Sex *n* [%] | | | | *p* = .927[b] |
| Boys | | 38 [53.5%] | 38 [54.3%] | |
| Girls | | 33 [46.5%] | 32 [45.7%] | |
| Highest parental educational level *n* [%] * | | | | *p* = .047[c] |
| Not specified | | 0 [0%] | 1 [1.4%] | |
| Completion of 10th grade | | 0 [0%] | 1 [1.4%] | |
| A-levels | | 4 [5.6%] | 1 [1.4%] | |
| Vocational school | | 2 [2.8%] | 0 [0%] | |
| Short master craftsman training | | 5 [7.0%] | 0 [0%] | |
| Bachelor´s degree | | 9 [12.7%] | 9 [12.9%] | |
| Master´s degree | | 36 [50.0%] | 47 [67.1%] | |
| PhD | | 15 [22.4%] | 11 [15.9%] | |
| Active in sports clubs *n* [%] | None | 10 [14.1%] | 17 [24.3%] | *p* = .313[b] |
| | One club | 38 [53.5%] | 34 [48.6%] | |
| | More clubs | 23 [32.4%] | 19 [27.1%] | |
| Active in programs outside of clubs *n* [%] | | 22 [31.0%] | 17 [24.3%] | *p* = .300[b] |
| Daily sitting time in hours *M* (*SD*)** | | 7.05 (1.38) | 7.42 (1.63) | *p* = .146[d] |
| One week back pain prevalence pretest N [%] | | 6 [8.5%] | 4 [5.7%] | *p* = .745[c] |
| One-month back pain prevalence pretest N [%] | | 10 [14.1%] | 5 [7.1%] | *p* = .275[c] |
| Three-month back pain prevalence pretest N [%] | | 12 [16.9%] | 9 [12.9%] | *p* = .637[c] |
| Acute back pain at pretest N [%] | | 1 [1.4%] | 3 [4.3%] | *p* = .366[c] |
| Assessed postural abnormalities in pretest *M* (*SD*) | | 0.97 (1.29) | 0.89 (1.37) | *p* =.530[a] |

**Note.** IG: N=71; CG N=70, * Not specified excluded in CG, ** Two outliers excluded in IG. [a] Mann-Whitney-U-Test, [b] Chi-Square Test, [c] Fisher-exact Test, [d] T-test

### *5.3.2 Descriptive Results*

Table 14 presents the number of participants exhibiting at least one abnormality across different categories. A detailed breakdown of these categories can be found in chapter 9.3. In both groups, visual abnormalities related to the upper body and spine had the highest prevalence, with approximately one-third of participants displaying at least one abnormality in these areas.

**Table 14**

*Frequency of Postural Abnormalities in Different Categories*

| | IG | | CG | |
|---|---|---|---|---|
| Summarized postural concept | Pretest *n [%]* | Posttest *n [%]* | Pretest *n [%]* | Posttest *n [%]* |
| Visual upper body and spine abnormalities | 30 [42.3%] | 22 [31.0%] | 24 [34.4%] | 23 [32.9%] |
| Visual lower extremity abnormalities | 9 [12.7%] | 10 [14.1%] | 7 [10.0%] | 15 [21.4%] |
| Functional restrictions | 10 [14.1%] | 11 [15.5%] | 8 [11.4%] | 6 [8.6%] |

The mean values and standard deviations of the other measured variables can be found in Table 15 for both groups and test times.

**Table 15**

*Overview of the Remaining Dependent Variables, Categorized by Group and Time Point*

| | IG | | CG | |
|---|---|---|---|---|
| | Pretest *M (SD)* | Posttest *M (SD)* | Pretest *M (SD)* | Posttest *M (SD)* |
| Matthiass test [s] | 84.46 (28.52) | 92.35 (30.13) | 86.89 (30.15) | 95.59 (31.54) |
| FMS | 12.82 (3.04) | 14.63 (2.90) | 13.33 (3.24) | 14.33 (3.41) |
| Trunk flexor endurance [s] | 46.17 (39.47) | 55.44 (39.56) | 54.76 (47.20) | 74.01 (76.73) |
| Difference from pre- to posttest [s] | 9.27 (42.56) | | 19.26 (56.69) | |
| Trunk extensor endurance [s] | 48.28 (33.76) | 61.07 (36.97) | 62.33 (39.09) | 73.46 (49.39) |
| Difference from pre- to posttest [s] | 12.79 (33.61) | | 11.13 (40.28) | |
| Back Knowledge | 3.08 (1.35) | 5.21 (1.58) | 2.90 (1.45) | 3.33 (1.55) |
| SCS-C | 3.29 (0.57) | 3.40 (0.65) | 3.44 (0.43) | 3.39 (0.59) |
| $\text{SCS-C}_{\text{Positive self-compassion}}$ | 3.35 (0.70) | 3.44 (0.75) | 3.45 (0.78) | 3.25 (0.81) |
| $\text{SCS-C}_{\text{Negative self-compassion}}$ | 3.23 (0.82) | 3.37 (0.79) | 3.44 (0.74) | 3.54 (0.73) |
| BSCI-Y | 42.23 (10.02) | 43.03 (9.93) | 44.09 (7.66) | 43.29 (7.87) |

**Note.** Difference scores reflect the calculated difference from pretest to posttest for each group.

Participants in the intervention group completed the activity log on an average of 45 days (*M* = 42.39, *SD* = 28.00, range: 0–113) and recorded the frequency of their habit tasks on an average of 31 days (*M* = 27.51, *SD* = 24.81, range: 0–81). Values exceeding the 12-week program duration resulted from delays in completing the videos, leading to a delayed progression to the next program week.

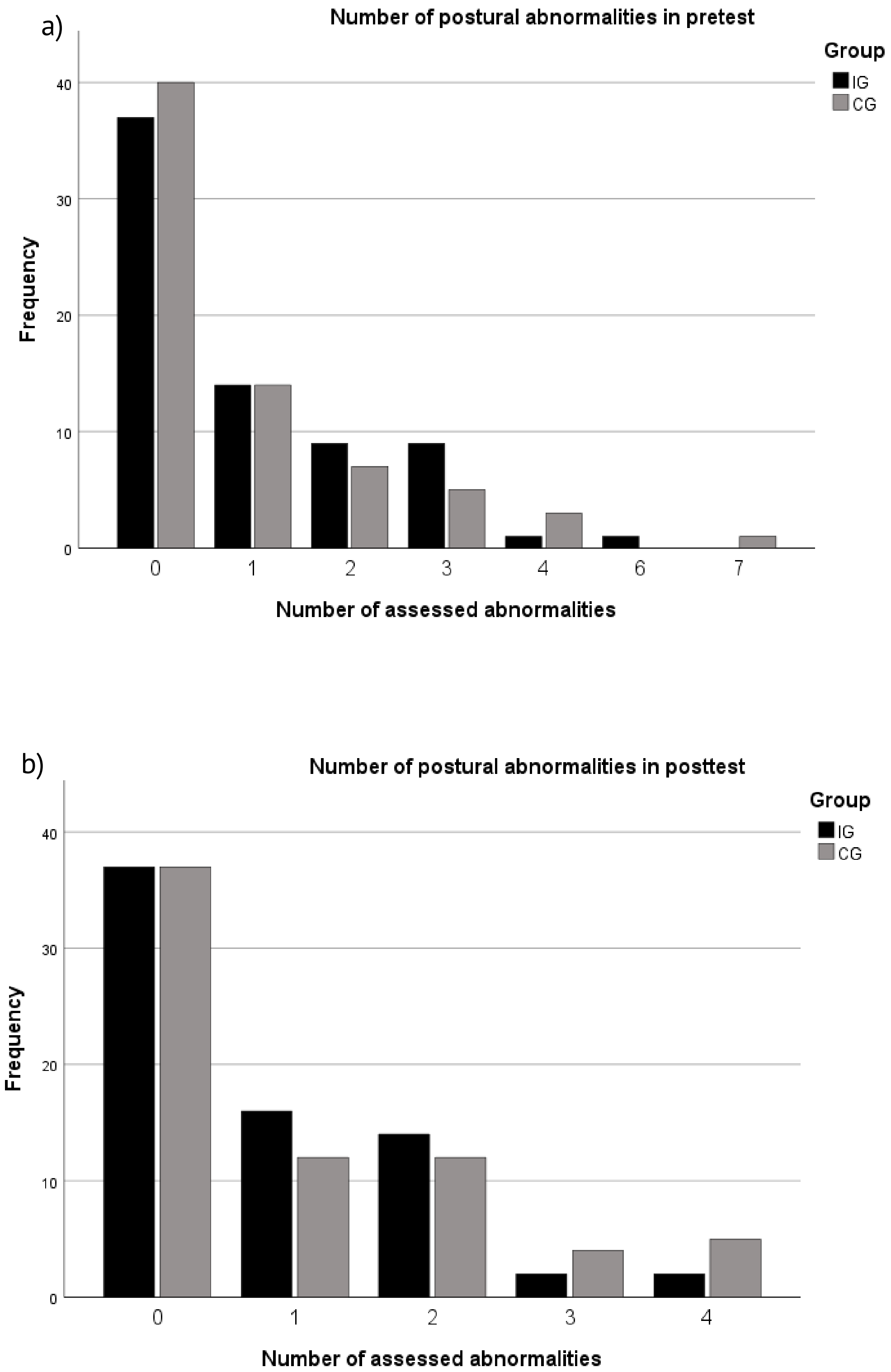
### *5.3.3 Postural Changes and Pain Outcomes*

Figure 3 illustrates the distribution of the assessed number of postural abnormalities across both groups and time points. In both groups, around half of the participants were asymptomatic (IG: 37 pre and post (52.1%), CG: 40 pre (57.1%) and 37 post (52.9%)). The frequency of individuals decreased as the number of assessed abnormalities increased. No substantial differences in distribution are observed between the groups. This finding is supported by the results of the Wilcoxon test at the corrected significance level $p$ = .025, which indicates no significant change in the number of postural abnormalities per participant for both groups (IG: $z$ = -0.858, $p$ = .391; CG: $z$ = 0.708, $p$ = .479).

In the pre-test, 15 (10.6%) parents reported that their child had experienced back pain in the past month, whereas this number decreased to 8 (5.7%) in the post-test. However, the group difference in the improvement of the one-month prevalence of back pain was not statistically significant ($\chi^2(1, 141) = 2.389$, $p$ = .122).

