Physical, psychological, and injury-related parameters in male youth soccer players with patellar tendinopathy: Aspects of assessment and training

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Abstract (English)

Background and objectives

Many adolescent soccer players suffer from patellar tendinopathy, which can result in periods of absence over many months, or even years, and even giving up the sport. Since conventional therapy programmes often do not lead to complete remission of symptoms, many athletes often return to competition before full recovery. This can lead not only to increased susceptibility to injury but also to reduced performance. The aim of this dissertation was therefore to investigate physical and psychological performance as well as injury- and pain-related parameters after therapy. The cross-sectional study (STUDY I) examined the difference between healthy and affected players, the meta-analysis (STUDY II) summarized the state of treatment methods and the intervention study (STUDY III) investigated the effects of a novel therapeutic intervention.

Methods

Physical, psychological, and injury-related parameters were analysed as part of a systematic review with meta-analysis, a cross-sectional study, and an intervention study. The cross-sectional study (STUDY I) examined differences between healthy (n = 17, age: 15.0 ± 1.0 years) and post-treatment soccer players with patellar tendinopathy (n = 18, age: 15.1 ± 0.8 years). Regarding the meta-analysis (STUDY II), a computerised systematic literature search was conducted in the electronic databases PubMed, Medline, and Web of Science from January 1960 to July 2020 examining 277 subjects (mean age 16–32 years). The intervention study (STUDY III) investigated the results of a conventional (n = 18, age: 15.1 ± 0.8 years) compared to a novel (n = 16, age: 15.4 ± 1.0 years) therapy program. In the cross-sectional and intervention study (STUDY I and III) muscle power (drop jump, jump-and-reach), change of direction speed (modified agility T-test), linear speed (30-m linear sprint, tapping test), endurance (Yo-Yo intermittent recovery test level 1), achievement motivation (Achievement Motive Scale-Sport), and injury-/pain-related data were assessed at four time points over 20 weeks after completion of therapy to measure long-term outcomes. The interventions carried out included a conventional eccentric strength training programme with a pain-adapted rest before starting, as well as a novel intervention programme that started immediately regardless of pain level and added additional cognitive tasks and instability strength training to the eccentric training.

Results

Regarding the cross-sectional study (STUDY I), athletes with patellar tendinopathy following treatment showed significantly worse physical performance over the entire measurement period, as well as inferior psychological performance in the first six weeks, compared to healthy players. In addition, there were significantly higher rates of injury to the lower limbs, as well as training interruptions due to injury and pain, indicating relevant long-term impairments. The meta-analysis (STUDY II) revealed that only three out of eleven studies conducted follow-up measurements after the end of therapy, which highlights the research gap in long-term treatment results. The heterogeneous results indicate that physical exercise is an effective therapy for improving pain intensity and symptom severity, but not physical performance. Concerning the intervention study (STUDY III), the alternative approach achieved greater improvements in physical performance, the same enhancements in psychological measures, and better values for injury-related or pain-related correlates. The novel intervention required a shorter duration of therapy compared to the conventional programme and significantly improved change of direction speed as well as injury- and pain-related parameters.

Conclusions

The cross-sectional study (STUDY I) showed that youth players with patellar tendinopathy exhibit physical and psychological performance impairments even after completing therapy, which increases the risk of injury and compromises career development. The results of the meta-analysis (STUDY II) highlighted that various methods of exercise therapy are effective, but little is known about the long-term effects on sport-specific performance. The intervention study (STUDY III) demonstrated that complex pathogenesis requires a multimodal therapeutic intervention characterised by increased complexity and intensity. Further research should investigate the effects of patellar tendinopathy on other psychological parameters and adapt the interventions more individually to the performance-determining factors of the sport.

Keywords

patellar tendinopathy; a jumper’s knee; young athletes; physical fitness; intervention

Zusammenfassung (German)

Hintergrund und Ziele

Viele jugendliche Fußballspieler leiden unter Patella-Tendinopathie, die zu monatelangen oder sogar jahrelangen Ausfallzeiten und sogar zur Aufgabe des Sports führen kann. Da herkömmliche Therapieprogramme oft nicht zu einer vollständigen Remission der Symptome führen, kehren viele Sportler vor ihrer vollständigen Genesung in den Wettkampf zurück. Dies kann nicht nur zu einer erhöhten Verletzungsanfälligkeit, sondern auch zu Leistungseinbußen führen. Ziel dieser Dissertation war es daher, die physische und psychologische Leistungsfähigkeit sowie verletzungs- und schmerzbezogene Parameter nach der Therapie zu untersuchen. Die Querschnittsstudie (STUDIE I) untersuchte den Unterschied zwischen gesunden und verletzten Spielern, die Meta-Analyse (STUDIE II) fasste den aktuellen Stand der Behandlungsmethoden zusammen und die Interventionsstudie (STUDIE III) prüfte die Effekte einer neuartigen therapeutischen Intervention.

Methoden

Im Rahmen eines systematischen Reviews mit Meta-Analyse (STUDIE II), einer Querschnittsstudie (STUDIE I) und einer Interventionsstudie (STUDIE III) wurden physische, psychologische und verletzungsbezogene Parameter untersucht. Die Querschnittsstudie (STUDIE I) betrachtete die Unterschiede zwischen gesunden Fußballspielern (n = 17, Alter: 15.0 ± 1.0 Jahre) und Fußballspielern mit Patella-Tendinopathie nach erfolgter Therapie (n = 18, Alter: 15.1 ± 0.8 Jahre). Für die Meta-Analyse (STUDIE II) wurde eine computergestützte systematische Literatursuche in den elektronischen Datenbanken PubMed, Medline und Web of Science von Januar 1960 bis Juli 2020 durchgeführt, bei der 277 Probanden (Durchschnittsalter 16–32 Jahre) inkludiert wurden. Die Interventionsstudie (STUDIE III) analysierte die Ergebnisse eines konventionellen (n = 18, Alter: 15.1 ± 0.8 Jahre) im Vergleich zu einem neuartigen (n = 16, Alter: 15.4 ± 1.0 Jahre) Therapieprogramm. In der Querschnitts- und Interventionsstudie (STUDIE I und III) wurden die Muskelkraft (Drop Jump, Jump-and-Reach), die Richtungswechselgeschwindigkeit (modified agility T-Test), die lineare Geschwindigkeit (30-m-Linearsprint, Tapping-Test), die Ausdauer (Yo-Yo intermittent recovery test level 1), das Leistungsmotiv (Achievement Motive Scale-Sport) und verletzungs- /schmerzbezogene Daten an vier Messzeitpunkten über 20 Wochen nach Abschluss der Therapie erfasst, um die langfristigen Ergebnisse zu messen. Die durchgeführten Interventionen umfassten ein konventionelles exzentrisches Krafttrainingsprogramm mit schmerzadaptierter Pause vor dem Beginn, sowie ein neuartiges Interventionsprogramm, welches unabhängig vom Schmerzniveau direkt startete und dem exzentrischen Training noch kognitive Zusatzaufgaben, sowie Instabilitätskrafttraining hinzufügte.

Ergebnisse

Sportler mit Patella-Tendinopathie nach erfolgter Therapie zeigten über den gesamten Messzeitraum signifikant schlechtere physische, sowie in den ersten sechs Wochen auch schlechtere psychologische Leistungsfähigkeit, im Vergleich zu gesunden Spielern (STUDIE I). Zudem konnten signifikant höhere Verletzungsraten der unteren Gliedmaßen, sowie verletzungs- und schmerzbedingte Trainingsunterbrechungen festgestellt werden, was auf relevante langfristige Beeinträchtigungen hindeutet. Die Meta-Analyse (STUDIE II) ergab, dass nur drei von elf Studien Folgemessungen nach dem Ende der Therapie durchführten, was die Forschungslücke bei den langfristigen Behandlungsergebnissen verdeutlicht. Die heterogenen Ergebnisse deuten darauf hin, dass körperliches Training eine wirksame Therapieform zur Verbesserung der Schmerzintensität und der Symptomschwere, nicht aber der physischen Leistungsfähigkeit ist. Hinsichtlich der Interventionsstudie (STUDIE III) erzielte der neuartige Ansatz größere Verbesserungen bei den physischen Leistungen, dieselben Verbesserungen bei den psychologischen Messwerten und bessere Werte für verletzungs- oder schmerzbezogene Parameter. Die neuartige Intervention benötigte im Vergleich zur konventionellen eine kürzere Therapiedauer und verbesserte die Richtungswechselschnelligkeit, sowie verletzungs- und schmerzbezogene Parameter signifikant.

Schlussfolgerungen

Die Querschnittsstudie (STUDIE I) zeigte, dass Jugendspieler mit Patella-Tendinopathie auch nach Abschluss der Therapie körperliche und psychologische Leistungseinbußen aufwiesen, was das Verletzungsrisiko erhöhen und die Karriereentwicklung beeinträchtigen kann. Die Ergebnisse der Meta-Analyse (STUDIE II) verdeutlichten, dass sich verschiedene Methoden der Trainingstherapie als wirksam erwiesen haben, jedoch wenig über die langfristigen Auswirkungen auf die sportartspezifische Leistung bekannt ist. Die Interventionsstudie (STUDIE III) ergab, dass die komplexe Pathogenese eine multimodale therapeutische Intervention erfordert, die durch erhöhte Komplexität und Intensität gekennzeichnet ist. Weitere Forschung sollte die Auswirkungen von Patella-Tendinopathie auf andere psychologische Parameter untersuchen und die Interventionen individueller an die leistungsbestimmenden Faktoren der Sportart anpassen.

Schlüsselwörter

Patella-Tendinopathie; Springerknie; junge Sportler; körperliche Fitness; Intervention

1. General introduction

This chapter will briefly outline the research problem to be addressed in this doctoral thesis. It will also introduce the aims and objectives of this thesis and provide an overview of the studies that have been carried out and implemented for this thesis.

1.1 Identification of the research problem

Reportedly, young soccer players experience incidence rates of overuse injuries as high as 50% (Dalton, 1992; Leppänen et al., 2019). These injuries, including patellofemoral syndrome, patellar tendinitis, and patellar tendinopathy (PT), are often attributed to high training volumes and more frequent competitions (Hägglund et al., 2011). The financial impact of PT is substantial, with patients incurring direct medical costs ranging from approximately £20,000 to £30,000 (in 2015 currency), comparable to medical costs associated with conditions like osteoarthritis and osteoporosis (Hopkins et al., 2016). Recent studies have shown that patients with PT experience a 16% loss of workability and a 36% decrease in productivity (De Vries et al., 2017), which contribute to indirect medical costs associated with the condition.

Rommers et al. (2020) have highlighted that adolescent soccer players, who confront growth-related stresses and undergo slow adaptations in their tendon structures, face an increased risk of injury. The patellar tendon is particularly vulnerable due to the demanding and repetitive nature of soccer training and competition, thus increasing the susceptibility of young athletes to PT (Gisslèn et al., 2005; Kaux et al., 2011). Despite having lower training intensities and overall volumes compared to adult players, youth players have not yet reached their maximum physical and psychological capacities. Nevertheless, they are subjected to high-intensity exercises and the pressure to uphold peak performance throughout competitive seasons (Cook & Purdam, 2014; Pfirrmann et al., 2016), potentially magnifying their vulnerability to injuries. Within the realm of adolescent soccer players, a considerable percentage experience PT, ranging from 11.7% (Florit et al., 2019) to 13.0% (Cassel et al., 2018), leading to extended periods of absence and setbacks in athletic performance.

Less is known about the long-term prognosis of PT, but there is evidence that many athletes experience long-lasting symptoms and are often forced to finish their sporting careers (Florit et al., 2019). Pain and impaired function associated with PT may lead to a reduction in training intensity and participation in matches. This limited physical activity can hinder motor skill development and conditioning, potentially resulting in a decline in overall performance. Downtime from injury due to persistent symptoms and recurrent pain, as well as diminished mental or physical performance, can affect the level of competitive success and thus impede the progression of an athlete's career (Johnson & Ivarsson, 2011). One-third of patients are unable to return to play for more than six months, and even with current treatments, only 31.5% of athletes can return to their sport at a similar level as before injury (Breda et al., 2021). However, the long-term effects of PT in adolescent soccer players go beyond the immediate impact on athletic performance. The frequent recurrence of symptoms after initial resolution can place a psychological burden on the athlete, leading to secondary injuries (Bell et al., 2018). In addition, athletes with this condition may struggle to maintain the same level of play as their healthy peers, which can have a negative impact on their self-confidence and overall mental health (Slagers et al., 2021).

Furthermore, persistent pain can lead to altered biomechanics and movement patterns. To compensate for the discomfort, players may alter their jumping and landing techniques, placing additional stress on other joints and muscles. These compensatory movements not only reduce performance but also increase the risk of secondary injuries such as ankle sprains or knee ligament strains (Pietrosimone et al., 2020). Witvrouw et al. (2001) conducted a prospective study that highlighted intrinsic risk factors such as abnormal knee kinematics, reduced ankle dorsiflexion range of motion, and deficits in lower limb muscle strength. These factors can lead to altered loading patterns on the patellar tendon, contributing to overuse and degeneration.

The management of this condition goes beyond addressing changes in athlete behaviour; understanding the altered biomechanics in athletes with PT is critical for the development of effective treatment and prevention strategies. Kongsgaard et al. (2009) investigated the effects of heavy slow resistance training on fibril morphology and tendon mechanical properties in individuals with PT. Their findings (e.g., increased collagen concentration and changes in the collagen crosslink profile) highlight the potential for targeted exercises to modify tendon biomechanical properties and promote recovery. Moreover, Rio et al. (2015) demonstrated that isometric strength exercises can induce analgesia and reduce inhibition in PT. These exercises target altered biomechanics by addressing neuromuscular control deficits and optimising loading patterns, ultimately aiding in pain management and functional improvement.