**Figure 3**

*Number of assessed postural abnormalities.*



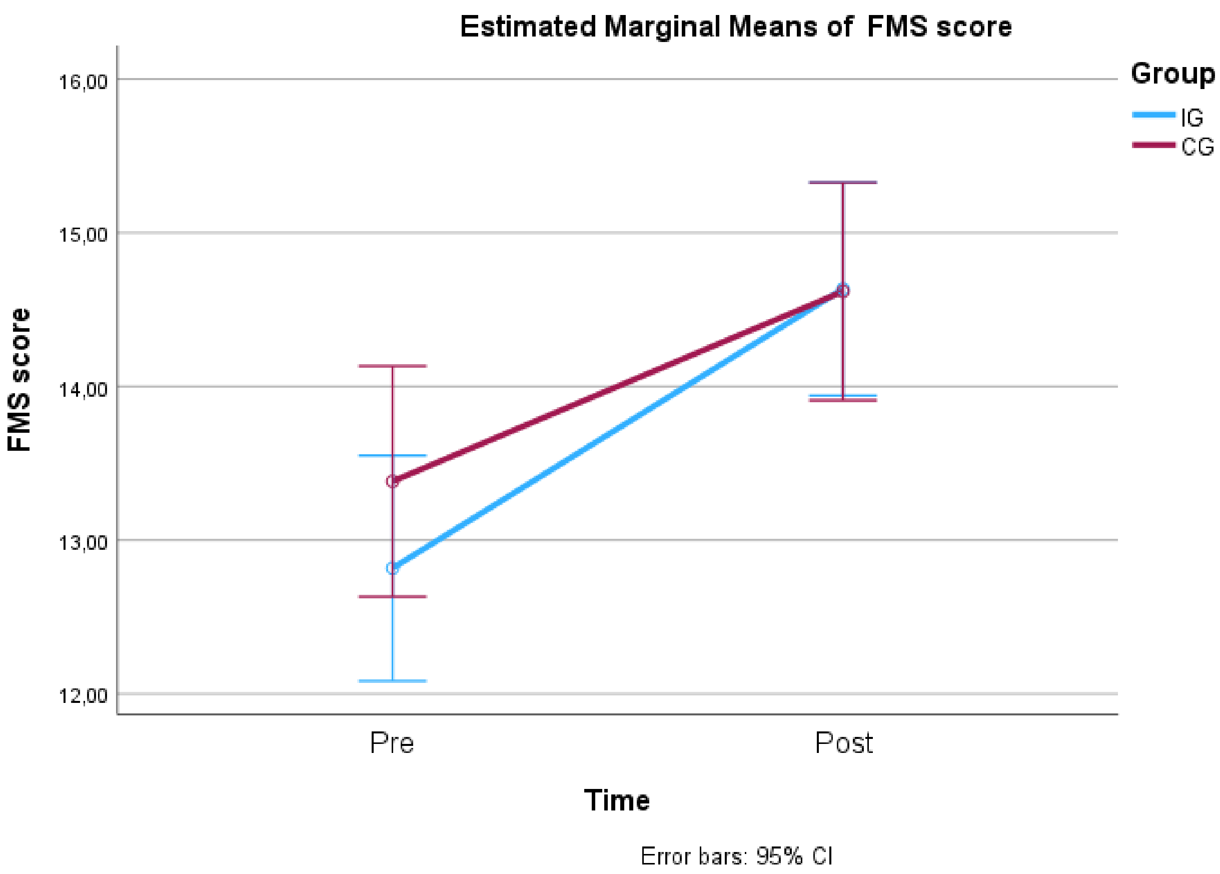

**Note.** a) shows the pretest results, b) shows the posttest results.

#### *5.3.4 Effects on Core Stability and Functional Mobility*

To account for multiple testing in the second hypothesis, the significance level was adjusted to $p$ = .0167. For FMS total score, two participants were excluded as outliers, resulting in a final sample of $N_{IG}$ = 71 and $N_{CG}$ = 68. The Group × Time interaction was not significant ($F(1, 137) = 1.555$, $p = .214$, partial $\eta^2 = .011$). A significant large main effect of Time ($F(1,137) = 42.837$, $p < .001$, partial $\eta^2 = .238$) was observed and is shown in Figure 4. The main effect of Group ($F(1,137) = 0.356$, $p = .552$, partial $\eta^2 = 0.003$) was statistically not significant.

**Figure 4**

*Time effect for the FMS score.*



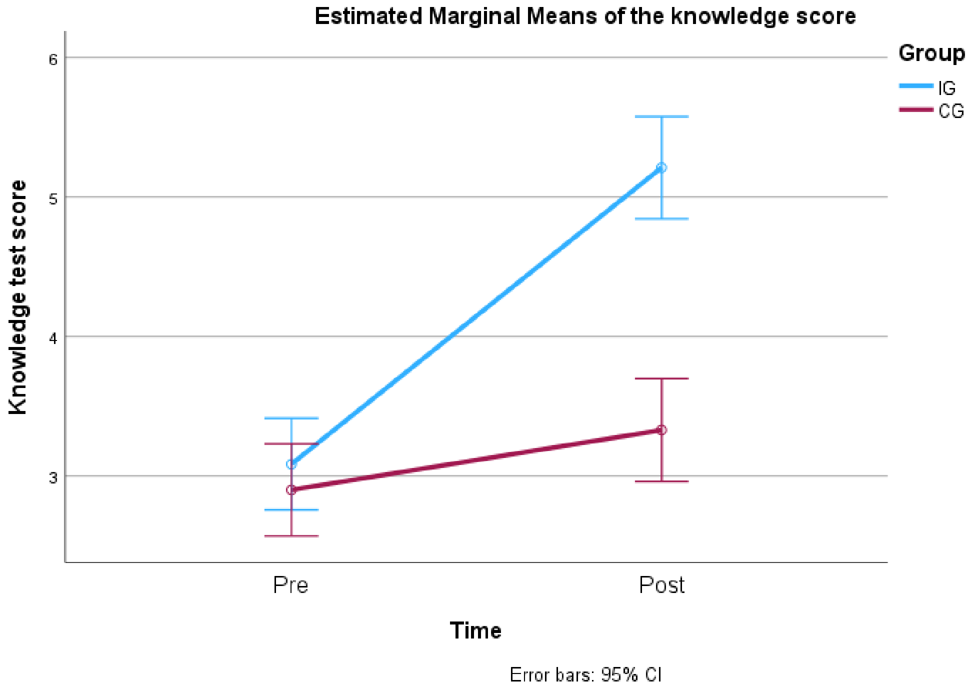
For trunk flexor endurance, four participants were excluded as outliers, resulting in a final sample of $N_{IG}$ = 70 and $N_{CG}$ = 67. The change from pre- to post-test did not differ significantly between the two groups, $F(1, 135) = 0.007$, $p = .936$, $\eta^2 = .014$. For trunk extensor endurance, three participants were identified as outliers and excluded, leading to a final sample of $N_{IG}$ = 71 and $N_{CG}$ = 67. Similarly, no significant difference was observed between the groups from pre- to post-test, $F(1, 136) = 0.641$, $p = .425$, $\eta^2 = .052$. Additional graphs visualizing these results can be found in chapter 9.4.

#### ***5.3.5 Back-related Knowledge***

For the score in the knowledge test no correction of the significance level of $p$ = .05 was necessary. Additionally, no outliers were present. Figure 5 shows the significant interaction Group x Time ($F(1, 139) = 40.955$, $p < .001$, partial $\eta^2 = .228$), which indicates a greater improvement of back-knowledge in the intervention group with a large effect size.

**Figure 5**

*Group x Time interaction of knowledge test scores.*



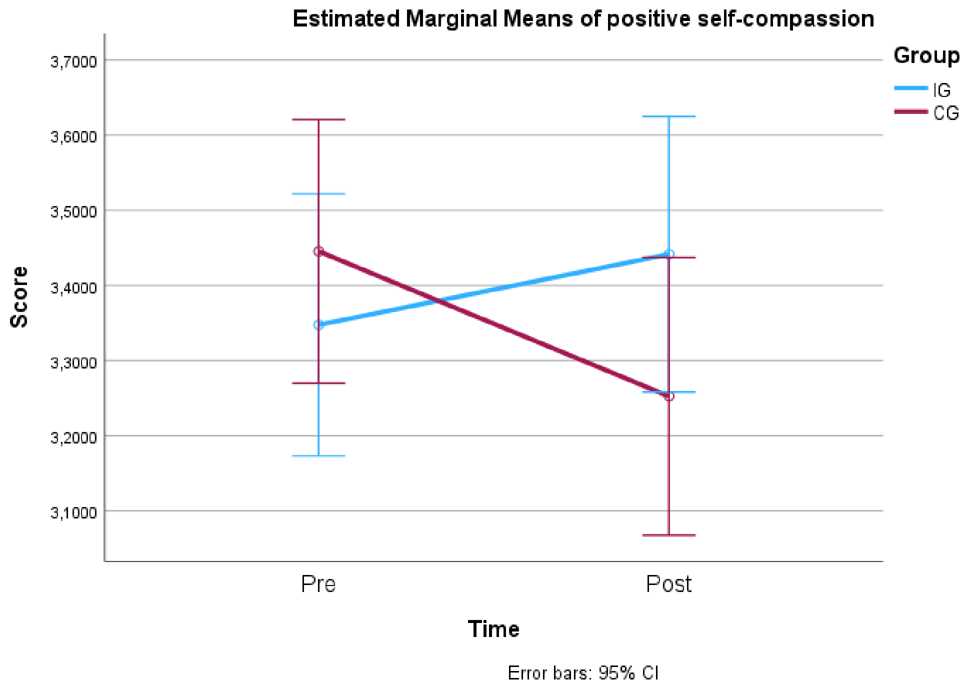

### *5.3.6 Psychological Effects*

Since the psychological effects of the intervention were analyzed using three separate calculations, the significance level was adjusted to $p$ = .0167 to account for multiple testing. For positive self-compassion, no outlier had to be excluded. The Group x Time interaction shown in Figure 6 was significant ($F$(1, 139) = 6.560, $p$ = .011, partial $\eta^2$ = .045) with a small to medium effect size.

The negative self-compassion was assessed in the sample $N_{IG}$ = $N_{CG}$ = 70 excluding one outlier from the IG. The Group x Time interaction was not significant ($F$(1, 138) = 0.024, $p$ = . 876, partial $\eta^2$ = .000). Neither the main effect of time ($F$(1, 138) = 3.959, $p$ = .049, partial $\eta^2$ = .028) nor for group ($F$(1, 138) = 2.045, $p$ = .155, partial $\eta^2$ = .015) were significant after the alpha level correction.

**Figure 6**

*Group x Time interaction of positive self-compassion.*




For self-concept, neither the Group × Time interaction ($F(1,137) = 1.794$, $p = .183$, partial $\eta^2 = .013$) nor the main effects of Group ($F(1,137) = 0.055$, $p = .814$, partial $\eta^2 = .000$) or Time ($F(1,137) = 0.009$, $p = .926$, partial $\eta^2 = .000$) reached statistical significance. The graphs illustrating the Group × Time interaction for both psychological variables can be found in chapter 9.4.

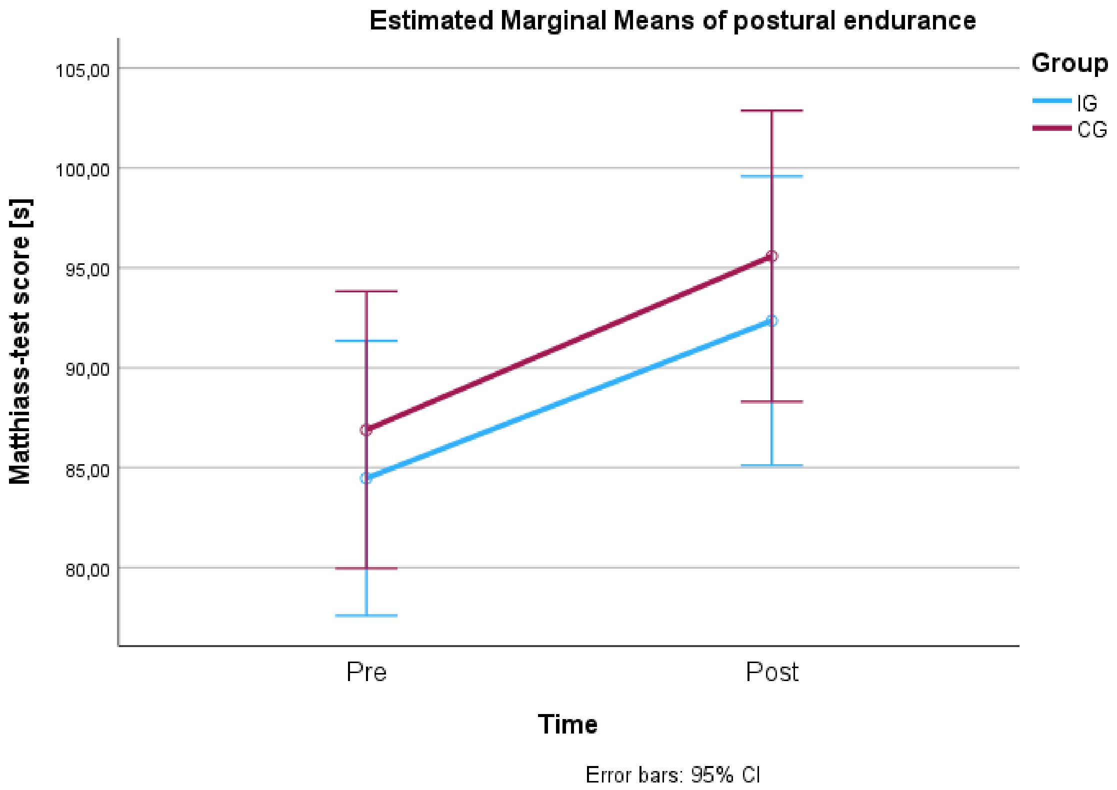
### *5.3.7 Explorative Analyses*

#### 5.3.7.1 Effects of the Intervention on Postural Endurance and daily sitting time

For the Matthiass test, no outlier had to be excluded. The analysis revealed no significant Group × Time interaction ($F(1,139) = 0.027$, $p = .869$, partial $\eta^2 = .000$) or Group main effect ($F(1, 139) = 0.407$, $p = .025$, partial $\eta^2 = .003$). However, a significant main effect for Time was observed ($F$(1,139) = 11.393, $p$ < .001, partial $\eta^2$ = .076), indicating a medium effect size (see Figure 7).

**Figure 7**

*Time effect for postural endurance.*




Three outliers had to be excluded for the analysis of the daily sitting time as values above 24 hours were reported, resulting in the sample $N_{IG}$ = $N_{CG}$ = 69. The results show no significant effect for the Group x Time interaction ($F$(1, 136)=0.059, $p$ = .809, partial $\eta^2$ = .000), the Time ($F$(1, 136) = 0.148, $p$ = .710, partial $\eta^2$ = .001) or Group main effect ($F$(1, 136) = 0.2.629, $p$ = .107, partial $\eta^2$ = .019). The corresponding graph can be found in chapter 9.4.

#### 5.3.7.2 Influence of Demographic Factors

When assessing the influence of sex and SES as independent factors on the dependent variables FMS score, trunk flexor and extensor endurance, knowledge, self-compassion, and self-concept within the intervention group, only sex showed a significant effect. In contrast, no significant influence of SES was found. Sex had a large effect on the difference in trunk extensor endurance ($F(1,67) = 13.738$, $p < .001$, partial $\eta^2 = .170$). Boys ($N = 38$) had a mean difference of -0.16s ($SD = 23.13$), whereas girls ($N = 33$) showed a mean difference of 27.70s ($SD = 37.74$). A detailed overview of the test statistics, significance levels, and effect sizes for all analyzed dependent variables can be found in chapter 9.4.

#### 5.3.7.3 Influences on Physical Improvements in the BackFit Program

To better understand potential factors within the intervention program that might have contributed to changes in back pain, subgroup analyses was conducted within the intervention group. Participants who showed improvements in back pain prevalence ($n = 8$) were compared to those who did not ($n = 2$), focusing on age, postural assessment outcomes, reported pre-existing conditions or known back problems, and physical performance data. However, no notable differences were identified between the two subgroups. A statistical significant difference could not be expected due to the small number of these groups.

The significance levels of group differences between participants who showed improvements in the physical tests and those who did not are summarized in Table 16.

**Table 16**

*Comparison of Relevant Factors Between Participants With and Without Improvements in the Three Physical Performance Tests*

| **Trunk flexor endurance** | **Improved** ($n$ = 47) | **Not Improved** ($n$ = 24) |
|---|---|---|
| | p-values of group difference | Effect size |
| Age | .920[a] | .01[a] |
| Sex | .353[b] | .11[b] |
| SES | .701[c] | .20[c] |
| Growth | .607[a] | .06[a] |
| Activity in sports club | .886[c] | .06[c] |
| Baseline level | < .001[a] | .43[a] |
| **Trunk extensor endurance** | **Improved** (n = 46) | **Not Improved** (n = 25) |
| | p-values of group difference | Effect size |
| Age | .479[a] | .08[a] |
| Sex | .071[b] | .21[b] |
| SES | .726[c] | .20[c] |
| Growth | .400[a] | .10[a] |
| Activity in sports club | .350[c] | .17[c] |
| Baseline level | .038[a] | .25[a] |
| **Functional mobility** | **Improved** ($n$ = 48) | **Not Improved** ($n$ = 23) |
| | p-values of group difference | Effect size |
| Age | .455[a] | .09[a] |
| Sex | .171[b] | .16[b] |
| SES | .785[c] | .17[c] |
| Growth | .755[a] | .04[a] |
| Activity in sports club | .317[c] | .17[c] |
| Baseline level | .005[d] | .74[d] |

| | a | b | c | d |
|---|---|---|---|---|
| Used test | Mann-Whitney-U Test | Chi-Square Test | Fisher-exact Test | T-Test |
| Effect size | Pearson’s *r* | Cramer’s *V* | Cramer’s *V* | Cohen‘s *d* |

A closer look at these subgroups revealed significant baseline differences across all three physical performance tests. For trunk flexor endurance ($p < .001$), the group with improvement had a mean baseline performance of 35.77 seconds (*SD* = 28.49), whereas those who did not improve averaged 66.54 seconds (*SD* = 49.65). For trunk extensor endurance ($p = .038$), the improvement group achieved a mean of 41.15 seconds (*SD* = 23.58), compared to 61.40 seconds (*SD* = 44.87) in the non-improvement group. In the functional mobility test ($p = .005$), participants who did not improve had a baseline average of 14.26 points (*SD* = 3.03), while those who improved scored 12.13 points (*SD* = 2.82) in the pretest.

To further explore the influence of sex-specific growth, interaction effects between sex and growth were tested using binary logistic regression for each of the three physical tests. In none of the models did the interaction term reach statistical significance (all $p > .48$). The interaction between sex and growth did not significantly predict improvement in the trunk flexor endurance, trunk extensor endurance, or the FMS score. The explained variance in all models was low (Nagelkerke $R^2 < .07$), and the odds ratios for the interaction ranged between 1.25 and 1.41, indicating no meaningful effect.

#### 5.3.7.4 Differences in Physical Outcomes at the Age Extremes of the Sample

The comparison of pre-to-post change scores in the physical tests between the ten youngest and ten oldest participants is shown in Table 17. It revealed no significant group differences for any of the three tests, with both trunk muscle endurance tests showing negligible effects. For the FMS score, however, the effect size (Hedges' *g* = .788) indicated a large effect. Comparing mean improvements, the youngest participants showed a greater average gain (2.50 ± 0.45) compared to the older subgroup (1.10 ± 0.62).

**Table 17**

*Comparison of Changes in the Physical Tests in the Extremes of the Sample*

| | | Youngest 10 Participants | Oldest 10 Participants |
|---|---|---|---|
| **Difference in trunk flexor endurance** | *M (SD)* | -20.7 (40.22) | -22.60 (46.61) |
| | *p* - values of group difference | .926[b] | |
| | Effect size | .04[b] | |
| **Difference in trunk extensor endurance** | *M (SD)* | -16.30 (28.23) | -18.20 (51.16) |
| | *p* - values of group difference | .912[a] | |
| | Effect size | .03[a] | |
| **Difference in FMS score** | *M (SD)* | 2.50 (0.45) | 1.10 (0.62) |
| | *p* - values of group difference | .086[b] | |
| | Effect size | .79[b] | |

| | a | b |
|---|---|---|
| Used test | Mann-Whitney-U Test | T-Test |
| Effect size | Pearson's *r* | Hedges' *g* |

### 5.3.7.5 Parental Feedback on Program Implementation

In total, parents of 46 children (32.6%) responded to the survey, including 29 from the intervention group and 17 from the control group. Parents rated the following four questions on a 5-point Likert scale: (1) How motivated was your child to follow the program regularly? (2) Did your child find the videos enjoyable or interesting? (3) How did you perceive the format of the videos in terms of length and complexity? (4) Was it easy for your child and family to integrate the program into daily life?