However, the treatment of PT is challenging, especially during the competitive season when athletes are under constant pressure to perform (van Ark et al., 2016). This is represented in the current literature with high variability in individual treatments (Burcal et al., 2018) and interventions (Aicale et al., 2020), a high rate of non-responders after six months of application (Everhart et al., 2017), and a few studies combining different approaches (Burton, 2022). In particular, most studies that have attempted to provide a treatment recommendation have focused on either eccentric or concentric exercises (Agergaard et al., 2021; Cannell et al., 2001; Jonsson & Alfredson, 2005; Lee et al., 2020; Ruffino et al., 2021; Young et al., 2005). Although the current literature demonstrates that various therapeutic modalities are successful in reducing pain and improving physical performance, the long-term effectiveness of these conventional treatments is often unsatisfactory. This may be due to the emotional response to the rehabilitation process (Tracey, 2003) or a combination of training methods and protocols that have not yet been investigated (Caine et al., 2021).

1.2 Objectives of this doctoral dissertation

This work aims to examine the heterogeneous study situation described above and to show the effects of different therapy programmes on physical, psychological, and injury-/pain-related parameters. In particular, the different therapeutic modalities, which are rarely used in combination, need to be investigated regarding their long-term effects after therapy. Therefore, this work aimed to investigate: (I) the differences between players with PT after physical therapy compared to healthy controls, (II) the effects of physical training on physical and psychological parameters, and (III) the changes in return to performance after a conventional compared to an alternative therapy programme. A cross-sectional longitudinal study (Niering & Muehlbauer, 2021a), a systematic review (Niering & Muehlbauer, 2021b), and a longitudinal intervention study (Niering & Muehlbauer, 2023) were conducted. The publication details are listed below:

<ins>Cross-Sectional Study</ins>

I **Niering, M.**, & Muehlbauer, T. (2021a). Differences in Physical and Psychological Parameters in Sub-Elite, Male, Youth Soccer Players with Jumper's Knee Following Physical Therapy Compared to Healthy Controls: A Longitudinal Examination. *International Journal of Sports Physical Therapy*, *16*(1), 114-125.

<ins>Systematic Review and Meta-Analysis</ins>

II **Niering, M.**, & Muehlbauer, T. (2021b). Effects of Physical Training on Physical and Psychological Parameters in Individuals with Patella Tendinopathy: A Systematic Review and Meta-Analysis. *Sports*, *9*(1), 12.

Erratum*: **Niering, M.**, & Muehlbauer, T. (2021). Effects of Physical Training on Physical and Psychological Parameters in Individuals with Patella Tendinopathy: A Systematic Review and Meta-Analysis. *Sports*, *9*(11), 151.

* Note: This erratum was necessary because the condition was incorrectly referred to as patella tendon myopathy, which was added by the editor shortly before publication.

Intervention Study

III **Niering, M.**, & Muehlbauer, T. (2023). Changes After a Conventional vs. an Alternative Therapy Program on Physical, Psychological, and Injury-Related Parameters in Male Youth Soccer Players with Patellar Tendinopathy During Return to Competition. *The Journal of Strength and Conditioning Research*, *37*(9), 1834-1843.

The results of this research will contribute to a better understanding of the effects of exercise and possible therapeutic options. In particular, the practical implementation of interventions by coaches, clinicians, and exercise therapists will be improved by new knowledge about the lasting effects of exercise therapy applications.

2. Theoretical background

First, a comprehensive description of the condition is given, with an emphasis on its impact on the athlete. This is followed by a description of the diagnosis and differential diagnosis, which is particularly important when considering the effects and treatment options. Finally, current approaches to exercise therapy, the closely related demands of the sport, and alternative treatment options are presented.

2.1 Patellar tendinopathy

PT, also known as "jumper's knee", is a condition involving pain and dysfunction of the patellar tendon, which connects the patella to the tibia. There are various definitions and classifications of PT that have been proposed in the medical literature (Blazina et al., 1973; Cook & Purdam, 2009; Khan et al., 1998). Therefore, the current state of research and the known particularities of sport are outlined below.

2.1.1 Epidemiology

Overuse injuries, such as PT, are a major concern among adolescent athletes, particularly those involved in high-impact jumping sports such as football, volleyball, and basketball (Cook, Khan, Kiss, & Griffiths, 2000; Dalton, 1992; Gisslèn et al., 2005; Kaux et al., 2011). With incidence rates scaling up to 50%, PT is particularly prevalent, affecting 31.9% and 44.6% of basketball and volleyball players, respectively (Lian et al., 2005). Treating injuries during competitive seasons is challenging due to the constant high-level performance pressure, which is further complicated by the fact that males are twice as likely to be affected as females (Cook & Purdam, 2014; Zwerver et al., 2011). Notably, symptom presentation is not significantly influenced by age (Cook et al., 2000). Adolescent soccer players, representing 11.7% to 13.0% of the patient group, often experience prolonged absences and performance regression due to PT (Cassel et al., 2018; Florit et al., 2019).

2.1.2 Aetiology

The onset of the pathology is characterised by alterations in cellular and matrix composition in the patellar tendon, particularly at its inferior pole where it connects with the patella (Khan et al., 1996). Repetitive stress and strain on the patellar tendon during high-intensity physical activities cause micro-traumas, which trigger a sequence of maladaptive responses at the cellular level (Ferretti, 1986). These responses comprise an influx of fibroblasts and enhanced production of type III collagen, resulting in alterations in the tendon's micro-architecture and biomechanical properties (Fearon et al., 2014). The alteration in the proportion of type I to type

III collagen impairs the tensile strength and elasticity of the tendon, making it more prone to further harm. Additionally, the process of neovascularisation within the affected segment of the tendon intensifies the condition by promoting the invasion of inflammatory cells and neuropeptides, which disturbs the structural integrity of the tissue, resulting in painful symptoms (Alfredson et al., 2000; Cook & Purdam, 2009).

The aetiology of PT is complex and involves a confluence of intrinsic and extrinsic factors (Cook & Purdam, 2009). Intrinsic risk factors such as individual biomechanics, muscle imbalances, and genetic predispositions contribute to the development of PT. Athletes who have maligned lower extremities, muscular imbalances, or ligamentous laxity are at risk of overloading the patellofemoral joint during physical activity, which increases the likelihood of patellar tendon overload and injury (Witvrouw et al., 2001). The genetic aspect of PT has been given considerable attention, with research suggesting that polymorphisms in genes that regulate collagen production and matrix remodelling, such as COL5A1 and MMP3, may predispose individuals to tendon pathology (Raleigh et al., 2009; September et al., 2016). Furthermore, growth-related stresses (Rommers et al., 2020) and frequent competitions (Leppänen et al., 2019) particularly in adolescent athletes, present a significant intrinsic risk factor for PT.

At the same time, factors external to the body, including the intensity of training, the type of playing surface, footwear, and technique, play a vital role in the initiation and advancement of PT. Training programmes that subject the patellar tendon to high loads, particularly those that include jumping, landing, and change-of-direction movements, are intrinsically dangerous (Malliaras et al., 2015). Furthermore, a sudden and unexpected increase in training volume, for example in pre-season preparation, leads to a significantly increased risk (Hägglund et al., 2011). Also, the surface on which athletes train and compete can affect the loading on the tendon. Harder surfaces transmit greater shock forces, which increases the risk of tendon loading and injury (Nigg et al., 2003). Poor footwear can lead to insufficient shock absorption, increasing the mechanical stress on the tendon (Hreljac, 2004). Inefficient or incorrect movement patterns during athletic activities amplify loading on the patellar tendon, contributing to the development of tendinopathy (Lin et al., 2023). This highlights the significant impact of the technique on PT. Therefore, its aetiology is intricate and multi-factorial, necessitating a comprehensive approach to prevention, diagnosis, and management.

2.1.3 Pathophysiology

PT progresses through a spectrum of stages, starting with reactive tendinopathy, an acute response to overuse, progressing to tendon disrepair when the rate of injury exceeds the repair capacity, and culminating in a degenerative phase often seen in chronic cases and older athletes (Scott et al., 2013). Each stage has distinct pathophysiological changes, ranging from tendon thickening and increased cell proliferation to widespread collagen disorganisation and cell death. These differences in tissue health and response to injury highlight the importance of stage-specific interventions in the management of this condition (Cook & Purdam, 2009).

Therefore, since the pathology is very versatile and complex, the pathophysiology is described in the area of anatomical, functional, and kinetic changes, which are intricately linked with the patient's daily activities and quality of life. To highlight the distinctive characteristics of the condition at the cellular level, histopathology considers molecular and vascular adaptations, separately. One primary anatomical characteristic of PT is tendinosis, a degenerative condition, primarily found in the posterior section of the patellar tendon near the inferior patellar pole (Golman et al., 2020). Tendinosis, unlike tendinitis, exhibits a progressive degeneration of the tendinous tissue, which has no inherent capacity for self-repair and is also not associated with inflammatory cells. The affected area undergoes a visual change, exhibiting a yellow hue commonly referred to as mucoid degeneration, which differs significantly from the typical healthy tendinous tissue appearing bright, white, and fibrous (Figueroa et al., 2016). Moreover, chronic tendinosis can lead to thickening of the tendon, a response to chronic injury, which can be palpated clinically and seen on imaging modalities such as ultrasound or magnetic resonance imaging. In some chronic cases, calcifications might form within the tendon, which represents a buildup of calcium deposits and can contribute to pain and further compromise tendon function (Breda et al., 2020). Beyond these changes, adaptations and deficits in the area of motor control also become apparent. In the sensorimotor system, changes such as reduced proprioception, which refers to the body's ability to sense its position and movements in space, are evident and pose a notable concern in PT (Torres et al., 2017). In the context of PT, the pain and structural alterations within the tendon can disrupt typical proprioceptive feedback mechanisms. This disruption can subsequently impair an individual's joint position sense at the knee, a crucial component of proprioception. When this is compromised, individuals might struggle to accurately recognize the position of their knee joint in space, leading to aberrant movement patterns.

As a functional consequence of these alterations, individuals with PT may adopt compensatory movement patterns to avoid pain or due to reduced tendon strength or proprioception (Canosa-Carro et al., 2022). These changes can lead to altered joint mechanics, which can, in turn, predispose other structures to injury. Therefore kinetic characteristics must also be considered, with some studies showing that patients with PT tend to have internal rotation and adduction moment in the lower leg at high extension moments (e.g., during peak take-off), in contrast to healthy individuals who have external rotation and abduction moment (Edwards et al., 2010; Obara et al., 2022).

2.1.4 Histopathology

Histopathological analysis of tissue samples from individuals with PT provides insights into the cellular and structural alterations that contribute to the disease process. Tendons possess a limited blood supply, primarily relying on diffusion from surrounding tissues for nutrition and waste removal (Merkel et al., 2021). This lack of direct blood supply hinders the healing process, especially in areas of chronic microtrauma. Tendinopathic tendons show fusiform swelling in their proximal insertion, caused by increased vascular infiltration in the paratendinous tissue and the tendon itself. These processes called neovascularization and angiogenesis are prominent histopathological features in PT, contributing to inflammation and impaired healing, as well as pain and discomfort due to nerve fibre infiltration and sensitization (Cassel et al., 2015).

Neovascularization refers to the formation of blood vessels, in a tissue in response to injury or pathological conditions. In the case of tendinopathy neovascularization occurs within the tendon itself and its surrounding structures. Angiogenesis, a type of neovascularization involves the growth and development of capillaries from existing blood vessels. Moreover, the interaction between nerves and blood vessels in the tendon plays a role in both pain perception and tissue healing (Tan & Chan, 2008). The increase in blood vessel formation, in tendinopathy may be influenced by nerve-induced angiogenesis. Nerve fibres can release signals that promote blood vessel growth. Conversely, the increased blood supply can cause nerve fibres to become more sensitive resulting in pain and discomfort.

In the early stages of PT, histological examination reveals a disorganised arrangement of collagen fibres within the tendon collagen matrix (Khan et al., 1998). Collagen is the primary structural protein in tendons, providing the tissue with its characteristic strength and resilience. According to Riley (2008) in PT, the collagen matrix undergoes significant changes in its arrangement and composition, leading to compromised mechanical properties and increased vulnerability to injury. This disruption of collagen fibril alignment is often seen in the deep region of the tendon, close to the bone-tendon insertion, where tensile forces are concentrated during movement. Collagen fibres, which normally align parallel to the tendon's long axis, become fragmented and haphazardly arranged. In response to mechanical overload and inflammation, there is an upregulation of matrix metalloproteinases, enzymes responsible for breaking down collagen and other extracellular matrix components. Excessive matrix metalloproteinase activity can lead to collagen degradation and contribute to the disorganized matrix structure. This disarray diminishes the tendon's ability to withstand mechanical loads, leading to decreased tensile strength and increased susceptibility to injury (Millar et al., 2021). Moreover, the altered matrix structure also contributes to pain and discomfort, as nerve fibres may become sensitized within the disrupted tissue. Understanding the underlying mechanisms driving matrix disorganization is crucial for developing targeted therapeutic strategies aimed at restoring the tendon's structural integrity and alleviating the symptoms associated with PT.