In the IG, the average parental rating for their child's motivation to regularly engage with the program was 3.35 (*SD* = 1.12). The videos were rated with an average of 3.98 (*SD* = 0.80) in terms of enjoyment and interest, 4.24 (*SD* = 0.85) for their perceived fit regarding length and complexity, and 3.15 (*SD* = 1.17) for ease of integration into daily routines. In the CG, motivation was rated at 3.34 (*SD* = 1.01), enjoyment and interest at 3.97 (*SD* = 0.73), video fit at 4.41 (*SD* = 0.63), and ease of integration at 3.14 (*SD* = 1.13).

## 5.4 Discussion

This study examined the effects of a digital back-care program targeting physical function, psychological well-being, and back-related knowledge. The findings present a nuanced picture: while the intervention significantly improved back-related knowledge and positive self-compassion, no group differences were observed for posture, back pain, core stability, mobility, or the other psychological outcomes. Each hypothesis is discussed in relation to the results and relevant literature in the following.

The observation of postural deviations in nearly half of the sample aligns with previous findings in children from the Czech Republic (Kratenová et al., 2007) and a broader sample of children and adolescents from Brazil (Batistão et al., 2016). In contrast, the prevalence of back pain in this sample was relatively low at both time points. For context, a large-scale survey by the German health insurance provider DAK reported that 25% of 5$^{th}$ to 10$^{th}$-grade students experienced back pain at least once per week, within a shorter reference period than the one-month prevalence assessed in the present study (Hansen et al., 2023). Similarly, a 2018 study found that 43% of German children and adolescents aged 0 to 17 reported experiencing back pain at least once per month (Greiner et al., 2018).

### *5.4.1 Effects of the Intervention*

The first hypothesis must be rejected concerning improvements in posture and back pain prevalence. The distribution and change in postural abnormalities did not differ between groups or across test times. Similarly, the reduction in pain prevalence was not significantly different between groups. It is important to note that the posture assessment focused solely on rating detectable abnormalities without a usual medical examination, keeping the outer garments on and was not conducted using objective measurement tools. Subtle improvements over the three-month intervention period may have gone unnoticed. Salsali et al. (2023) also suggest that postural deviations caused by muscular factors may be more responsive to changes through exercise-based interventions than those related to structural or skeletal conditions. Moreover, posture and its control in children are subject to diurnal and activity-related variation (Bourelle et al., 2014) and can also be influenced by emotional states that fluctuate independently of the intervention (Penha et al., 2005). Findings related to back pain should be interpreted with caution, as only a small number of participants reported symptoms at either time point. This limited prevalence particularly affected the exploratory subgroup analysis within the intervention group: due to the small number of cases, it was not possible to identify characteristics that might facilitate improvements in back pain as a result of the program. The absence of group differences in postural endurance improvements aligns with prior research in fifth-grade students (Dullien et al., 2018). A learning effect may explain the main effect of time. Additionally, increased motivation during the second testing session, regardless of group, may have improved performance. A ceiling effect could also affect results, as 31.2% of participants reached the 120-second maximum in the pre-test and 48.2% in the post-test.

The second hypothesis must also be rejected regarding changes in trunk endurance and functional mobility. One possible limitation was the difficulty children experienced in following exercise instructions via video. G. Gupta and Sehgal (2012) reported a generally high error rate when comparing video- to handout-based exercise instructions in children aged 10–12, citing ongoing cognitive development and lack of visual feedback. Those challenges are likely even greater in our slightly younger sample. Similar difficulties were observed during the physical performance tests despite prior demonstrations. Furthermore, primary school children generally engage in less intense physical activity than their older peers (Song et al., 2021), which may have limited the intervention's effectiveness due to low training intensity. This effect could be amplified in home settings, as peers have been shown to increase physical activity in young children (Barkley et al., 2014). In addition, intrinsic motivation plays a key role in physical performance. It has been linked to higher test outcomes in children, whereas extrinsic motivators like verbal instruction or rewards at the testing show no such relationship (Lohbeck et al., 2021). Intrinsic motivation may vary across test times, which may have influenced the observed results. The significant main effect of time in the FMS may reflect either increased posttest motivation or a learning effect. A notable sex difference emerged in trunk extensor endurance: average performance increased among girls but remained stable among boys. This is in line with a sex difference observed by Dejanovic et al. (2012), where girls outperformed boys across all ages from 7 to 14. Future research should further examine the mechanisms behind these sex-specific patterns.

When examining potential differences between participants who showed improvements in the motor tests and those who did not, it became evident that individuals who improved in motor tests demonstrated significantly lower baseline scores. This suggests that especially children with weaker motor skills profit from the provided exercise videos. Supporting this interpretation, a large effect size was observed for improvements in FMS scores when comparing the youngest participants to the oldest subgroup. The fact that this difference did not reach statistical significance may be due to the small sample size in these age-based subgroups.

Furthermore, no significant differences were observed between the subgroups with and without improvement in the physical tests regarding age, sex, participation in organized sports, growth status (sex-specific or general), or socioeconomic background. However, due to the subdivision of the intervention group and the uneven distribution of improvements, all subgroup sizes were relatively small, limiting the generalizability of these exploratory findings.

The third hypothesis, regarding improvements in psychological well-being, has to be partially supported and partially rejected based on the mixed pattern of results. The missing effects are consistent with a meta-analysis that found no conclusive effects of physical activity interventions on mental health and well-being in children when adolescent samples were excluded (Rodriguez-Ayllon et al., 2019). It raises questions about the extent to which the body–mind connection, as suggested by embodiment theory (Michalak et al., 2012), is applicable in younger age groups. However, the improvement in positive self-compassion may be attributable to the structure of the exercise videos in the IG. Each video featured an adult, a child, and a mascot, fostering a warm and supportive atmosphere, especially during greetings and cooldowns. As self-compassion is closely associated with empathy and social connectedness (Lathren et al., 2021), this setting may have contributed to the observed group differences. In contrast, the CG watched brief, animated videos without human role models. Another possible explanation for this effect could be the simultaneous decrease in positive self-compassion in the control group, which, together with the increase observed in the intervention group, contributes to the observed interaction effect.

The fourth hypothesis, concerning improvements in back-related knowledge, can be accepted. These findings suggest that the results of Dullien et al. (2018) can be extended to a younger population and to remotely delivered educational content outside traditional classroom settings. Given the growing use of the internet for health-related purposes among children and adolescents, with information-seeking being one of the most common activities (Park & Kwon, 2018), short digital videos appear to be an effective and accessible method for knowledge transfer in this age group. Interestingly, however, the gain in knowledge did not lead to behavioral changes in sitting habits, as no greater reduction in daily sitting time was observed in the intervention group compared to the control group.

The lack of a significant influence of SES is somewhat unexpected, as better +socioeconomic background in this age group has previously been associated with greater access to physical activity opportunities and fewer opportunities for sedentary use (Tandon et al., 2012), both of which could have influenced outcomes in this study. However, caution is warranted when interpreting this result, as the overall educational level in the sample was high. Due to a median split, even children with one parent holding a master’s degree were sometimes classified into the lower SES group.

A broader challenge was the uneven adherence to the program, as reflected in the considerable variation in activity logs and habit trackers entries. Despite the web-based format and engaging content, the innovative approach aimed at fostering participation, as suggested by Hill and Keating (2016), did not achieve the desired level of engagement. This was evident in participants’ progression: while some completed the program in the intended 12 weeks, others required the full 15 weeks or dropped out due to delays. In total, 36 participants (20.34%) discontinued the program, twice the estimated 10% dropout rate. Most attrition was due to low engagement or difficulties consistently completing the intervention. This pattern was also reflected in the parental feedback, with both groups reporting moderate ratings for items related to motivation and ease of integration into daily life, whereas questions concerning interest, enjoyment, and the perceived fit of the videos tended to receive higher ratings.

Moreover, the intensity and quality with which the children performed the training videos and their attention during the educational videos could not be monitored due to the remote setting. These factors must be considered when interpreting the findings.

Another possible explanation lies in the sample's relatively young and developmentally broad age range. Children in this age exhibit high individual variability and undergo substantial changes in physical development, including sex-specific trajectories (Jenni, 2020), cognitive abilities (Weinert & Helmke, 1998), everyday behavior (Perone et al., 2020), and motivation (Hornstra et al., 2013). Consequently, their needs and requirements for engaging with such a program vary widely. Challenges commonly reported in digital learning for younger children, such as the need for adult supervision due to limited self-regulation, short attention spans, or low intrinsic motivation (Reich, 2020), may also have reduced engagement quality in this web-based intervention. These factors may further explain the inconsistent use of the movement diary and habit tracker, as some children likely had more parental support or greater self-efficacy. In contrast, others skipped the tasks for various individual reasons.

As previously mentioned, the observed time effects may reflect group-independent increases in motivation during the second testing session. These effects may also be attributable to the project's design: since group assignment occurred after the initial testing, participants had already expressed interest in a back-care program. Even those assigned to the CG may have become more aware of the topic, sought information independently, or made changes to movement and sitting habits outside the intervention.

### *5.4.2 Practical Implications*

Several practical implications can be drawn from these findings. Future back-prevention programs may benefit from integrating educational videos, as these proved effective in improving back-related knowledge. Since no significant improvements were observed in physical or psychological outcomes, further research is needed to identify effective strategies for this age group. Active video games have demonstrated a range of health benefits (Gao et al., 2015; Gkintoni et al., 2024), suggesting that enhanced gamification could improve both adherence and outcomes. Additionally, stronger involvement of parents or community networks, shown to be effective in mental health promotion (Weare & Nind, 2011) and obesity prevention (Andrews et al., 2010), could enhance program impact.

#### *5.4.3 Strengths and Limitations*

Strengths of the study include its controlled design, multidimensional outcome assessment, and the comprehensive BackFit website, which enabled independent implementation. Among the limitations is the relatively short program duration of three months, which may have been insufficient, particularly when interrupted by illness or holidays. Another limitation is the lack of objectivity in posture assessment, which could be improved by incorporating more advanced tools such as a posture scanning system used in Study 1. The young target group also presents challenges: motivation may fluctuate between test sessions, potentially affecting scores independently of the intervention. Moreover, the wide age range and sex-specific developmental differences within the sample add further complexity to interpreting the results. Furthermore, apart from brief end-of-video prompts, there was no way to verify whether the videos were attentively followed or whether the exercises were performed correctly, factors that can substantially influence training outcomes. Lastly, the sample, characterized by high average SES and low back pain prevalence, cannot be considered representative of the general population.

Taken together, these findings underscore the need for further refinement of digital back-care programs for young children. Promising directions include stronger gamification, increased parental involvement, extended program duration, and tools to monitor participation and the consistency of program implementation more accurately.