2.1.5 Prognosis in sports

Although limited information is available on the long-term prognosis of PT, it is evident that many affected athletes endure persistent symptoms, often leading to premature termination of their sporting careers. This, along with the psychological burden resulting from frequent symptoms' recurrence and the risk of secondary injuries, presents a challenging situation for the patients (Bell et al., 2018). Even with the application of modern treatment methods, it is alarming that only 31.5% of athletes manage to return to their pre-injury performance level, with one-third of patients unable to play for more than six months after injury (Breda et al., 2020). This situation highlights the crucial need for increased research and advanced treatment methods in dealing with overuse injuries, specifically PT, to protect the well-being and professional development of young athletes.

2.2 Diagnosis of patellar tendinopathy

This condition is often associated with a difficult clinical presentation (Malliaras et al., 2015), as well as a frequently incorrect differential diagnosis in the area of tendon morphology (Figueroa et al., 2016). For this reason, the current state of knowledge regarding various diagnostic procedures is outlined below.

2.2.1 Palpation

Palpation is a diagnostic technique used in the identification and evaluation of PT. The cost-effective and non-invasive qualities of this diagnostic procedure are of particular importance (Cook & Purdam, 2009). Practitioners carry out palpation, using subtle pressure to assess the texture, thickness, and temperature of the tendon. They also identify any anomalous features, such as masses or depressions, that differ from the neighbouring healthy tissue (Maffulli et al., 2003). To conduct efficient palpation, the practitioner should methodically examine the tendon, beginning at the inferior pole of the patella and moving distally. The tendon’s proximal insertion requires particular attention, as this is where pathological alterations that suggest PT frequently manifest (Lian et al., 2005). The identification of pain at the tendon's point of insertion and noticeable changes in its structural characteristics through palpation are essential diagnostic markers for PT (Kongsgaard et al., 2009). Palpation's diagnostic efficacy is intrinsically linked to the examiner's expertise, as both onset sensitivity and overall specificity depend on the clinician's proficiency (Cook et al., 2000). To enhance diagnostic accuracy, it is advised to cautiously incorporate palpation observations with the patient's clinical history and symptoms (Visnes & Bahr, 2007). Palpation is not only used for diagnosis but also serves as a valuable tool to monitor the tendon's response to therapy. It plays a critical role in modifying and optimizing treatment plans for patients with PT (Malliaras et al., 2015). Thorough palpation enables clinicians to obtain significant information concerning the status of the tendon and the progression of PT. This information aids in creating informed treatment strategies, without the need for invasive methods or costly imaging modalities (Scott et al., 2013).

2.2.2 Imaging

Imaging techniques play a crucial role in the diagnosis and evaluation of PT, providing detailed insight into the structural and pathological changes within the tendon. Various techniques, such as magnetic resonance imaging, radiographic image, and ultrasound, are commonly used to gain an in-depth understanding of the extent and nature of tendon degeneration and other associated abnormalities, thereby assisting clinicians in the development of targeted therapeutic strategies (Khan et al., 1996).

The following discourse focuses on ultrasound due to its unique advantages, such as being a cost-effective, non-invasive, and accessible technique that provides real-time imaging and dynamic assessment capabilities for immediate and accurate diagnosis and evaluation of PT (McAuliffe et al., 2016). Ultrasound effectively delineates the morphological characteristics and integrity of the patellar tendon, allowing the identification of hallmark features of PT, including hypoechoic regions, disorganised collagen structure, and neovascularity (Cook et al., 2000). Furthermore, the use of ultrasound enables the assessment of the tendon's functionality under dynamic conditions, offering valuable insights into the functional limitations caused by the pathology (Gisslèn et al., 2005). The implementation of Doppler and Elastography techniques significantly enhances the diagnostic potential of ultrasound, allowing the visualisation of neovascularisation within the tendon (Hoksrud et al., 2008) as well as its stiffness (Ooi et al., 2016), which are strongly correlated with the symptomatic pain experienced by individuals with PT (Breda et al., 2020). Thus, ultrasound is a crucial instrument for guiding therapeutic interventions by providing timely and essential details of the condition's progression and response to treatment, besides its diagnostic precision (Docking & Cook, 2016). However, the operator-dependent nature of the technique and the importance of skilled interpretation of the images produced must be recognised. Although ultrasound is capable of detecting structural anomalies, the relationship between these identified features and the patient's clinical symptoms or prognosis is not straightforward, necessitating further exploration and understanding (van Ark et al., 2016).

2.3 Interventions during and after patellar tendinopathy

The classic theoretical model for the management of PT is the continuum model of tendinopathy described by Cook and Purdam (2009). This model divides tendinopathy into stages (reactive tendinopathy, tendon disrepair and degenerative tendinopathy), as seen in Figure 1.

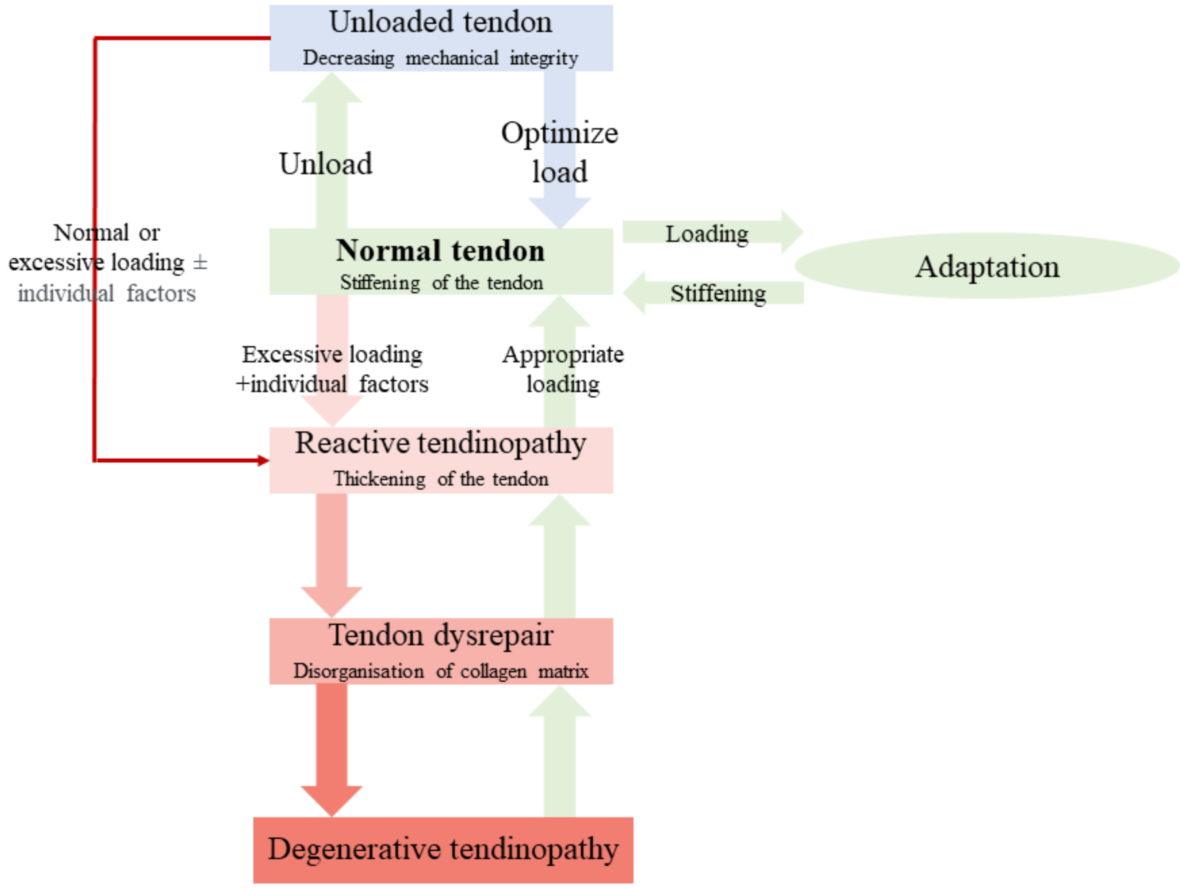

Figure 1. *Continuum model of tendinopathy according to Cook and Purdam (2009).*

Each stage, characterised by different pathophysiological changes, suggests stage-specific interventions ranging from initial activity modification to progressive exercise and return to activity. Building on this basic model, current treatment modalities for PT have evolved, incorporating new evidence and innovative techniques.

Thus, interventions to counteract PT require strategies that address both immediate symptoms and long-term effects of the pathology, which can have a lasting impact on affected individuals. Initial interventions aim to alleviate acute symptoms through pain management and stress reduction (Mascaró et al., 2018). However, complete rest is not recommended as it may result in tendon stiffness and weakness (Visnes & Bahr, 2007). Silbernagel et al. (2007) propose a pain-monitoring model in which load and its effects are specifically observed and subsequently adapted.

When considering return-to-competition strategies, the persistent nature of PT requires sustained rehabilitation efforts to mitigate its long-term consequences (Rio et al., 2016). A targeted approach should result in adaptive remodelling of the tendon that improves its mechanical properties and functionality over time (Visnes et al., 2005). However, the outcomes of long-term recovery interventions exhibit considerable heterogeneity, with studies indicating diverse results in different individuals (van Ark et al., 2016). These findings suggest that athletes may experience ongoing functional impairments even after successful PT rehabilitation when compared to healthy athletes (Mendonça et al., 2018). Furthermore, Malliaras et al. (2013) emphasise that despite systematic rehabilitation, athletes still had deficits in tendon structure and neovascularisation compared to healthy individuals. Beyond these physical limitations, psychological factors have a significant impact on the athlete's return to competition. Fear of re-injury or recurrent pain can affect the athlete's confidence and lead to hesitation and caution in participating in sports that require rapid and heavy loading of the tendon (Ardern et al., 2016).

2.3.1 Physical and psychological demands during return to competition

Returning to competition after an injury requires both physical and psychological readiness. Ardern et al. (2016) emphasize the need for a progressive programme of exercise and therapy to rebuild muscular strength and motor skills lost during the period of injury. Rehabilitation, as highlighted by Ivarsson et al. (2017), should be individualized and systemic, including a sequence of exercises to recondition the body effectively while reducing the risk of re-injury.

However, besides the physical demands, psychological obstacles, as recognised by Podlog and Eklund (2007), usually involve concerns and worries regarding performance and re-injury. If not addressed, these concerns can negatively impact an athlete's confidence and focus, influencing their ability to return to competition. To address psychological challenges Walker et al. (2007) suggest employing mental and cognitive strategies in the rehabilitation process. The authors outline that improving athletes' mental resilience and developing a positive mindset are critical components for effective reintegration into the competitive environment. Additionally, Lu and Hsu (2013) emphasise the critical role of social support from peers, coaches, and family in providing valuable emotional and motivational support during this stressful period. The interplay of physical and psychological elements throughout the recovery process demands a coordinated, multidisciplinary approach to rehabilitation.

Athletes recovering from PT are required to rebuild knee tendon strength and flexibility to promote tendon healing and adaptation, as well as to help athletes gradually regain their former capacity for explosive movements (Malliaras et al., 2013), which are crucial for jumping and sprinting in soccer (Dolci et al., 2020). Throughout this process, workload and symptoms need to be managed carefully to prevent overuse and to avoid worsening of the condition (Visnes & Bahr, 2007). Particularly with patellar tendon injuries, complex movement patterns are impaired, requiring athletes to engage in neuromuscular training, which is effective in restoring joint stability and motor control (Papadopoulos et al., 2015). Regarding the rehabilitation period, it must also be considered that PT affects the athlete over a longer period, ranging from six months (Cook et al., 1997) to four years (Lian et al., 2005). This highlights the particular importance of patient education in the return to competition process of PT, allowing the athlete to realistically adjust their expectations (Rutland et al., 2010).

2.3.2 Current approaches in exercise therapy

In addition to exercise therapy, there are a variety of other surgical and non-surgical methods, which demonstrate inconsistent results, but may be useful as an addition to exercise therapy and may also lead to better overall outcomes (Chen et al., 2019; Everhart et al., 2017; Vander Doelen & Jelley, 2020). These include leukocyte-rich platelet-rich plasma injections (Andriolo et al., 2019; Filardo et al., 2010; Le et al., 2018), extracorporeal shock wave therapy (Chen et al., 2019; Everhart et al., 2017; Liao et al., 2018; Rompe et al., 2009), skin-derived tenocyte-like cells (Kader et al., 2021; López-Royo et al., 2020), ultrasound-guided percutaneous needle electrolysis (Abat et al., 2014, 2015; De La Cruz Torres et al., 2016), dry needling (Cotchett et al., 2014; Gattie et al., 2017; James et al., 2007; Sharif et al., 2023; Stoychev et al., 2020), and corticosteroid injections (Coombes et al., 2010; Everhart et al., 2017). However, they are not part of this thesis and therefore will not be characterized in detail. Therefore, in the following section, the current approaches in exercise therapy will be further outlined.

To rehabilitate and prevent further incidents of PT, recommendations include stage-specific therapy with a progressive load, taking into account the patient's specific symptoms (Figure 2) (Hagen et al., 2024; Malliaras et al., 2015; Mascaró et al., 2018; Scattone Silva et al., 2023).

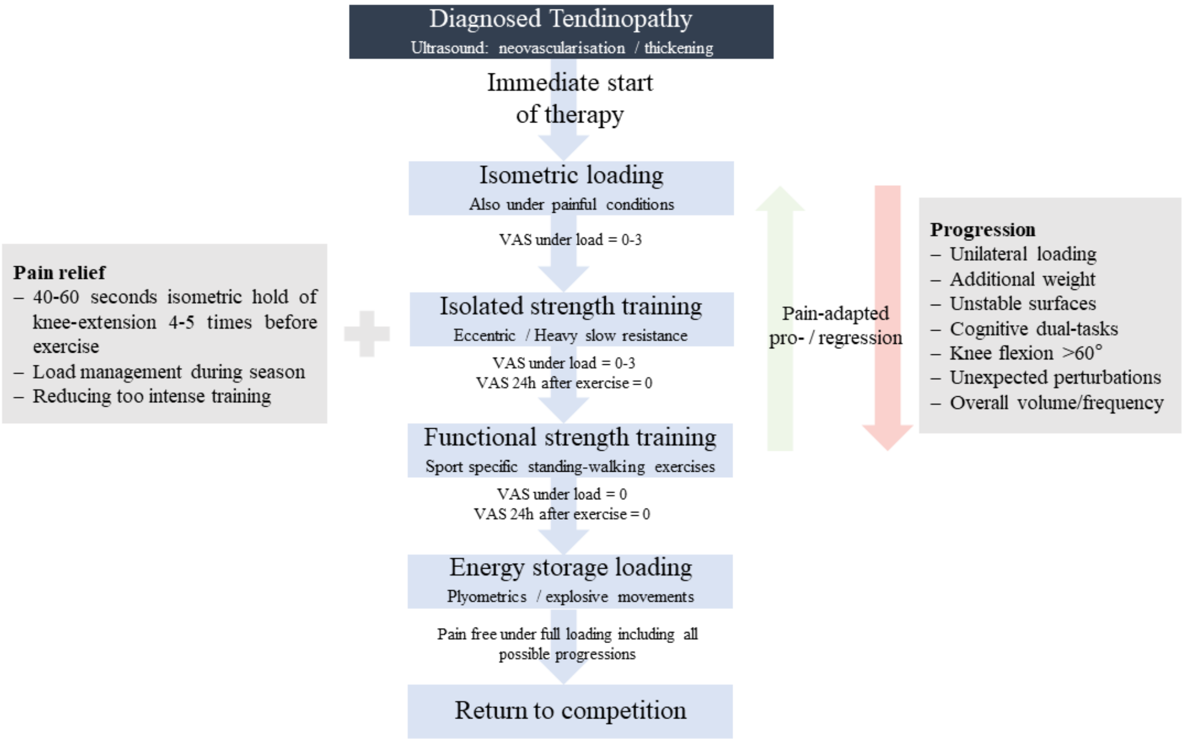

Figure 2. *Stage-specific progressive load therapy according to Hagen et al., 2024; Malliaras et al., 2015; Mascaró et al., 2018; Scattone Silva et al., 2023.*

Recognised methods for dealing with PT include stretching, isometric and eccentric training of the quadriceps, as well as exercises that progressively load the tendons (Agergaard et al., 2021; Breda et al., 2021; Lee et al., 2020; Rio et al., 2015; Ruffino et al., 2021). However, eccentric exercises that result in heightened pain levels may impede muscle performance and limit the effectiveness of this treatment approach (Visnes et al., 2005). Overall, it is apparent that most studies proposing treatment options concentrate solely on isometric, eccentric or concentric exercise routines (Agergaard et al., 2021; Biernat et al., 2014; Cannell et al., 2001; Croisier et al., 2001; Frohm et al., 2007; Jonsson & Alfredson, 2005; Lee et al., 2020; Visnes et al., 2005; Young et al., 2005), have small participant samples ranging from 5–11 athletes (Cannell et al., 2001; Croisier et al., 2001; Jonsson & Alfredson, 2005; Rio et al., 2015; Romero-Rodriguez et al., 2011; Young et al., 2005), or involve short study durations of less than twelve weeks (Cannell et al., 2001; Croisier et al., 2001; Dimitrios et al., 2012; Jonsson & Alfredson, 2005; Rio et al., 2015, 2017; Romero-Rodriguez et al., 2011; van Ark et al., 2016).

Although current literature proves different therapy methods as successful in reducing pain and increasing physical performance, the effectiveness of these conventional treatments is often unsatisfactory in the long term. This can be due to the emotional response to the rehabilitation process and can be improved by engaging the athlete in a series of tasks, forcing the body to experience its current limitations in various performance variables (Tracey, 2003). Therefore, a therapy programme should not only include the training methods that have been applied in the past but should also be able to increase the level of difficulty to adapt to the individual patient's current needs to reach or even outperform the performance requirements of their sport on a competitive level. To address these variables and varying demands, an individualized exercise programme should incorporate other treatment modalities, which are presented below.

According to current literature on psychological approaches to athletic injuries, it is suggested that factors such as self-confidence and achievement motivation should be prioritised to ensure a successful return to sports (Podlog et al., 2020). Additionally, addressing sources of confidence information, observational experiences and confidence restoration as soon as possible after an injury is related to a higher likelihood of treatment success (Tufekcioglu et al., 2014). In particular, a recent study conducted by Slagers et al. (2021) demonstrated the significance of psychological factors influencing the return to competition in patients with PT. The study highlighted a lack of psychological readiness and emphasised the importance of objective evaluations to accurately inform medical decisions in these cases.

In terms of the potential contribution of the proprioceptive and vestibular system in the context of exercise therapy, research has found evidence of diminished proprioception (Torres et al., 2017) and postural balance (Fendri et al., 2022) among athletes suffering from PT, which also needs to be taken into account when designing an effective therapy programme. Especially in sports that involve complex knee movements, like jumping or cutting, compromised proprioception and balance can affect performance (Han et al., 2015; Paillard, 2019) and elevate the risk of subsequent injuries (Kraemer & Knobloch, 2009). Recognizing these challenges, modern rehabilitation approaches for PT often incorporate proprioceptive training (Theodorou et al., 2023). Exercises tailored to improve balance and joint position sense can aid in restoring proprioceptive integrity and, in turn, enhance overall functional outcomes. Rio et al. (2016) highlight a notable link between PT, cortical inhibition, and the benefits of neuromuscular control exercises. Although the authors primarily focused on pain modulation and cortical inhibition, the underlying theme emphasized the essential role of neuromuscular control, inclusive of proprioception, in managing tendinopathies. However, it remains crucial to note that while there's a growing interest in the intersection of proprioceptive deficits and musculoskeletal disorders, more targeted research is needed to elucidate the specific relationship between PT and proprioception.

Also in the area of training methodology, heavy slow resistance training, first presented by Kongsgaard et al. (2009), is an effective and even superior alternative to eccentric training (Kongsgaard et al., 2010). In this method, the concentric and eccentric phases are each performed very slowly (i.e. 3 seconds) to increase tendon collagen synthesis while reducing pain levels. While this method is effective in other tendon pathologies such as Achilles tendinopathy (Beyer et al., 2015) and plantar fasciitis (Riel et al., 2019), only recent studies have demonstrated its efficacy in PT (Morrison & Cook, 2022; Muaidi, 2020; Ruffino et al., 2021).

Concerning training implementation, strength training on unstable surfaces is only partially recommended for improving balance and proprioceptive skills (Behm et al., 2015), and little is known about combining proprioceptive and strength training in adolescents. Since both programmes showed positive results in young patients with lower limb injuries (Baydogan et al., 2015) it seems reasonable to propose that a combination of both could have positive effects on physical performance.

2.4 Research questions and hypotheses

The previous chapters have shown that although there is a wide range of therapeutic approaches from different disciplines for PT, the body of evidence is still very heterogeneous in many areas. In particular, there is a need for further research into the effects of different combinations of therapies, as well as long-term outcomes after the complete absence of pain. For this reason, this thesis examines i) differences in performance of athletes with PT compared to healthy individuals after therapy (STUDY I), ii) effects of different physical training methods (STUDY II), and iii) changes after a novel compared to a conventional therapy method (STUDY III). Figure 3 illustrates the scientific framework of this doctoral thesis.

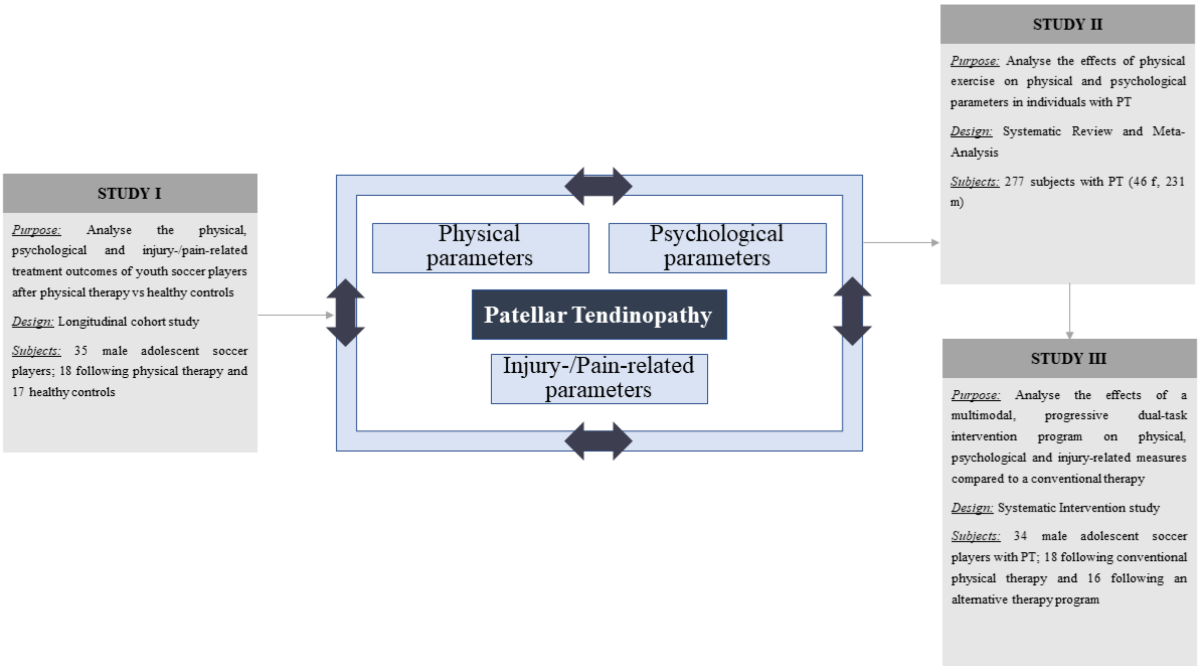

Figure 3. *Schematic illustration of the scientific approach of the doctoral thesis.*

In the subsequent section, the individual questions and hypotheses are presented and explained further.

Previous studies on the effectiveness of exercise therapy for PT have only looked at the effects of short or long-term outcomes during the therapy period (Lim & Wong, 2018). However, changes in physical (Bennell et al., 2012; Maffulli et al., 2011) and psychological (Nippert & Smith, 2008; Zafra et al., 2009) performance after injury, especially in adolescent athletes (Maffulli et al., 2009, 2010), last much longer than the initial recovery period. The question therefore arises as to whether future studies should also examine the effects after successful therapy, i.e. during the return to competition. Therefore, this thesis (STUDY I) investigates the differences in physical and psychological parameters in adolescent athletes after successful PT therapy compared to healthy athletes.

In terms of therapy approaches previous reviews have highlighted a large body of evidence for physical eccentric training but unclear results for other methods of exercise (Figueroa et al., 2016; Gaida & Cook, 2011; Larsson et al., 2012; Schwartz et al., 2015). Furthermore, it has been noted that previous studies mainly recommend monotherapy and rarely use combined therapies (Everhart et al., 2017). Therefore, a further aim of this dissertation (STUDY II) was to determine the current state of research on physical training to develop a rationale for further therapeutic approaches and research projects. These results were then incorporated into STUDY

III to combine several effective training methods into a novel multimodal exercise programme and to investigate its long-term outcomes.

3. Materials and methods

This section provides an overview of the material and methods used in the studies of this doctoral thesis. A summary is given of the literature search, the investigated participants, the testing procedures used, the applied tests and interventions as well as the used methods for data and statistical analyses. For further information on the individual aspects, please refer to the full-text studies shown in chapter 4.1.

3.1 Systematic literature search

As part of a systematic review and meta-analysis, a computer-assisted literature search was performed in the PubMed, Medline, and Web of Science databases to identify matching articles on therapeutic procedures for PT. The following Boolean search strategy was used: ("patellar OR patella") AND (tendinopathy OR tendinosis OR "tendon pain" OR tendinitis OR "jumpers knee" OR "jumper's knee") AND (treatment OR therapy OR exercise OR training)". The search was restricted to full-text availability, publication date (1 January 1960 to 31 July 2020), language (English), and type of article (no review). To identify other suitable results, the reference lists of the included articles were reviewed to include them in the analysis. The complete information on the systematic literature search can be found in the full text of STUDY II (cf. chapter 4.1).

3.2 Participants

All articles of this thesis included athletes who had patella overuse symptoms diagnosed with imaging or palpation technique. STUDY I compared male adolescent sub-elite football players who suffered from PT with symptom-free players (healthy controls = [HC]) of the same age and performance group. In STUDY III, two groups (i.e., subdivided into a conventional [CON] and alternative [ALT] group) of symptomatic players were compared. All participants and their parents were informed in advance about the testing protocols and interventions and gave their consent. Participating players were required to provide regular feedback on current pain levels. The Human Ethics Committee of the Faculty of Educational Sciences at the University of Duisburg-Essen gave its consent to conduct the studies. Further information on the participants can be found in the methods sections of the respective studies (cf. chapters 4.1 and 4.3).