## 5.5 Conclusion

This study demonstrates that a web-based back-care program can effectively enhance back-related knowledge among primary school children and improve positive self-compassion. However, no significant group differences were observed in physical or other psychological outcomes, and the use of the movement diary and habit tracker varied substantially between participants. These findings underscore the challenges of promoting health-related behaviors through digital interventions in young children, whose developmental stages and engagement levels can vary widely. Future programs may benefit from more interactive and motivating formats, greater involvement of caregivers, and improved tools to monitor participation and implementation compliance. Additionally, the inclusion of more representative samples would improve the generalizability of findings. The large physical differences within the wide age range from 6 to 11 years needs to be considered for further investigation focussing on a smaller age range. Clinical examination must be considered according to medical requirements. A bigger number of participants is necessary to assess the performed physical testings.

## 5.6 Deviations from Preregistration

Several minor deviations from the preregistered protocol occurred during the study. The manuscript title was revised to more accurately reflect the study design and focus. The structure of the hypotheses was adjusted to group related outcomes and improve clarity, which also led to the application of different significance thresholds due to corrections for multiple comparisons. One hypothesis, originally formulated to examine a general time effect in the postural endurance test, was reclassified as part of the exploratory analyses, as the confirmatory analyses focused on outcomes for which greater improvements were expected in the intervention group. Due to inconsistent use of the daily movement diary and habit tracker, only the average number of days with completed entries was reported. No further analyses were conducted regarding the specific types of physical activity or the frequency and potential impact of reported habits. Exploratory subgroup analyses were also conducted to investigate potential differences in program responsiveness among various subgroups of the sample. As described in the statistical analysis section, one-way ANOVAs were used for the trunk endurance variables, as the assumptions required for two-way ANOVAs were not met. Furthermore, the calculated sample size could not be achieved due to external constraints, as detailed in the Methods section.

# 6 General Discussion

## 6.1 Summary

The goal of this thesis was to examine the construct of body posture in primary school children, focusing on comparisons between assessment methods, its associations with physical and psychological health dimensions, and the effects of a web-based back pain and posture prevention program. To address these objectives, three complementary studies were conducted: a methodological comparison, a cross-sectional analysis, and an intervention evaluation.

The first study compared a clinical orthopedic assessment with a rasterstereographic scan in a sample of third-grade children. While both methods indicated a high prevalence of postural deviations, rasterstereography identified a substantially greater number of abnormalities, particularly regarding spinal curvature. These findings highlight the sensitivity of technical diagnostic tools, while also reflecting discrepancies in detection thresholds and interpretive frameworks between methods.

The second study examined the cross-sectional associations between muscular fitness, posture, and psychological constructs, namely physical self-concept, self-compassion, and psychological well-being. The latter was operationalized via self-concept. Muscular fitness was positively associated with postural endurance. In contrast, no significant associations emerged between postural measures and the psychological variables. Notably, the psychological constructs themselves were significantly intercorrelated, indicating internal coherence within the psychological domain, but limited alignment with physical parameters in this age group.

The third study assessed the effects of a 12-week digital back-care intervention targeting both physical and psychological outcomes. The program led to improvements in back-related knowledge and, to a lesser extent, in positive self-compassion. However, no significant changes were observed in posture, motor performance, or broader psychological measures. Variability in engagement was considerable across participants.

Overall, the three studies yield a differentiated picture of postural health in childhood. They demonstrate a consistently high prevalence of postural deviations, a robust link between muscular fitness and posture, and a relative independence of psychological and physical constructs at this developmental stage.

## 6.2 Theoretical Integration and Conceptual Implications

The following subchapters examine how the findings of the present studies can be interpreted in light of theoretical models, developmental processes, and conceptual considerations related to posture and psychological functioning in childhood.

### *6.2.1 Interpretation of (In)Consistent Patterns Across Studies*

The results from Studies 2 and 3 suggest that the expected psychophysical associations may not yet be fully established within this age group and might only emerge later in childhood or adolescence. However, in Study 3, neither of the physical outcomes, posture or muscular fitness, showed any improvement. This parallel absence of change supports, or at least does not contradict, the connection observed between muscular fitness and posture in Study 2. It points to a possible developmental relationship between these physical domains, while associations with psychological factors may still be in the process of forming. However, it is important to note that Studies 2 and 3 were conducted with the same sample and within the same overall project framework, meaning that the observed associations must be interpreted within this shared context.

Both Study 1 and Study 3 found a high number of postural deviations, even though they examined different samples using different methods. These findings are consistent with previous research (Batistão et al., 2016; Kratenová et al., 2007; Wilczyński et al., 2020; Yang et al., 2020). At the same time, Study 3 showed a relatively low prevalence of back pain. The combination of frequent postural deviations and low reported pain supports the idea that there may not be a direct link between posture and back pain in children, at least not when posture is assessed in a global way as in the present studies (Kamper et al., 2016; Kripa & Kaur, 2021; Martinez-Merinero et al., 2020).

### *6.2.2 Psychophysical Connections in Child Development*

The findings from Studies 2 and 3 can be interpreted in light of theoretical models that describe the interaction between physical and psychological connections and development in childhood. One such framework is the embodiment theory, which assumes that bodily postures and movements are not merely passive reflections of psychological states but actively shape self-related processes such as affect, motivation, and self-perception (Michalak et al., 2012; Niedenthal, 2007). However, the present data do not support this assumption for primary school-aged children. Study 2 found no significant associations between postural endurance and the psychological constructs physical self-concept, psychological well-being or self-compassion. In addition, muscular fitness, although clearly related to posture, was also unrelated to psychological outcomes. This suggests an overall lack of observable psychophysical integration at this stage of development.

In Study 3, the digital intervention led to a selective improvement in positive self-compassion. However, this effect was not accompanied by measurable changes in either postural parameters or motor performance. Other psychological variables did not show significant pre-post differences. These findings indicate that while isolated psychological improvements can occur, they do not necessarily coincide with changes in physical functioning, at least not in the short term or within a broadly healthy child population.

The lack of consistent psychophysical associations may indicate that the connections proposed by embodiment theory are not yet fully established or measurable in primary school-aged children. It is likely that limited cognitive maturity, developing bodily self-awareness, and less differentiated self-concepts restrict the extent to which posture can influence psychological functioning during this phase of development (Ahn, 2022; DelGiudice, 2018; Gerlach, 2008). Another possible explanation for the lack of psychophysical connections could be the limited validity of the instruments used to assess the psychological constructs at this age. For instance, a systematic review by Hubbard et al. (2025) rated the quality of the SCS-C used for self-compassionas low, scoring only 4 out of 14 possible points. According to the authors, the scale lacked input from experts and children, did not capture the element of compassion, and several key measurement properties, such as test–retest reliability and interpretability, were not assessed. In addition, as noted by Dreiskämper et al. (2022), selecting appropriate instruments to assess aspects of self-concept in this age group remains a significant challenge.

The dynamic model of motor development proposed by Stodden et al. (2008) and expanded by Lima et al. (2022) provides an additional explanatory perspective. These models describe a reciprocal and age-dependent relationship between actual motor competence, perceived competence, and physical activity. The consistent association between muscular fitness and postural endurance observed in both Studies 2 and 3 fits within this framework and suggests that postural capacity in childhood may be more strongly influenced by physical factors than by psychological ones. In contrast, the lack of associations between fitness or posture and psychological variables supports the idea put forward by Neuenschwander and Gunten (2025). They suggest that the cognitive processes underlying self-related constructs such as self-compassion are still developing in childhood and are therefore not yet closely aligned with objectively measurable physical attributes. The use of self-reported measures to assess these constructs in children is discussed in more detail in Section 6.4

### *6.2.3 Conceptual Challenges of Posture-Related Constructs*

Beyond developmental and methodological considerations, the construct of posture itself presents definitional and conceptual challenges. Across disciplines, posture is described either as a static alignment of body segments (Winter, 1995), a dynamic process of balance and adjustment (Wilczyński et al., 2020), or sometimes even a visible expression of psychological states (Dael et al., 2012; Lopez et al., 2017). Different definitions and ways of operationalizing posture lead to varying assessment procedures. This is evident, for example, in the meta-analysis by Salsali et al. (2023) on the relationship between physical activity and posture, as well as in Dugan’s (2018) review of posture interventions in primary schools. Such inconsistencies make it difficult to clearly operationalize posture in empirical research. In the present studies, posture was assessed both through a visual clinical judgment and an endurance-based task, each capturing different aspects of postural function.

## 6.3 Relevance for Educational and Health Contexts

Although the methods differed, both approaches in Studies 1 and 3 indicated that a substantial proportion of primary school children exhibit deviations from normative postural alignment. This finding highlights the need for more systematic posture screening and increased awareness within schools, as also emphasized by Magee et al. (2012) in a study conducted in the United States. From a health perspective, it is important to identify more severe postural issues at an early stage. This allows for diagnostic clarification when needed and may help prevent long-term damage or chronic pain caused by persistent postural strain (Sharma & Rawat, 2023), even though the direct and acute relationship between postural deviations and back pain remains a subject of debate. Moreover, the school setting offers a promising opportunity to ensure broad participation and reach all children with health promotion, as they spend a significant amount of time in this environment (Guirado et al., 2021; Kriemler et al., 2011). Such an approach could also help include both children and their parents, regardless of ethnicity, language barriers, SES, or other sociocultural factors. This stands in contrast to the present studies, which primarily involved families with higher socioeconomic status and higher parental education.

The school environment may play an important role in posture and back pain prevention for two additional reasons. First, several reviews have highlighted the potential effectiveness of primary school-based interventions in other health-related areas such as physical activity, obesity prevention, and mental health (Brown et al., 2016; Errisuriz et al., 2018; Fenwick-Smith et al., 2018). Second, many potentially non-back-friendly behaviors occur directly within the school setting, including prolonged sitting, the use of ergonomically unsuitable furniture, and the carrying of heavy school bags (Guirado et al., 2021; Syazwan et al., 2011). This makes the school context a relevant and practical setting for raising awareness and promoting healthy behaviors. However, school-based interventions also face barriers to implementation and long-term integration. These include the prioritization of academic outcomes under time and resource constraints, insufficient funding and materials, staff turnover, and a lack of ongoing professional training (Herlitz et al., 2020). Moreover, the experience of back pain in children is closely tied to individual developmental milestones, which highlights that children should not simply be viewed as small adults in this context (Pate et al., 2022). As a result, broad preventive interventions may risk being insufficiently individualized. This underlines the importance of interdisciplinary approaches that involve parents, teachers, and other key stakeholders who can provide comprehensive insights into relevant environmental factors.

The benefits of digital health promotion were only partially evident in the present project. As noted by Ferretti et al. (2023), the program was easy to access, and large-scale use of the platform would offer a cost-effective solution. However, the increased adherence often associated with gamification, as described by Suleiman-Martos et al.