3.3 Description of the study designs

Both, STUDY I and STUDY III used a longitudinal study design to assess physical, psychological, and injury-/pain-related parameters over the course of a competitive season. In both studies, players were tested at four time points (T1-T4). The tests were conducted at the start of the season (T1), six weeks (T2), 16 weeks (T3), and 20 weeks (T4) after the start of the season. STUDY I compared the performance of asymptomatic players after conventional PT therapy with HC. Before the first test, all players had to complete at least one pain-free full-load training session and also participate in the test procedures completely pain-free. STUDY III used an identical design, comparing two asymptomatic groups with PT, where the intervention group (ALT) completed a novel therapy programme and the control group (CON) completed the conventional therapy programme before the first test. Each player was tested at the end of the individual therapy period, which was also characterised by complete freedom from pain under a full training load.

3.4 Assessment of physical fitness parameters

In STUDY I and STUDY III, identical tests were used to collect data on physical fitness parameters in the order presented below with 10-minute rest periods between each test. These resulted in measures of cyclic and linear speed, muscle power, change-of-direction speed (CODS), as well as endurance, at the beginning of which a standardised warm-up protocol (i.e., 15 minutes of running, jumping, movement preparation, and acyclic speed exercises) was conducted. In the following, these procedures are presented individually and the conditions for their implementation are mentioned.

3.4.1 Assessment of cyclic and linear speed

To determine cyclic speed performance, the 15-s foot tapping test (FTT15) was used, for which moderate to near perfect (intraclass correlation coefficient [ICC] = 0.69–0.98) reliability has been reported (Krauss, 2010). Athletes were asked to stand barefoot on a gym floor within OptoJump® bars with their feet hip-width apart. Participants were instructed to make as many ground contacts as possible with both feet during the 15-s test procedure. As soon as the athlete took the first step, the measurement started and was performed in three trials with 60-s rest periods in between. From all trials, the highest frequency of taps by both was included in the further analysis. Tapping frequency (Hz) was identified and extracted as a relevant parameter for the research question of this test procedure, as it depends on the motor capabilities of the participant (Djuric-Jovicic et al., 2018) and, unlike the fatigue index, measures speed and not endurance.

Linear sprint performance was measured over a 30-m straight line distance using timing gates (Smartspeed Lite®, Fusion Sport, Brisbane, Australia), while split times were taken at 5 m and 10 m. A visual stimulus was used as a start signal and the test was conducted on an artificial grass surface in dry weather conditions in soccer shoes. Three trials with 60-s rest periods were performed with each participant individually and the best result (i.e., shortest time in seconds) was used for further analysis. For this test procedure, large to near-perfect ICC values of 0.80 (5 m), 0.87 (10 m), and 0.97 (30 m) were reported (Lockie et al., 2013).

3.4.2 Assessment of leg muscle power

The leg muscle power of the players was determined with the drop jump (DJ) and jump-and-reach (JaR) test on the gym floor (Menzel et al., 2010; Young et al., 2005). In the DJ, the players started in an upright position on a 40-cm-high box with their hands on their hips. After this initial position, players descended from the box with one leg, dropped and landed on both feet before directly performing a vertical jump. High reliability (i.e., ICC = 0.95) was reported for this test procedure (Markwick et al., 2015). Jump height (cm) was measured using OptoJump photocells (Microgate, Bolzano, Italy), a device consisting of two side-by-side rods connected to a laptop via OptoJump software.

During the JaR, which was clinically acceptable and had near-perfect reliability (ICC = 0.97) (Menzel et al., 2010), players stood in an upright position and were then asked to perform a maximum countermovement jump. Subjects were instructed to touch a scale attached to the wall in 0.5 cm increments for measurement purposes, leaving a mark with stamping ink at their maximum JaR height. The jump height (cm) was determined by subtracting the height (cm) of the reach while standing from the JaR height (cm). The standing jump height was determined to the nearest 0.5 cm.

All players were instructed to jump as high as possible (DJ, JaR) and to keep the ground contact as short as possible. Both jump tests were performed a total of five times (two practice attempts followed by three attempts for data collection), with the highest jump height used for further analysis. Breaks of ten minutes and 30 seconds were taken between the jump tests and the individual jump attempts, respectively.

3.4.3 Assessment of change-of-direction speed

Acyclic sprint (AS) time was measured using timing devices (Smartspeed Lite®, Fusion Sport, Brisbane, Australia). The design of the test is comparable to the modified agility T-test, which uses a shorter distance than the CODS test and shows high reliability (ICC = 0.95) (Sassi et al., 2009). In conducting the test, side steps were replaced by sprints, as side steps are less practically relevant in soccer than linear sprints (Rehhagel, 2011). The start was signalled by a visual stimulus and participants were instructed to run straight to the first cone (5- m distance), then change direction to the second cone (2.5-m distance) and run back the same way. The first attempt was performed with a change of direction to the left (AS left), while the second attempt involved a change of direction to the right (AS right). To standardise environmental variables, the test was conducted on an artificial turf pitch, in dry weather and soccer shoes. A total of six trials (three per direction) were performed with 60 seconds rest in between. For further data analysis, the fastest trial in seconds for each direction of movement was used.

3.4.4 Assessment of endurance

The Yo-Yo intermittent recovery test level 1 (YYIRL1) was used to determine soccer-specific endurance, which has excellent reliability (ICC = 0.84–0.98) and construct validity (non-sports vs. soccer players; $p \leq .016$, $d = -2.806$) in adolescent soccer players between 9 and 16 years of age (Póvoas et al., 2016). The test was performed on dry artificial turf in soccer shoes. The set-up consisted of 2 x 20-m sprints followed by 2 x 5-m recoveries, with the increase in speed signalled acoustically. Each 40-m distance was followed by a 10-m phase of active recovery in which the player jogged slowly for ten seconds. After missing the finish line twice within the allotted time, the test was stopped. The total distance (m) covered was measured.

3.5 Assessment of psychological parameters

The Achievement Motives Scale (AMS) Sport was used to identify psychological variables and measure changes during return to competition. The two components of the achievement motive "hope for success" and "fear of failure" were assessed using a questionnaire completed individually by the participants without further explanation. Each scale consists of 15 items, with the response scheme ranging from 1 (does not apply to me at all) to 4 (applies to me exactly). To calculate the net hope, the sum of the component "fear of failure" was subtracted from the sum of the component "hope of success" (Elbe et al., 2005).

3.6 Assessment of injury- and pain-related parameters

Pain-related parameters were assessed through continuous tracking of training data by the coaching and athletic staff of the participating clubs using a visual analogue scale (0–10). Injury-related characteristics were assessed including information on the incidence rate of contact and non-contact lower-extremity injuries, the period of injury-related rest and overall exposure time of soccer training and competition. Documentation was implemented through an online database (SoccerWeb, SoccerCollection oHG, Iserlohn, Germany), where any reports of injuries or pain-related training interruptions were recorded throughout the period of testing. The definition of an injury has been established as an injury sustained by a player during a training session or competition in the participating clubs that prevents him from participating fully in training or competition for at least one full day.

3.7 Interventions

One study in this doctoral thesis (i.e., STUDY III) conducted interventions during return to competition in male sub-elite youth soccer players, to compare a conventional (CON) with an alternative (ALT) therapy approach. The start of the interventions was scheduled for the end of the season in May. Up to this point, all players still participated in training and competitions in a pain-adapted manner. Players in both groups were instructed to continue with reduced-intensity soccer training consisting of soccer-specific dribbling and skill exercises at an average of 50% of the maximum heart rate reserve. This approach is based on the findings of Kongsgaard et al. (2009), according to which a limited amount of continued participation in sports allows for physical and psychological benefits in the process of returning to competition.

3.7.1 Conventional therapy programme

The CON intervention has been shown to be successful in previous studies (Everhart et al., 2017; Young et al., 2005). Part of it was an initial pain-related rest period (13.3 ± 4.1 days) that lasted until no pain was experienced during daily activities. The CON group then began unilateral eccentric leg squats (3 x 20 repetitions per leg) on a flat surface, followed by unilateral eccentric leg squats (3 x 20 repetitions per leg) on a decline board, both to a knee flexion of approximately 60°. The execution was supervised by a physiotherapist who also explained it to the subjects. The players were instructed to perform the eccentric phase of the squat with the symptomatic leg and the concentric phase with the asymptomatic leg. In addition, a static stretching exercise for quadriceps and hip flexors (3 x 60 s per leg) was carried out. Sessions were performed 2–3 times per week, lasted approximately 30 minutes and were supervised by a physiotherapist.

3.7.2 Alternative therapy programme

The ALT intervention was developed based on previous research (Breda et al., 2021; Kraemer & Knobloch, 2009; Millar et al., 2021; Reinking, 2016; Reneker et al., 2019) and experience in exercise and rehabilitation therapy, which was intended to combine different successful approaches. The ALT group performed the first exercises immediately on the day after diagnosis, regardless of whether pain occurred or not. Thus, there was no pain-related rest period. The therapy programme started with unilateral balance exercises (4 x 30 seconds per leg) on different unstable devices (Balance Pad, Balance Beam, SoftX coordination seesaw, Alcan Airex AG, Sins, Switzerland). After subjects felt confident balancing without any other difficulties such as juggling or kicking a soccer ball, unexpected perturbations were added to adapt the exercise to the specifics of the sport and simulate its activities (Reneker et al., 2019).

The strength training routine began with a bilateral eccentric hamstring exercise (4 x 10 repetitions) on a balance pad, followed by four sets each of 60-second unilateral isometric split squats and bilateral isometric sumo squats on various unstable equipment, both to a knee flexion of approximately 100°. For unilateral exercises, the asymptomatic leg was loaded first and the symptomatic leg second to promote neuromuscular adaptation (Carroll et al., 2006) and benefit from the principle of unilateral neural priming (Stoykov et al., 2017). Additional weights (dumbbells of 1–6 kg per hand or a barbell of 15 or 20 kg) were added if the subject performed the strengthening exercises without difficulty. The stretching programme began with a static stretch of the quadriceps and hip flexors (3 x 60 s per leg), followed by a static stretch of the hamstring (3 x 60 s per leg). These sessions were performed 3–4 times per week, lasted approximately 60 minutes, and were supervised by an athletic trainer.

3.8 Statistical analyses

To analyse the differences in physical and psychological parameters between the two groups (jumper's knee versus healthy controls), in STUDY I an univariate analysis of variance (ANOVA) was used to test for significant group differences at T1-T4.

To determine the effectiveness of physical training on physical and psychological parameters in STUDY II (systematic literature review and meta-analysis), the weighted standardized mean difference (*SMD* = (mean post-test value for the intervention [INT] group minus mean post-test value of the control [CON] group)/pooled variance) was calculated. If studies only stated median and range, or confidence intervals, they were converted to standard deviations according to the respective guidelines of Hozo et al. (2005) and the Cochrane Handbook of Systematic Reviews of Interventions (Deeks et al., 2019). According to Deeks et al. (2019), heterogeneity was classified as being either trivial ($0\% \leq I^2 \leq 40\%$), moderate ($30\% \leq I^2 \leq 60\%$), substantial ($50\% \leq I^2 \leq 90\%$), or considerable ($75\% \leq I^2 \leq 100\%$). The calculations and weighting for the systematic review with meta-analysis were made using a random-effects meta-analysis model provided by the Review Manager 5.3 software (version 5.3.5, The Nordic Cochrane Centre, Copenhagen, Denmark).

For STUDY III first, a univariate ANOVA was calculated to test for significant group differences at T1. Afterwards a 4 (test: T1, T2, T3 or T4) x 2 (group: ALT vs. CON) repeated measures ANOVA was performed at test (T1, T2, T3 or T4). Parameters that showed significant group differences at T1 were included as covariates in the model. In case of a significant test × group interaction effect, differences between the four-time points were analysed separately for each group using the simple main contrast method. For the injury- and pain-related outcome measures, group differences were calculated using univariate ANOVA.

In agreement with Cohen (1992), effect size values of $0 \leq d \leq 0.49$ indicate small, of $0.50 \leq d \leq 0.79$ indicate medium, and of $d \geq 0.80$ indicate large effects. Statistical analyses for STUDY I and III were performed using the Statistical Package for Social Sciences version 24.0 (IBM Corp., Armonk, NY, USA) and statistical significance was set at $p < 0.05$.

4. Main results

This chapter presents the main results collected in the studies of this PhD thesis. Figure 4 gives an overview of the studies and their results in relation to physical, psychological, and injury- /pain-related parameters.

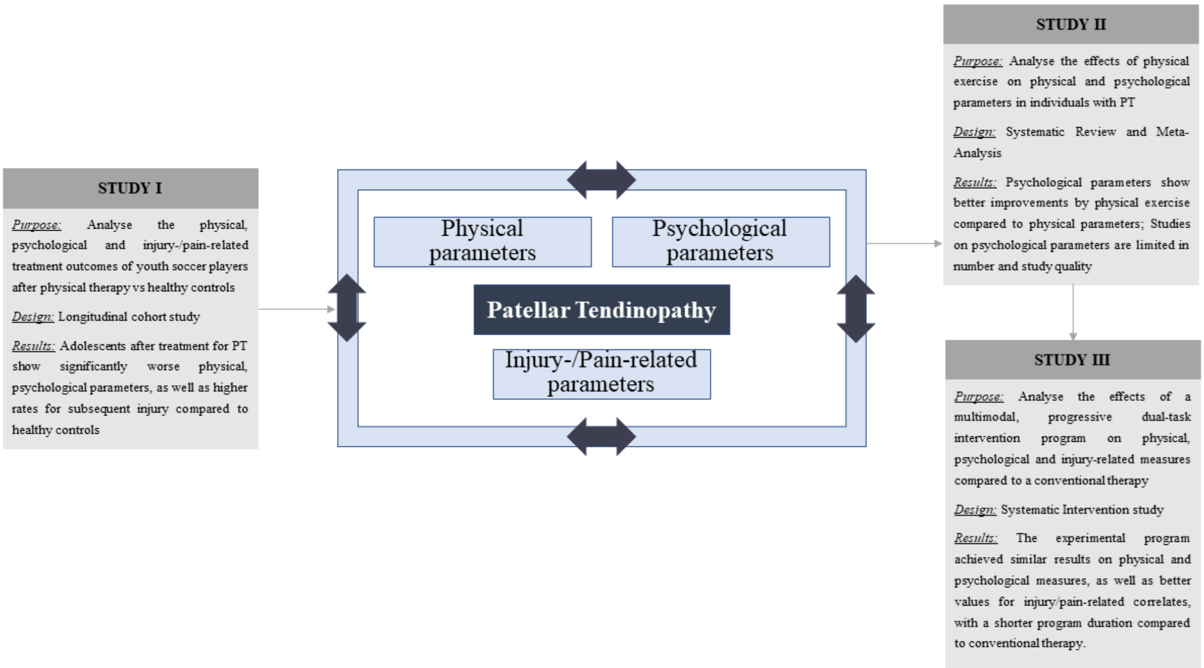

Figure 4. *Schematic illustration of the scientific approach of the doctoral thesis stating the most important results of the conducted studies.*

Details on the results of the studies conducted can be found in the following chapters 4.1–4.3, presenting their key aspects as well as the corresponding full-text articles.

4.1 STUDY I – "Differences in physical and psychological parameters in sub-elite, male, youth soccer players with jumper's knee following physical therapy compared to healthy controls: a longitudinal examination"

Purpose and hypothesis: The objective of STUDY I was to investigate differences in physical, psychological, and injury/pain-related parameters in male sub-elite youth soccer players who had previously undergone physiotherapy for PT (15.1 ± 0.8 years) compared to healthy controls (15.0 ± 1.0 years) over the course of one season. It was hypothesised that subjects with previous PT would have significantly worse physical and psychological performance, as well as higher levels of injury/pain-related variables over the course of a season, compared to healthy controls.

Results and conclusion: The PT group demonstrated significantly worse physical performance in change of direction speed (to the left: $1.37 \leq d \leq 1.51$; $p < 0.001$ / to the right: $1.24 \leq d \leq 1.53$; $p < 0.001$) and linear speed ($0.48 \leq d \leq 1.26$; $p < 0.007$) at the different testing sessions [T1-T4] compared to healthy controls. Furthermore, psychological parameters showed worse results in the PT group compared to the healthy control group, which showed a significant difference especially at T1 ($d = 0.65$; $p = 0.032$ / $d = 0.68$; $p = 0.027$) and T2 ($d = 0.50$; $p = 0.076$ / $d = 0.80$; $p = 0.012$). These results suggest that there are significant differences in the physical and psychological performance of youth football players after physiotherapy for those with PT compared to healthy controls. Therefore, the short-, medium-, and long-term effects of the injury should be considered when designing rehabilitation and/or training programmes, as well as when determining to return to sport.

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Original Research

Differences in Physical and Psychological Parameters in Sub-Elite, Male, Youth Soccer Players with Jumper's Knee Following Physical Therapy Compared to Healthy Controls: A Longitudinal Examination

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Keywords: young athletes, physical fitness, performance testing, patellar tendinosis/tendinitis/tendinopathy, movement system, adolescence

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Purpose/Background

Many adolescent athletes suffer from jumper's knee (JK) over a long period of time and return to sports before symptoms are fully resolved. Current treatment methods may not reduce pain in the short term, especially not during a competitive season. The purpose of this study was to investigate differences in physical, psychological, and injury-/pain-related parameters in sub-elite male youth soccer players, who previously underwent physical therapy for JK compared to healthy controls (HC) over the course of a season.

Methods

All subjects were tested four times (start of the season [T1], 6 [T2], 16 [T3], and 20 [T4] weeks after the start of the season). Outcome measures included muscle power (drop jump, jump-and-reach), change of direction speed [CODS] (acyclic sprint), speed (tapping, 30-m linear sprint), endurance (Yo-Yo intermittent recovery test level 1), the Achievement Motives Scale (AMS) Sport, and injury-/pain-related data. Univariate analysis of variance was used to compare differences in variables between the two groups over the course of a soccer season.

Results

Over the season, the jumper's knee group (JK; 15.1 ± 0.8 yr) demonstrated significantly worse physical performance in CODS (to the left side: 1.37 ⩽ Cohen's $d \leqslant 1.51$ [T1-T4]; $p < 0.001$ / to the right side: $1.24 \leqslant d \leqslant 1.53$ [T1-T4]; $p < 0.001$) and speed ($0.48 \leqslant d \leqslant 1.26$ [T1-T4]; $p < 0.007$) compared to healthy controls (HC; 15.0 ± 1.0 yr). Further, psychological parameters showed worse values in JK than in HC for the AMS Sport items "hope for success" and "fear of failure" that especially showed a significant difference at T1 ($d = 0.65$; $p = 0.032$ / $d = 0.68$; $p = 0.027$) and T2 ($d = 0.50$; $p = 0.076$ / $d = 0.80$; $p = 0.012$). Moreover, the JK group showed significantly higher incident rates for non-contact lower limb injuries ($d = 0.69$; $p = 0.049$) per 1,000 hours (i.e., practices/competitions), injury-related rest periods ($d = 2.06$; $p = 0.043$), and pain-related training interruptions ($d = 1.35$; $p < 0.001$).

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Conclusions

The observed findings imply that there are significant differences in physical and psychological performance of youth soccer players after physical therapy for JK compared to HC. When designing rehabilitation and/or training programs, as well as determining the point of return to sport the impact of the injury needs to be taken into account.

Level of Evidence:

1b

INTRODUCTION

Jumper's knee (JK), also referred to as patellar tendinopathy, is a functional overload injury that can occur after a time of intense and repeated stress to the patellar or quadriceps tendon.[1,2] Sports that involve a lot of jumping or abrupt stops can increase the risk for developing JK. Soccer, considered as an explosive start-stop sport, is considered one of the high-risk sports.[1] Epidemiological data show incident rates of JK of 13% in elite youth soccer players.[3] Male adolescents[4] aged 15 years or older[1] are commonly affected. Elite and sub-elite youth soccer players have to perform repetitive maximal, multidirectional movements over a long period of time with only little time to recover.[5] Although youth players have lower intensity of exercise and overall training volume in comparison to adult players, they have not reached their maximum physical and psychological capacity. Yet, they are required to perform high-intensity exercises and pressured to maintain a high level of performance during a competitive season,[6] which could ultimately lead to a higher risk of injury. The large amount of total training and competition can result in an increased risk of sustaining an injury of the lower-extremity, [7] most commonly in form of overuse injuries like JK.[8,9] In addition Kucera et al.[10] described a consistently decreasing rate of injuries with increasing soccer and league experience in youth soccer players, which also leads to the conclusion that younger athletes are more susceptible to injury than adults.

Injury downtime due to ongoing symptoms along with recurring pain, as well as decreased mental or physical performance, can affect the level of competitive success and thus may impede the progress of an athlete's career.[11] Given the prevalence and high risk of sustaining JK at the beginning of a young athlete's career, it is important to gather sufficient scientific data on performance changes that this injury results in. Previous studies[12–20] that examined differences in physical and psychological characteristics in athletes with JK compared to healthy controls (HC) revealed varying results. For example, a cross-sectional study by Lian et al.[13] showed a significantly better performance in vertical jump height for adult male volleyball players with JK (n=12, age: 23.6 ± 3.0 yr) in comparison with HC (n=12, age: 24.8 ± 4.6 yr). Siegmund et al.[21] reported no significant differences in jump height in adult male basketball players (n=12, age: 18-29 yr) with JK compared to HC (n=12, age: 18-29 yr). Lastly, Cook et al.[12] could not find a significant difference in jump height or 10-m sprint in affected (n=33, age: 14-18 yr) versus healthy (n=38, age: 14-18 yr) adolescent non-professional male basketball players. However, it is important to note that none of these studies compared subjects after a completed therapy to HC. Therefore, the final impact of JK on a youth athlete in the matter of physical performances following therapy has not been adequately reported upon in the current literature. Besides differences in physical performances, there is also evidence for discrepancies in psychological variables between injured and non-injured athletes. According to Nippert et al.,[19] increased levels of psychologic stress, fear of injury or low self-esteem following injury can result in lower sport performance. In this regard, Zafra et al.[20] compared psychological variables of injured tennis players with HC. They described a negative relationship between tendinitis and the influence of performance assessment as a psychological variable. Especially in players suffering from tendinitis, stress management during performance assessment was poor compared to HC.

In sum, the existing studies focus on varying attributes and do not look into the effects of JK on measures of physical and psychological performance in different dimensions of human performance, therefore not reflecting all the abilities required to perform physically demanding activities.[22] Furthermore, the described studies were limited by (i) relatively small sample sizes of N=7-19 athletes,[13,17,21] (ii) determining mostly physical but rarely psychological characteristics,[12–14,16–18,21,23] and (iii) studying adult but not adolescent players.[13,14,16–18,21,23] Moreover, previous studies have uniquely examined differences in physical[12–18] or psychological[20] performance in JK and HC. However, there is evidence that JK is an injury that affects an athlete over a longer period of time, varying from six months[4] to four years.[24] Therefore, a longitudinal approach was adopted in the present study in order to evaluate if the loss of performance could be observed only at the beginning of the season or if it also occured over the course of a season. Additionally, the occurrence of further injuries was considered because a lower level of physical[25,26] or psychological[27,28] performance measures is associated with an increased risk of injury.

The purpose of this study was to investigate differences in physical and psychological variables in a comparatively large sample (N=35) of sub-elite male youth soccer players, who previously underwent physical therapy for JK compared to HC over the course of a season. The authors hypothesized that subjects with previous JK would show significantly (i) worse physical and psychological performances and (ii) greater values of injury-/pain-related variables over the course of a season.

METHODS

PARTICIPANTS

Eighteen young sub-elite male soccer players, who previously underwent physical therapy for JK (*n*=18, age: 15.1 ± 0.8 yr, body mass: 60.5 ± 8.5 kg, body height: 170.7 ± 6.6 cm) and a group of 17 HC (*n*=17, age: 15.0 ± 1.0 yr, body mass: 62.9 ± 6.9 kg, body height: 170.0 ± 6.2 cm) participated in this study. The conventional therapy was conducted two to three times a week and was composed of unilateral eccentric squat exercises, as well as static quadriceps and hip flexor stretching. All subjects were originally examined by a physician and diagnosed with pain in the inferior pole of the patella or the proximal patellar tendon by palpation of the tendon and its attachments. An ultrasound was performed, and in cases where the tendon was classified as abnormal, a hypoechoic lesion and/or fusiform swelling was located in the proximal insertion of the patellar tendon. If neither of these pathological changes were evident the tendon was classified as being normal and therefore the subject excluded from the study. In addition, all included subjects reported pain during jumping exercises, as well as explosive stop-start movements at the time of the physical examination. Before entering the study, participants were familiarized with the testing protocol. Prior to each training session, participants were continuously questioned about their present level of pain using a visual analogue scale. The JK group was recruited from different soccer teams. At the beginning of the therapy program, the JK group was advised to maintain a pain-related rest period (13.3 ± 4.1 days) and to perform a limited training load during their period of therapy (58.2 ± 24.6 days). All subjects of the JK group had completed their therapy program and participated in at least one full team training session without experiencing pain in the week prior to the first testing for the current study. All participants were required to have at least four sessions of team practice per week and were questioned about their level of pain prior to each training session. Subjects were excluded if they had (i) surgical treatment in the last twelve months, (ii) any kind of other injury six weeks prior to the start of the study, (iii) any pain during full training load, or (iv) been originally diagnosed with patellofemoral pain syndrome, plica syndrome, Osgood-Schlatter, or Sinding-Larsen-Johansson syndrome. Furthermore, all participants were instructed to complete all tests without using any kind of pain medication, taping, or medical insoles and to discontinue testing immediately if any patellar pain occurred. Subjects were only allowed to participate in testing when no pain (visual analogue scale = 0) was present at the beginning of the test. The Human Ethics Committee at the University of Duisburg-Essen, Faculty of Educational Sciences approved the study protocol.

PROCEDURES

A longitudinal study design was used to assess physical, psychological, and injury-/pain-related parameters of both groups over the course of a competitive season. All athletes were tested four times (T1-T4) (Figure 1). The tests were conducted at start of the season (T1) as well as six weeks (T2), 16 weeks (T3), and 20 weeks (T4) after the start of the season. A variety of physical fitness tests were used, including 15-s foot tapping [FTT15], drop jump [DJ], jump-and-reach [JaR], acyclic sprint [AS], 30-m linear sprint, and Yo-Yo intermittent recovery test level 1 [YYIRL1]. All tests were performed on the same day in the order mentioned above and with 10-minutes rest periods between each test. A standardized warm-up protocol (i.e., 15-minutes of running, jumping, movement preparation, and change-of-direction speed [CODS] drills) was performed before the testing started. In addition, psychological variables were assessed using the Achievement Motives Scale (AMS) Sport[29] prior to the physical tests. Concerning injury- and pain-related characteristics, the incidence rate of lower extremity injuries and non-contact lower extremity injuries per 1,000 houtrs (i.e., practices/competitions) as well as the period of injury-related rest and the number of pain-related training interruptions were documented.