(2021), was not confirmed in this case, given the high dropout rates. While the training videos may have lacked effectiveness due to the absence of direct instruction, the knowledge component in Study 3 was successful. This indicates the potential of using digital formats to complement in-person sessions, which could help reduce the personnel demands of school- or club-based programs. According to Ferretti et al. (2023), digital health strategies should continue to be pursued, both to engage young people in ways that reflect their everyday environment and to strengthen their digital and health-related competencies. This may help them become more informed and independent users of technology. However, when designing digital interventions for younger children, it is important to consider the role of parents in enabling access. In our young sample, media usage was often reported to occur via a parental device, suggesting that parents had to actively facilitate their child's access to the digital content.

## 6.4 Methodological Reflections

Several methodological challenges emerged during the implementation of the studies, which are briefly discussed below. The broad age range of the sample in Studies 2 and 3 was intentionally chosen to investigate associations between various health parameters and posture, as well as to evaluate the effectiveness of the prevention program across the entire span of middle childhood, typically defined as ranging from 6 to 11 years (DelGiudice, 2018). This approach also enabled access to a larger target population, aiming to mitigate anticipated challenges in participant recruitment. Nevertheless, recruitment difficulties were still present within the selected sample, and the intended sample size for the intervention program could not be fully achieved.

One challenge resulting from the broad age range of the sample was the considerable developmental variation among children, as discussed in Study 3. Differences in physical, cognitive, and motivational development made it difficult to design an intervention program that was appropriately engaging, supportive, and suitably complex for all participants. This challenge was further compounded by the need to differentiate both exercise and educational content even within the same age group to adequately meet individual needs (AM et al., 2023; León-Reyes et al., 2025). The results of the parental feedback following the intervention suggest high levels of interest and enjoyment regarding the video content, as well as an appropriate fit in terms of complexity and duration. However, it is important to note that only a relatively small subset of parents who completed the full program provided feedback, and overall dropout rates during the intervention were high. It is therefore possible that some parents did not respond, or that children may have discontinued the program, because the intervention content was perceived as unengaging or mismatched to their needs.

These observations underline the relevance of motivational factors in intervention contexts. According to Sansone's model of self-regulation of motivation (Sansone & Thoman, 2005; Schwinger & Stiensmeier-Pelster, 2012), task interest can enhance performance and persistence. Previous research has shown that motivation predicts participation and effort in physical education, as reflected in the volume and intensity of physical activity among third- and fourth-grade students. In this context, intrinsic motivation emerged as a key predictor for both boys and girls (Pavlović et al., 2023). This predictive role of motivation in physical education settings may also be transferable to the effort children invested in the test situations of the present studies. Furthermore, another study linked intrinsic motivation to better outcomes in physical performance tests  (Lohbeck et al., 2021). Since intrinsic motivation in children is not stable but can vary from day to day, depending on contextual factors such as perceived autonomy, competence, and social support (Deci & Ryan, 2000), it may have influenced task performance in all tests conducted in Studies 2 and 3. The level of intrisic motivation may also have differed between pre- and posttests in the intervention. Fluctuations or limitations in attention during testing may also have influenced the results. Due to the comprehensive nature of the assessment, the testing sessions lasted between 60 and 90 minutes, which is relatively long for a young target group. Children's attention spans are still limited and subject to various external factors, such as physical activity habits and time of day (Batejat et al., 1999; Greenberg & Harris, 2012; Ober et al., 2024). These factors can vary both between different children and between the two testing time points, potentially affecting concentration and thereby influencing test performance.

In addition to motivational and attentional factors, sample characteristics may also have influenced the findings. Due to the voluntary nature of participation in the program, Studies 2 and 3 included a parent sample with a relatively high level of education. Higher parental education has been associated with better childhood health outcomes (Huebener, 2020), and enhanced cognitive development (Noble et al., 2015). This may have influenced the observed associations between the various health dimensions as well as the effects of the educational component of the program.

Another methodological consideration relates to the use of self- and parent-reported data. There is ongoing debate and limited clarity regarding the age at which children are able to fully comprehend and reliably self-report health-related concepts and experiences. General cognitive competencies, self-awareness, and children's understanding of health and illness can all influence the accuracy of their responses (Bevans et al., 2010). Nevertheless, several studies have found self-reports of various health-related outcomes to be sufficiently valid from as early as six or seven years of age (Olson et al., 2007; Riley, 2004; Varni et al., 2007). The psychological constructs measured in Studies 2 and 3 were assessed using age-adapted self-report questionnaires that are used in comparable samples, but are likely to have reached their limits of conceptual sensitivity and discriminative power at the lower end of the age range. The inclusion of parent reports offers a valuable means of complementing children's self-reports (Bevans et al., 2010), as was done in the present study for information such as health history, back pain prevalence, and sedentary behavior.

In Studies 2 and 3, the time limit for the Matthiass test was set according to the standard test description (Tittlbach & Bös, 2002). However, the large number of children reaching the maximum performance suggests a potential ceiling effect. Future studies may consider using an extended or open-ended time frame to allow for greater variability and more sensitive differentiation among participants.

Furthermore, the intervention duration of 12 weeks for Study 3 was chosen based on previous interventions targeting trunk strength or low back pain in children and adolescents, which have demonstrated effectiveness with durations as short as six weeks (Allen et al., 2014; Michaleff et al., 2014). However, due to interruptions in participation and potentially reduced exercise intensity, this program length may still have been too short to produce measurable physical changes.

## 6.5 Limitations

Beyond the specific limitations of each study, several overarching limitations should also be acknowledged. One limitation lies in the use of both parent-reported and self-reported measures, specifically the SCS-C, BSCI-Y and the PSK-K questionnaires, which are susceptible to various forms of bias. These include systematic agreement or disagreement tendencies, preference for extreme or neutral responses, and the influence of social desirability. Moreover, aspects such as item phrasing, question order, and individual differences in cognitive ability or motivation may affect the reliability and validity of the data, potentially distorting associations with other variables (Podsakoff et al., 2012).

Furthermore, differing conceptual definitions and operationalizations of self-concept and self-compassion across studies may have introduced inconsistencies that limit theoretical comparability and interpretability.

Additionally, it was not always possible to conduct the testing procedure with children in a fully standardized manner. Factors such as attention, motivation, and physical condition led to variations in the testing process. While instructions and the sequence of tasks were kept consistent, the total duration of testing varied. A further limitation relates to the Matthiass test used for assessing postural endurance, which showed signs of a ceiling effect, with many children reaching the maximum score. This restricted variance may have limited the ability to detect meaningful associations with other variables, particularly in relation to physical and psychological outcomes. Moreover, the previously mentioned lack of representativeness of the sample limits the generalizability of the findings. In particular, the restriction to a single local primary school in Study 1 and the high level of parental education in Studies 2 and 3 must be acknowledged.

The main limitation in the posture assessment lies in the visual evaluation conducted while children were wearing outer garments, performed by different examiners in Studies 2 and 3. This approach resulted from ethical, logistical, and personnel-related constraints. To allow for a more holistic assessment of body posture, a postural endurance test was included. Nevertheless, the chosen assessment method remains a central limitation of this thesis, as it may yield more favorable ratings compared to objective measurement approaches and is subject to a greater number of influencing factors, as discussed in Study 1.

## 6.6 Outlook

Some relevant questions emerged during the course of this thesis that could not be fully explored. Therefore, there are still many opportunities for future research.

As the assment of body posture still is a complex problem and the used methods in scientific studies are diverse, further studies assessing a standarized method for posture evaluation are needed (Du et al., 2023; Woldendorp et al., 2022). Such standardization is also essential to improve the comparability of studies examining postural characteristics across different populations and settings.

As the psychophysical connection observed in adults could not be confirmed in children in Studies 2 and 3, longitudinal studies are needed to better understand how this interaction develops over time. Other researchers in this field have also emphasized the importance of long-term research, such as in the Move for Health study by

Dreiskämper et al. (2025), which focuses on the relationship between physical activity and mental health. To capture the developmental stages and emerging connections under the rapidly changing conditions of middle childhood (DelGiudice, 2018), such longitudinal research should include fine-grained observations across multiple time points.

Given the limited body of research on low back pain prevention in children, and considering that most available evidence comes from studies conducted with adults in high-income countries (Foster et al., 2018), prevention efforts targeting back pain in childhood clearly remain an important and underexplored area. They should therefore continue to be investigated. As mentioned in Section 6.3, hybrid models that combine in-person training with digital components, such as the delivery of educational content, could be considered. This approach may help reduce the time and resource burden in school settings. Hybrid programs have already shown promising effects in slightly older children and adolescents, for example in reducing chronic pain (Palermo et al., 2020) and in the prevention of alcohol and tobacco use (Williams et al., 2025). Similar combinations of digital and face-to-face formats have also been found effective for promoting mental health in adolescents, although outside school contexts (Lyzwinski et al., 2024). Given the importance of supervision during physical activity interventions, which was especially relevant in our young sample, hybrid approaches that ensure guided physical exercise while integrating digital elements for knowledge delivery may represent a promising option for back pain and posture prevention in childhood.

Further enhancing the gamification of intervention content could be a valuable strategy for engaging younger children. This approach has already proven effective in improving both physical and mental health outcomes in children and adults (Gkintoni et al., 2024; Xie, 2022). However, to increase its effectiveness, careful attention must be given to the design of the gaming environment. Creating experiences that are engaging, safe, and meaningful, while also ensuring that screen time remains within healthy limits, requires multidisciplinary teams involving experts from the fields of health, education, game development, and psychology (Gkintoni et al., 2024). The integration of exercise into video games, often referred to as active video games (W. Liu et al., 2020), has already been associated with reductions in BMI and body weight (Oliveira et al., 2020), as well as improvements in physical fitness among children and adolescents (W. Liu et al., 2020). These positive effects suggest that gamified approaches and active video games could also be a useful tool for promoting healthy posture in younger children. This potential should be further explored in future studies.

Larger longitudinal studies are also needed to evaluate prevention approaches. An example is the TransformUs project in Australia, which includes two tailored versions for primary and secondary schools. Both versions involve follow-up assessments at 12 and 24 months to examine long-term behavioral changes in physical activity and are currently still ongoing (Contardo Ayala et al., 2025; Koorts et al., 2023).

To advance research on posture, back pain, and psychophysical development in childhood, future studies should consider longer intervention durations and larger sample sizes. This would help to compensate for dropout and improve the reliability of findings. In our own studies, participants predominantly came from families with a high level of parental education. Broader recruitment is therefore needed to better represent children from different socioeconomic backgrounds, as it is tightly connected to childhood health and development (Poulain et al., 2020). In addition, narrower age ranges would allow for more age-appropriate interventions and assessments. More precise age grouping could help to better match program content and measurement tools to children's cognitive and emotional capacities.