ASSESSMENT OF PHYSICAL PARAMETERS

MUSCLE POWER

DJ and JaR were used to determine players' muscle power.[30,31] Both jump tests were performed on a gym floor wearing athletic shoes. For the DJ test, the players stood in an upright position on a box (height: 40 cm), with their hands on their hips. They were instructed to step off the box with one leg, drop down, and land on both feet immediately followed by a maximal vertical jump. This test procedure has been reported to have a high reliability (ICC = 0.95).[32] Jump height was determined using OptoJump® photoelectric cells (Microgate, Bolzano, Italy), which were connected to a laptop using OptoJump® software. During the JaR, players stood in an upright position and were then asked to perform a maximal countermovement jump, which was clinically acceptable showing a nearly perfect reliability (ICC = 0.97).[30] Subjects were instructed to touch a scale marked in 0.5-cm increments for measurement purposes attached to the wall leaving a mark with stamp ink at their maximal JaR height. Jump height was assessed by subtracting standing reach height from JaR height. Standing reach height was determined to the nearest 0.5 cm. All players were instructed to jump as high as possible (DJ, JaR) and to keep ground contact as short as possible during DJ. Both jump tests were performed a total of five times (two practice trials followed by three trials for data collection), of which the greatest jump height value was used for further analysis. Breaks of ten minutes and 30 seconds were given between jump tests and single jump trials, respectively.

CHANGE OF DIRECTION SPEED

The AS time was measured using timing gates (Smartspeed Lite®, Fusion Sport, Brisbane, Australia). The setup of the test is comparable to that of the modified agility T-test, which uses a shorter distance than the CODS test and shows a high reliability (ICC = 0.95).[33] In the execution of the test, side-steps were replaced by sprints, because side-steps are less relevant in soccer than linear sprints.[34] After the start of a trial, which was signaled using a visual stimulus, participants were instructed to run straight to the first cone (5-m

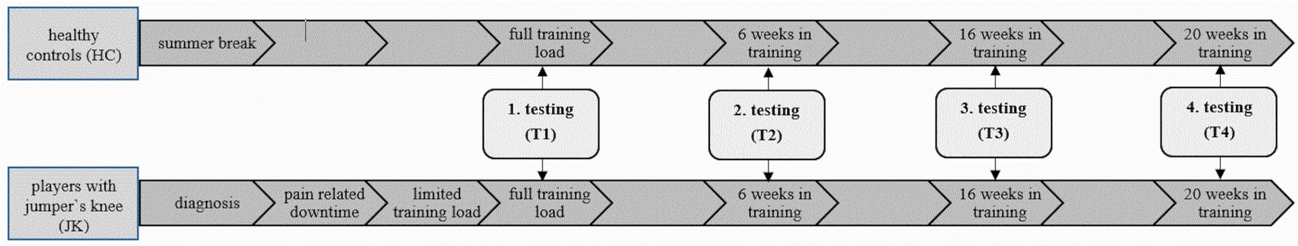

Figure 1. Schematic description of the longitudinal study design.

distance), then change direction to the second cone (2.5-m distance), and return the same way back. The first trial was performed with a change of direction to the left (AS left) while the second attempt included a directional change to the right (AS right). The test was performed on a surface with artificial grass in dry weather conditions wearing soccer shoes. A total of six trials (three per direction) were executed with 60-s breaks in between. Only the fastest trial for each direction of movement was used for data analysis.

SPEED

The FTT15 was used to assess cyclic speed performance and has been reported as moderate to nearly perfect (ICC = 0.69-0.98) regarding reliability.[35] The athletes stood barefoot on a gym floor within OptoJump® bars with their feet hip-width apart. Athletes were instructed to perform as many floor contacts as possible with both feet during 15 s. Measurement started with an athlete's first step. Three trials with 60-s rest periods in between were performed. Only the tapping frequency was assessed as it depends on a subject's motor capabilities,[36] thus representing a measure of speed whereas the fatigue-index is a measure of endurance. The trial with the highest frequency of taps of both legs combined was included in the analysis.

Sprinting performance was measured over a 30-m straight distance with interims at 5 m and 10 m using timing gates (Smartspeed Lite®, Fusion Sport, Brisbane, Australia). The start of a trial was signaled by a visual stimulus. The test was performed on an artificial grass surface in dry weather conditions wearing soccer shoes. Each athlete performed three trials with 60-s breaks between trials and the best result (i.e., shortest time) was used for further analysis. For this test procedure, large to near perfect ICC-values of 0.80 (5 m), 0.87 (10 m), and 0.97 (30 m) were reported.[37]

ENDURANCE

As previously described by Krustrup et al.,[38] the YYIRL1 was used to determine soccer-specific endurance and is described as a reliable test procedure for young athletes (ICC = 0.82-0.94).[39] The test consists of 2 x 20-m sprints alternated with 2 x 5-m recovery phases and was performed at increasing velocities on artificial grass in dry weather conditions wearing soccer shoes. The progressive increase in velocity as well as the allocated time to reach the finish line were signaled acoustically using a portable CD player (JVC, RVNB20W, Yokohama, Japan). Following each 40-m distance, the athlete had a 10-m phase of active rest lasting a total of 10 s during which he jogged slowly. Testing was terminated after an athlete failed to reach the finish line twice within the given time over the course of the entire test. The total distance (m) covered was measured and used for analysis.

ASSESSMENT OF PSYCHOLOGICAL PARAMETERS

The AMS Sport was used to determine differences in psychological variables between athletes. The two achievement motive components "hope for success score" and "fear of failure score" were assessed using a questionnaire, which was filled out by the participants individually and without further explanation. Each scale has 15 items, with an answering scheme ranging from 1 (not true for me at all) to 4 (exactly true for me). To calculate the net hope, the sum of the component "fear of failure" was subtracted from the sum of the component "hope for success".[29]

ASSESSMENT OF INJURY- AND PAIN-RELATED PARAMETERS

Injury- and pain-related characteristics were assessed through day-to-day tracking of data by the coaches and the athletic department of the participating clubs using a visual analogue scale (0-10). Any injuries or pain-related training interruptions were continuously documented using an online database (SoccerWeb, SoccerCollection oHG, Iserlohn, Germany). The operational definition of injury was an injury acquired during training or competition within the club that completely prevents the player from continuing soccer for at least one day.

STATISTICAL ANALYSES

Data are reported as means and standard deviations (SD) after normal distribution was confirmed by the Shapiro-Wilk test ($p > 0.05$). For each testing session, a univariate analysis of variance (ANOVA) was applied to analyze differences in physical and psychological parameters between the two groups. Further, effect sizes were calculated by converting partial eta-squared to Cohen's *d*.[40] Statistical analyses were conducted using SPSS version 24.0 (IBM Corp., Armonk, NY, USA). Statistical significance was set at $p < 0.05$.

RESULTS

Differences in physical fitness and psychological variables of sub-elite youth soccer players, who completed physical therapy after JK compared to HC across the season are presented in Table 1.

PHYSICAL PARAMETERS

The ANOVA revealed significantly lower levels of performance for the AS left (Δ 0.29-0.34 s; Δ2.5-6.5%; $p < 0.001$; $1.37 \leqslant d \leqslant 1.51$ [T1-T4]; Figure 2A), the AS right (Δ 0.28-0.35 s; Δ5.3-6.7%; $p \leqslant 0.001$; $1.24 \leqslant d \leqslant 1.53$ [T1-T4]; Figure 2B), and the 30-m linear sprint time (Δ 0.17-0.24 s; Δ3.8-5.4%; $0\ p \leqslant 0.007$; $0.48 \leqslant d \leqslant 1.26$ [T1-T4]; Figure 3) in players with previous JK compared to HC at each of the four testing timeframes. None of the other physical performance tests showed statistically significant differences at any of the four testing times.

PSYCHOLOGICAL PARAMETERS

At the start of the soccer season (T1; Δ-14.8%; $p = 0.009$; $d = 0.85$) and six weeks after (T2; Δ-17.2%; $p = 0.007$; $d = 0.89$), "net hope" was significantly lower in players with previous JK than in HC (Figure 4). Further, the ANOVA yielded significantly lower values for "hope for success" (Δ-2.5%; $p = 0.032$; $d = 0.65$) in players with previous JK compared to HC at T1 (Table 1). Lastly, significantly higher values for "fear of failure" occurred among players with previous JK as in HC at T1 (Δ97.9%; $p = 0.027$; $d = 0.68$) and T2 (Δ135.6%; $p = 0.012$; $d = 0.80$) (Table 1). No further differences were found in these variables for the remaining testing points.

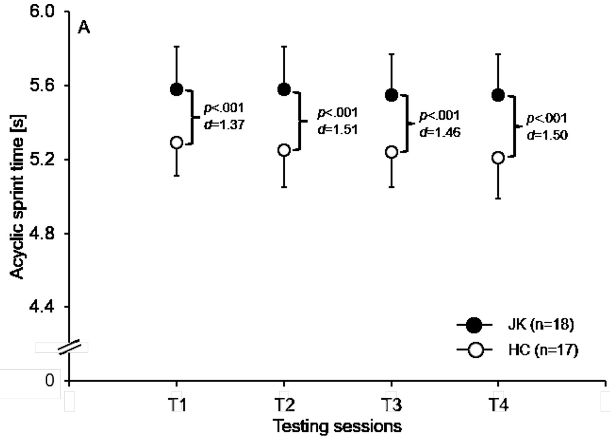

Figure 2A. Illustration of acyclic sprint time with first change to the left between soccer players after conventional therapy for jumper's knee (JK) compared to healthy controls (HC) over the course of the soccer season.

T1 = start of the season; T2 = 6 weeks after the start of the season; T3 = 16 weeks after the start of the season; T4 = 20 weeks after the start of the season.

Table 1. Differences in physical fitness and psychological variables of sub-elite male youth soccer players after conventional therapy for jumper's knee (JK) compared to healthy controls (HC) during the season. Values are presented as means with standard deviations in parentheses.

Variables	T1			T2			T3			T4		
	HC (*n*=17)	JK (*n*=18)	%; *p*-/*d*-value	HC (*n*=17)	JK (*n*=18)	%; *p*-/*d*-value	HC (*n*=17)	JK (*n*=18)	%; *p*-/*d*-value	HC (*n*=17)	JK (*n*=18)	%; *p*-/*d*-value
Physical parameters												
DJ height (cm)	30.6 (2.9)	30.8 (3.1)	0.7; 0.427/ 0.06	32.0 (3.2)	30.6 (3.5)	-4.4; 0.117/ 0.41	32.2 (3.4)	31.6 (4.0)	-1.9; 0.334/0.14	33.6 (3.2)	32.7 (4.4)	-2.7; 0.262/0.22
JaR height (cm)	48.9 (4.5)	50.1 (4.7)	2.5; 0.231/ 0.25	51.3 (4.0)	49.8 (4.6)	-2.9; 0.162/ 0.34	51.8 (4.3)	51.1 (4.6)	-1.4; 0.340/0.14	53.4 (4.6)	52.3 (5.1)	-2.1; 0.259/0.22
AS left (s)	5.29 (0.18)	5.58 (0.23)	2.5; <0.001/ 1.37	5.25 (0.20)	5.58 (0.23)	6.3; <0.001/ 1.51	5.24 (0.19)	5.55 (0.22)	5.9; <0.001/ 1.46	5.21 (0.22)	5.55 (0.22)	6.5; <0.001/ 1.50
AS right (s)	5.30 (0.19)	5.58 (0.24)	5.3; 0.001/ 1.24	5.27 (0.21)	5.57 (0.25)	5.7; 0.001/ 1.30	5.25 (0.19)	5.56 (0.23)	5.9; <0.001/ 1.47	5.19 (0.21)	5.54 (0.23)	6.7; <0.001/ 1.53
FTT15 (Hz)	5.94 (0.64)	6.00 (0.44)	1.0; 0.390/ 0.10	6.14 (0.63)	5.82 (0.44)	-5.2; 0.095/ 0.58	6.08 (0.65)	6.00 (0.41)	-1.3; 0.330/0.15	6.17 (0.60)	6.19 (0.40)	0.3; 0.449/ 0.04
5-m time (s)	1.23 (0.06)	1.21 (0.08)	-1.6; 0.271/ 0.21	1.20 (0.07)	1.22 (0.09)	1.7; 0.206/ 0.28	1.20 (0.08)	1.20 (0.07)	0; 0.453/ 0.04	1.18 (0.09)	1.20 (0.06)	1.7; 0.229/ 0.25
10-m time (s)	1.99 (0.08)	2.01 (0.10)	1.0; 0.247/ 0.23	1.97 (0.08)	2.02 (0.14)	2.5; 0.092/ 0.46	1.97 (0.07)	2.00 (0.09)	1.5; 0.184/ 0.31	1.92 (0.08)	1.97 (0.08)	2.6; 0.051/ 0.57
30-m time (s)	4.51 (0.15)	4.68 (0.22)	3.8; 0.007/ 0.89	4.49 (0.15)	4.70 (0.23)	4.7; 0.003/ 0.48	4.50 (0.17)	4.73 (0.21)	5.1; 0.002/ 1.12	4.44 (0.14)	4.68 (0.23)	5.4; 0.001/ 1.26
YYIRL1 (m)	2,018 (302)	1,892 (355)	-3.8; 0.135/ 0.38	2,096 (336)	2,044 (441)	-2.5; 0.349/ 0.13	2,298 (425)	2,192 (347)	-4.6; 0.216/0.27	2,186 (481)	2,336 (323)	6.9; 0.152/ 0.35
Psychological parameters												
Net hope (pt)	39.1 (6.1)	33.3 (7.2)	-14.8; 0.009/0.85	39.5 (6.6)	32.7 (8.5)	-17.2; 0.007/0.89	38.7 (7.8)	36.8 (7.7)	-4.9; 0.247/0.23	39.7 (7.0)	36.9 (8.5)	-7.1; 0.147/0.36
Hope for success (pt)	43.9 (1.3)	42.8 (1.9)	-2.5; 0.032/ 0.65	44.0 (1.1)	43.2 (1.9)	-1.8; 0.076/ 0.50	43.8 (1.8)	43.4 (2.1)	-0.9; 0.291/0.19	44.2 (1.0)	43.4 (2.1)	-1.8; 0.075/0.50
Fear of failure (pt)	4.8 (6.1)	9.5 (7.5)	97.9; 0.027/ 0.68	4.5 (6.3)	10.6 (8.5)	135.6; 0.012/0.80	5.1 (6.7)	6.6 (7.3)	29.4; 0.273/0.21	4.5 (6.5)	6.5 (7.5)	44.4; 0.207/0.28

AS left = acyclic sprint with first change of direction to the left; AS right = acyclic sprint with first change of direction to the right; DJ = drop jump; FTT15 = 15-s foot tapping test; JaR = jump and reach test; T1 = start of the season; T2 = 6 weeks after the start of the season; T3 =

16 weeks after the start of the season; T4 = 20 weeks after the start of the season; YYIRL1 = Yo-Yo intermittent recovery test level 1.
The percentage value indicates the mean difference between groups by measurement date. The *p*-value indicates statistical significance between groups by measurement date. The *d*-value means Cohen's *d* effect size with $0 \leqslant d \leqslant 0.49$ indicating small, $0.50 \leqslant d \leqslant 0.79$ indicating medium, and $d \geqslant 0.80$ indicating large effects.