## 6.7 Implications and Conclusions

The results of this dissertation offer several scientific and practical implications, which will be summarized in this section. The high prevalence of postural deviations observed in Studies 1 and 3 is consistent with previous research (Batistão et al., 2016; Wilczyński et al., 2020; Yang et al., 2020). However, the relationship between posture and back pain remains inconclusive in accordance to Kamper et al. (2016). Longitudinal studies are needed to investigate the development of posture and its health relevance, especially in light of the increasing prevalence of back pain during adolescence. In the context of posture research, there is a need for accessible and standardized assessment methods to allow for broad comparability of findings as proposed by Woldendorp et al. (2022). Such longitudinal approaches are also essential for examining how psychophysical associations, as investigated in Study 2, evolve throughout physical and cognitive development in childhood. Developmentally sensitive research would benefit from smaller age intervals in order to better adapt the measurement tools to the respective developmental stages.

From a practical perspective, the remote and self-directed implementation of the prevention program in Study 3 proved to be mostly ineffective and was associated with adherence issues. This suggests that guided delivery within schools or sports clubs may be more suitable, as the anticipated relief of institutional burden through fully digital back prevention programs appears not to be feasible for this age group. In addition, school-based delivery would help ensure that children from all socioeconomic backgrounds are reached and sensitized to the topic. To reduce institutional workload while still utilizing the potential of low-threshold engagement, hybrid formats could be a promising alternative. These could integrate elements such as the digital knowledge components tested as effective in Study 3. Given the complexity of posture and its development during childhood and adolescence (Pate et al., 2022), regular posture screenings could also be incorporated more systematically into school health examinations or be included in special health-related school events. This would further allow trained professionals to monitor postural development more consistently across the entire student population. More intensive and routine screening could also enable earlier identification of emerging postural issues and support timely intervention. To help make this possible, widespread training and awareness-raising efforts targeting teachers and parents could be a valuable way to reduce reliance on health professionals while still ensuring consistent observation of children’s postural development. This early observation could potentially prevent the progression of pronounced postural deviations while also allowing for earlier management of developing back pain.

Taken together, the findings of this dissertation contribute to a more differentiated understanding of posture-related health in childhood. While clear associations between muscular fitness and postural endurance were identified, no robust links to psychological constructs such as physical self-concept, self-concept or self-compassion were found. These results underscore that psychophysical integration may not yet be fully established or detectable in younger children. At the same time, the high prevalence of postural deviations highlights the relevance of posture as a developmental and public health concern. Overall, this work advances theoretical, empirical, and practical knowledge in the field and illustrates the importance of developmentally appropriate, interdisciplinary approaches to both research and intervention.

# 7 Declarations

## 7.1 Ethical Standards

All experiments were conducted in accordance with the Declaration of Helsinki and received approval from the Ethics Committee of the University of Regensburg. All relevant considerations necessary to assess the ethical legitimacy of the studies were communicated.

## 7.2 Informed Consent to Participate and to Publish

Informed consent for participation and the publication of anonymized results was obtained from all individuals involved in the studies.

## 7.3 Acknowledgements

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## 7.4 Open Research Practices

The second and third studies were preregistered on OSF.io, with the third study additionally registered in the German Clinical Trials Register. The data supporting the findings of Study 1 are available in the published article, and the data for Studies 2 and 3 will be made available upon publication.

## 7.5 Competing Interests

There were no competing interests for any of the studies.

## 7.6 Funding

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# 9 Appendix

## 9.1 Additional Data for Study 2

**Table 18**

*Demographic Characteristics of the Children*

| | *N* | *M* | *SD* | *Range* |
|---|---|---|---|---|
| Boys | 97 (55.7 %) | | | |
| Girls | 77 (44.3 %) | | | |
| Age [years] | 174 | 8.61 | 1.33 | 6 – 11 |
| Heigth [m] | 174 | 1.37 | 0.11 | 1.17 – 1.67 |
| Bodyweight [kg] | 174 | 31.8 | 8.0 | 18.2 – 63.4 |
| BMI [kg/m$^2$] | 174 | 16.7 | 2.4 | 12.6 – 26.1 |
| Healthyweight according to BMI | 139 (79.9 %) | | | |
| Underweight according to BMI | 17 (9.8 %) | | | |
| Overweight according to BMI | 18 (10.3 %) | | | |

**Note.** The categorization was based on BMI percentiles according to Kromeyer-Hauschild et al. (2001).

**Table 19**

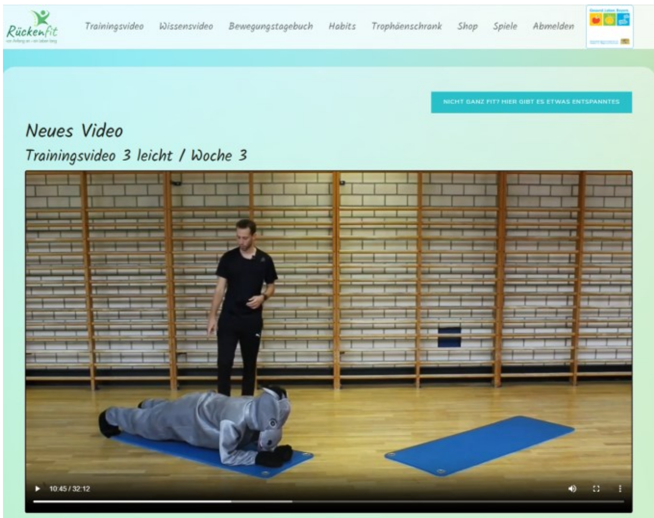
*Correlation Between Posture, Muscular Fitness and Physical Self-Concept Subscales*

| Observed connection | | *r* | 95% CI | *p*-value |
|---|---|---|---|---|
| Posture | $PSK\text{-}K_{General\ Athleticism}$ | -.07 | [-.130, .049] | .377 |
| | $PSK\text{-}K_{Attractiveness}$ | .07 | [-.042, .136] | .297 |
| | $PSK\text{-}K_{Endurance}$ | .04 | [-.062, .114] | .565 |
| | $PSK\text{-}K_{Mobility}$ | -.04 | [-.119, .062] | .540 |
| | $PSK\text{-}K_{Coordination}$ | .03 | [-.060, .093] | .676 |
| | $PSK\text{-}K_{Strength}$ | -.06 | [-.122, .054] | .451 |
| | $PSK\text{-}K_{Speed}$ | -.05 | [-.136, .067] | .507 |
| Muscular Fitness | $PSK\text{-}K_{General\ Athleticism}$ | .11 | [-.013, .110] | .123 |
| | $PSK\text{-}K_{Attractiveness}$ | .01 | [-.079, .085] | .947 |
| | $PSK\text{-}K_{Endurance}$ | .11 | [-.020, .122] | .158 |
| | $PSK\text{-}K_{Mobility}$ | .04 | [-.054, 092] | .606 |
| | $PSK\text{-}K_{Coordination}$ | .03 | [-.045, 069] | .680 |
| | $PSK\text{-}K_{Strength}$ | .04 | [-.049, .083] | .609 |
| | $PSK\text{-}K_{Speed}$ | .11 | [-.017, .129] | .131 |

## 9.2 Contents of the BackFit Program

**Figure 8**

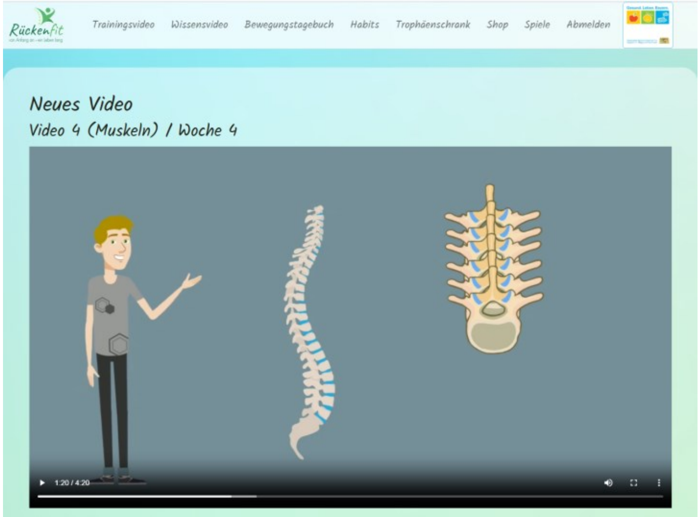
*Exercise video for the intervention group.*




**Note.** The tabs above the video display the remaining contents of the BackFit website.

**Figure 9**

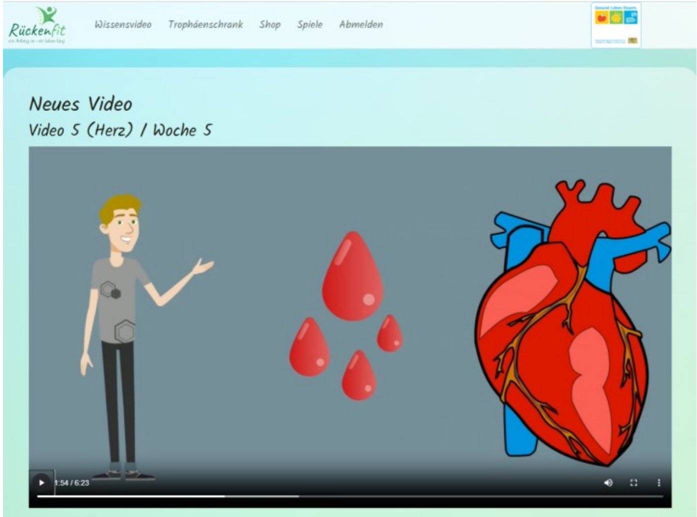
*Knowledge video for the intervention group.*




**Note.** The tabs above the video display the remaining contents of the BackFit website.

**Figure 10**

*Knowledge video for the control group.*




**Note.** The tabs above the video display the remaining contents of the BackFit website.

## 9.3 Categorization of Postural Abnormalities for Study 3

**Table 20**

*Categorization of Postural Abnormalities*

| Summarized Concept | Included Abnormalities |
|---|---|
| Visual upper body and spine abnormalities | Shoulder tilt<br>Plumb line deviation<br>Cervical lordosis<br>Thoracic lordosis<br>Lumbar lordosis |
| Visual lower extremity abnormalities | Leg axis<br>Foot position<br>Knee axis |
| Functional restrictions | Gait pattern<br>Single leg-stance<br>Toe walking<br>Heel walking<br>Spinal rotation<br>Spinal reclination |

## 9.4 Additional Visualisation for Study 3

**Figure 11**

*Time x Group interaction for trunk flexor endurance.*

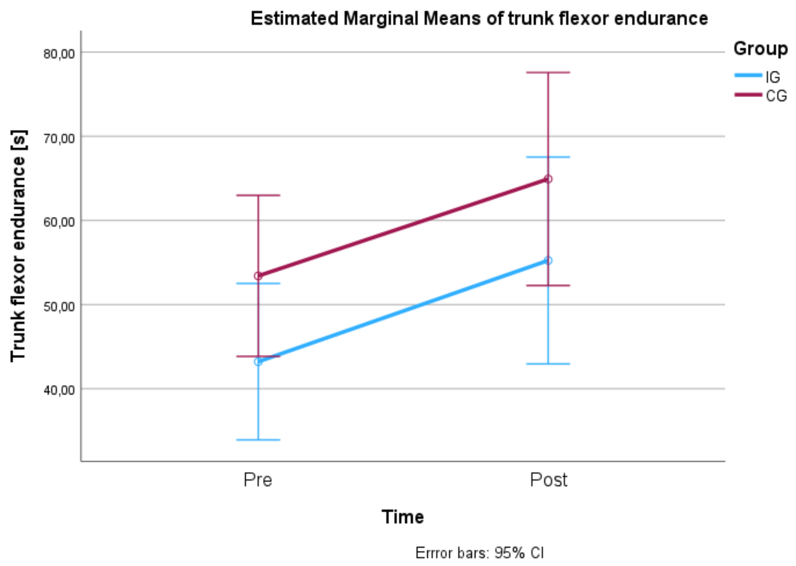


**Figure 12**

*Time x Group interaction for trunk extensor endurance.*

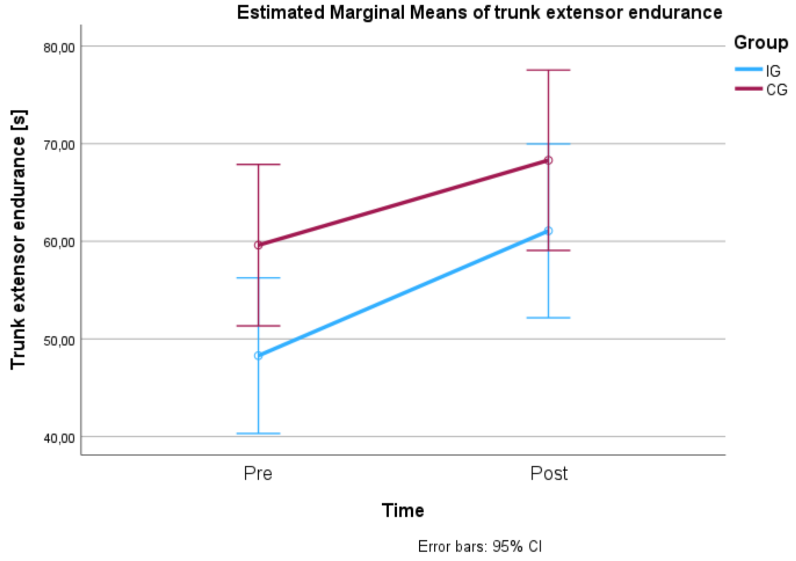



**Figure 13**

*Time x Group interaction for self-compassion.*

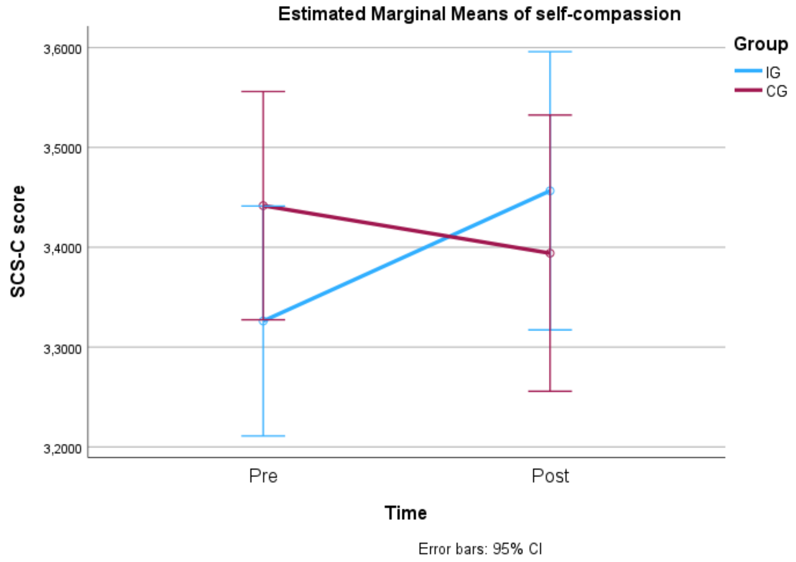


**Figure 14**

*Time x Group interaction for self-concept.*

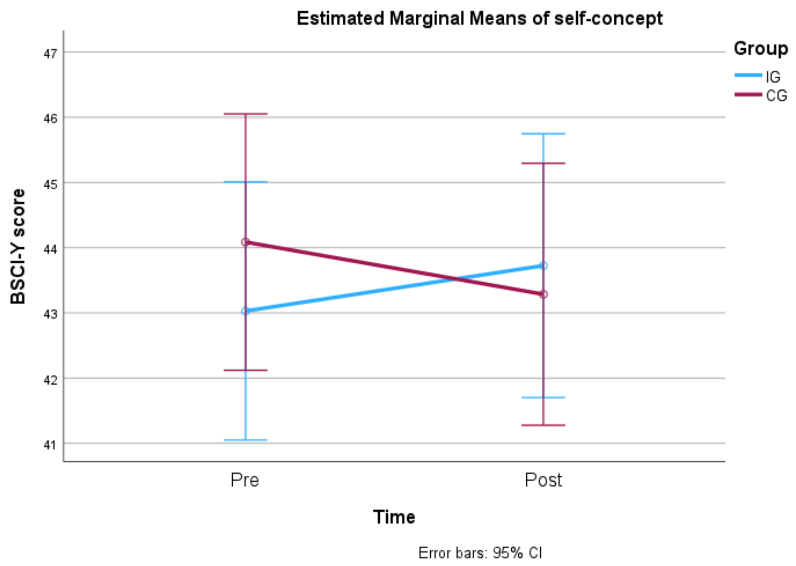
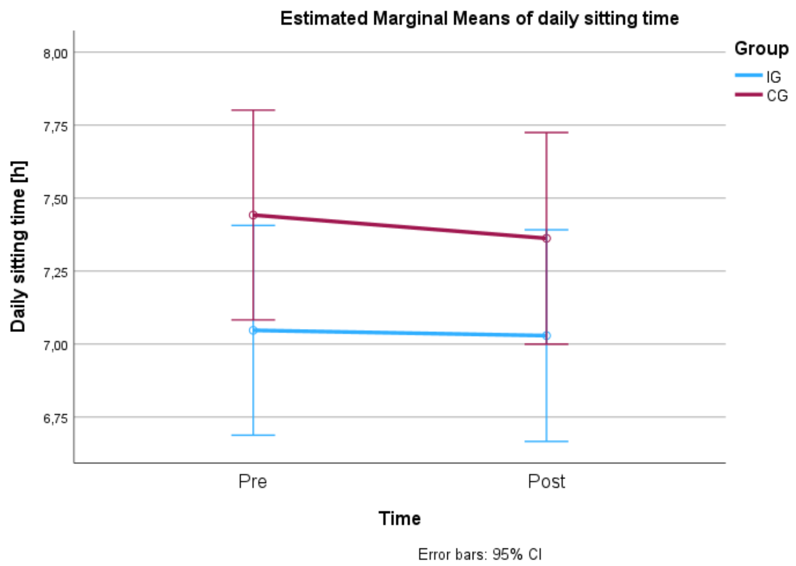



**Figure 15**

*Time x Group interaction for daily sitting time.*



## 9.5 Complete Exploratory Results from Study 3

**Table 21**

*Influence of Sex and SES on FMS Scores*

| | Test Statistics | *p-value* | *Partial $\eta^2$* |
|---|---|---|---|
| Sex | $F(1, 67) = 1.907$ | .172 | .349 |
| SES | $F(1, 67) = 0.667$ | .417 | .010 |
| Sex x SES | $F(1, 67) = 0.352$ | .555 | .005 |

**Table 22**

*Influence of Sex and SES on Trunk Flexor Endurance*

| | Test Statistics | *p-value* | *Partial $\eta^2$* |
|---|---|---|---|
| Sex | $F(1, 66) = 0.828$ | .366 | .012 |
| SES | $F(1, 66) = 1.902$ | .172 | .028 |
| Sex x SES | $F(1, 66) = 0.14$ | .905 | .000 |

**Table 23**

*Influence of Sex and SES on Trunk Extensor Endurance*

| | Test Statistics | *p-value* | *Partial $\eta^2$* |
|---|---|---|---|
| Sex | $F(1, 67) = 13.738$ | < .001 | .170 |
| SES | $F(1, 67) = 0.019$ | .890 | .000 |
| Sex x SES | $F(1, 67) = 0.608$ | .438 | .009 |

**Table 24**

*Influence of Sex and SES on Knowledge Test Scores*

| | Test Statistics | *p-value* | *Partial $\eta^2$* |
|---|---|---|---|
| Sex | $F(1, 67) = 0.145$ | .705 | .002 |
| SES | $F(1, 67) = 2.250$ | .138 | .032 |
| Sex x SES | $F(1, 67) = 0.089$ | .767 | .001 |

**Table 25**

*Influence of Sex and SES on Self-Compassion*

| | Test Statistics | *p-value* | *Partial* $\eta^2$ |
|---|---|---|---|
| Sex | $F(1, 67) = 0.050$ | .823 | .001 |
| SES | $F(1, 67) = 0.124$ | .726 | .002 |
| Sex x SES | $F(1, 67) = 0.042$ | .838 | .001 |

**Table 26**

*Influence of Sex and SES on Self-Concept*

| | Test Statistics | *p-value* | *Partial* $\eta^2$ |
|---|---|---|---|
| Sex | $F(1, 67) = 0.678$ | .413 | .010 |
| SES | $F(1, 67) = 0.025$ | .875 | .000 |
| Sex x SES | $F(1, 67) = 0.382$ | .539 | .006 |

**Table 27**

*Influence of Sex and SES on Postural Endurance*

| | Test Statistics | *p-value* | *Partial* $\eta^2$ |
|---|---|---|---|
| Sex | $F(1, 67) = 0.058$ | .811 | .001 |
| SES | $F(1, 67) = 0.157$ | .693 | .002 |
| Sex x SES | $F(1, 67) = 0.042$ | .839 | .001 |