Table 2. Differences in exposure time, lower limb injury incidence, injury-related rest period, and pain-related training interruptions of sub-elite male youth soccer players after conventional therapy for jumper's knee (JK) compared to healthy controls (HC) during the season. Values are presented as means with standard deviations in parentheses.

Variables	HC (*n*=17)	JK (*n*=18)	*p*- and *d*-values
Exposure time (hours)	8,927.4 (1,910.9)	8,616.4 (2,335.0)	$p = 0.335$; $d = 0.23$
All injuries (incidence rate per 1,000 h)	7.90 (14.49)	10.65 (14.57)	$p = 0.580$; $d = 0.19$
Non-contact injuries (incidence rate per 1,000 h)	1.92 (3.07)	6.65 (9.07)	$p = 0.049$; $d = 0.69$
Period of injury-related rest (hours)	3.71 (6.45)	18.17 (33.1)	$p = 0.043$; $d = 2.06$
Pain-related training interruptions (number)	0	1.3 (1.3)	$p < 0.001$; $d = 1.35$

The *p*-value indicates statistical significance between groups by measurement date. The d-value means Cohen's *d* effect size with $0 \leqslant d \leqslant 0.49$ indicating small, $0.50 \leqslant d \leqslant 0.79$ indicating medium, and $d \geqslant 0.80$ indicating large effects.

INJURY- AND PAIN-RELATED PARAMETERS

Differences in exposure time and injury-/pain-related variables between players with a history of JK and HC across the season are shown in Table 2. In terms of exposure time and incidence rate incorporating all injuries, the ANOVA showed no significant differences. However, significantly higher values for incidence for non-contact lower extremity injury ($p = 0.049$; $d = 0.69$), period of injury-related rest ($p = 0.043$; $d = 2.06$), and pain-related training interruptions ($p < 0.001$; $d = 1.35$) were found in players with previous JK compared to the HC over the course of the season.

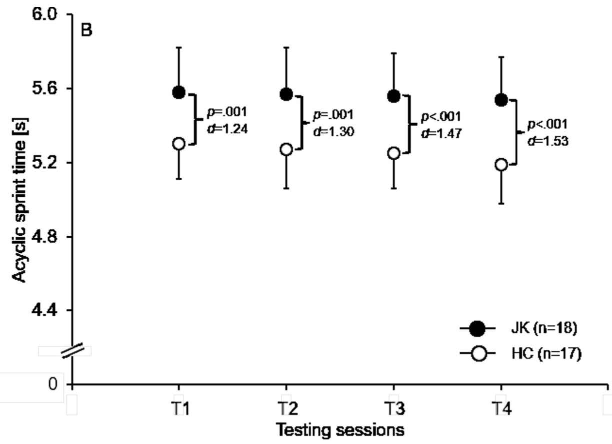

Figure 2B. Illustration of acyclic sprint time with first change to the right between soccer players after conventional therapy for jumper's knee (JK) compared to healthy controls (HC) over the course of the soccer season.

T1 = start of the season; T2 = 6 weeks after the start of the season; T3 = 16 weeks after the start of the season; T4 = 20 weeks after the start of the season.

DISCUSSION

To the authors' knowledge, few studies have examined differences in physical, psychological, and injury-/pain-related variables over the course of a season between sub-elite male youth soccer players, who previously underwent physical therapy for JK versus HC. The main findings of this study revealed that players with a history of JK, in comparison to HC, have (i) significantly worse physical fitness values for measures of CODS (acyclic sprint time) and speed (30-m linear sprint time) at all four testing times, (ii) significantly worse values in psychological variables (i.e., net hope, hope for success, fear of failure) in the first two testing sessions after zero and six weeks (T1 and T2), (iii) no significant differences in muscle power (DJ and JaR) and endurance (YYIRL1), and (iv) significantly higher values for non-contact lower limb injuries, injury-related rest period, and pain-related training interruptions over the course of a competitive season. In addition to the *p*-value (indicator for statistical significance), the *d*-value was also quantified, which is used to determine whether a difference is of clinical relevance. According to Cohen[40], the *d*-value can be classified as small ($0 \leqslant d \leqslant 0.49$), medium ($0.50 \leqslant d \leqslant 0.79$), and large ($d \geqslant 0.80$). All of the detected significant differences in physical, psychological, and injury-/pain-related performance, can be considered as medium to large clinical relevance.

DIFFERENCES IN PHYSICAL VARIABLES ACROSS THE SEASON

Differences in the level of physical performance were found at all four testing times measuring CODS and speed that concur with the initial hypothesis, suggesting that subjects with previous JK will show significantly worse physical performances over the course of a season. More specifically, acyclic sprint time (CODS) and 30-m linear sprint time (speed) were significantly worse in soccer players with previous JK compared to HC at all times of data collection covering a range of 20 weeks. This was supported by medium to large effect sizes (AS left: d = 1.37-1.50 / AS right: d = 1.24-1.53 / 30-m linear sprint: 0.48-1.26) indicating a real difference in performance. The present study highlights a difference in CODS performance between the two groups. The largest difference between JK and HC was observed at the last testing (AS left: $p < 0.001$; $d = 1.51$ / AS right: $p \leqslant$

0.001; d = 1.53), which means JK (AS left / AS right: 2.7 m/s) is on average 0.98 m behind HC (AS left / AS right: 2.9 m/s), when HC crosses the finish line. Similarly, HC (6.7 m/s) performed better than JK (6.4 m/s) in 30-m linear sprint (p < 0.007; d = 1.26), so that JK were 1.62 m behind HC. Under consideration of performance during competition these differences in velocity may decide which player takes possession of the ball first and therefore takes control of the game. This finding is partially in accordance with that of previous studies as some of them also reported lower physical performance levels in athletes with JK than in HC.[14,17,41] Others, however revealed higher levels of performance[15] or found no significant performance difference.[12,18] For example, Bisseling et al.[42] reported lower eccentric muscle activity and a stiffer landing strategy in asymptomatic subjects with previous JK performing DJ compared to HC. They interpreted their findings as a consequence of the persistent presence of pain associated with jumping exercises during their previous JK injury. Lower CODS and speed performances for athletes who previously underwent treatment for JK compared to their healthy counterparts may be explained by the greater tensorial stress occurring during the acyclic and linear sprint tests. The CODS test used in this study included directional changes at high velocities and multiple high impact stops. Furthermore, the athletes had to perform almost full unilateral knee extensions during the change of direction, which could have led to a higher tendon stress[3] and forced the patella to provide 31% of total knee extension torque[43], thus impairing performance in athletes recovering from JK. Moreover, a previous study[42] examining athletes after completing JK therapy associated tendon stiffness with lower performance in high-velocity movements, which could also help to interpret these findings. From a practical perspective, a reduction of physical performance regarding CODS and speed suggests a specific emphasis of these components during testing and training of athletes with previous JK. In other words, assessments of CODS and speed should be incorporated in return to play guidelines for JK by carefully introducing CODS and speed exercises in post-rehabilitation training routines.

The findings of differences in physical performance were limited to parameters of CODS and speed. However, measurements of muscle power (i.e., DJ and JaR) and endurance (i.e., YYIRL1) were not significantly different between the two groups of players. This suggests that some components of performance (i.e., CODS, speed) seem to be more susceptible to a loss in performance due to patellar tendinosis/tendinitis/tendinopathy in youth athletes than others (i.e., muscle power, endurance). Since there are no prior studies that have measured CODS and speed post-rehabilitation, only speculative assumptions can be made of its causes. Dauty et al.[44] measured a deficit in knee extension torque in players with symptomatic JK compared to HC using isokinetic tests. Assuming this deficit is persistent in subjects who completed rehabilitation after JK, this may be the cause of poorer performance in CODS and speed. Furthermore, a lower sensitivity of the applied jump (i.e., DJ and JaR) and endurance (i.e., YYIRL1) tests in the detection of JK-related changes in physical performance could be another reason for the lack of discrepancies between JK and HC. Further research should consider the inclusion of a wider range

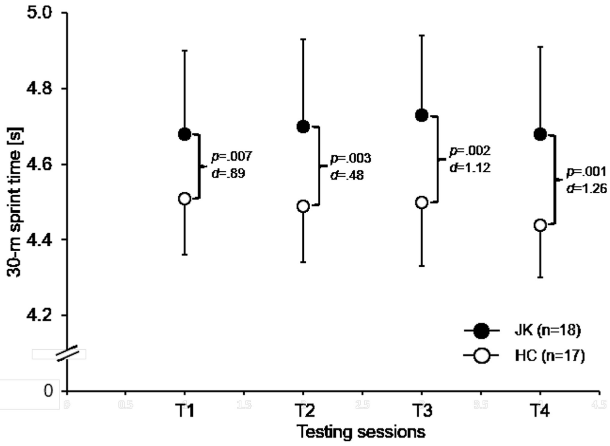

Figure 3. Illustration of 30-m linear sprint time between soccer after conventional therapy for jumper's knee (JK) compared to healthy controls (HC) over the course of the soccer season.

T1 = start of the season; T2 = 6 weeks after the start of the season; T3 = 16 weeks after the start of the season; T4 = 20 weeks after the start of the season.

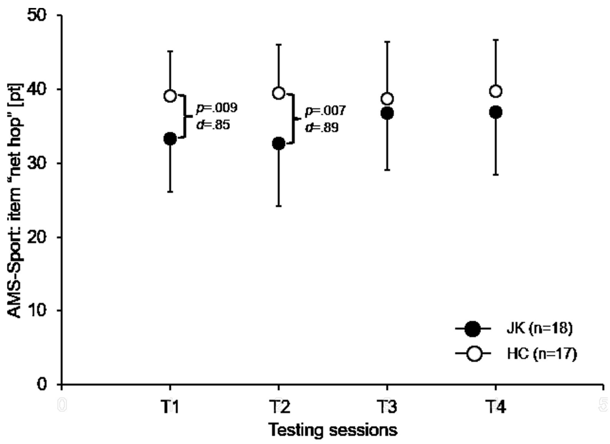

Figure 4. Illustration of "net hope" (item of the Achievement Motives Scale [AMS] Sport) between soccer players after conventional therapy for jumper's knee (JK) compared to healthy controls (HC) over the course of the soccer season.

T1 = start of the season; T2 = 6 weeks after the start of the season; T3 = 16 weeks after the start of the season; T4 = 20 weeks after the start of the season.

of high-speed activities in the test procedures, such as the cutting maneuver test[45] or repeated-shuttle-sprint ability test.[46] We could not confirm significant differences between JK and HC in muscle power, whereby the therapy routine of JK, focusing solely on strength training rather than high velocity exercises, could provide an explanation. When interpreting the lack of significant differences in endurance, we should also consider the fact that the JK group had a long period of limited training load during their period of therapy (58.2 ± 24.6 days), involving mostly low velocity technique and endurance training. Therefore, further research is needed to reveal whether these measurements of muscle power and endurance are less sensitive in detecting differences in physical performance in youth soccer players with a history of JK compared to those of CODS and speed.

DIFFERENCES IN PSYCHOLOGICAL VARIABLES ACROSS THE SEASON

In accordance to the initial hypothesis of worse psychological performance values over the course of a season, significantly worse values in the parameters net hope, hope for success, and fear of failure were found in soccer players with previous JK than in HC. The low score of JK in "hope for success" shows the athlete's fundamental insecurity in facing and mastering an athletic challenge, or in other words the capability believing in his own physical abilities. A significantly higher score in "fear of failure" of JK compared to HC suggests an increased anxiety of failing in competition or not being able to perform certain movement skills. The criteria "fear of failure" and „hope for success" only showed significantly different scores at the first two testing sessions (i.e., start of the season and six weeks thereafter) and disagree with the finding of Elbe et al.[29] who stated that the factors of the AMS Sport are consistent within a subject's life and do not change under any circumstances. The effect sizes of the first two testing times (net hope: d = 0.85-0.89 [T1 and T2] / hope for success: d = 0.50-0.65 [T1 and T2] / fear of failure: d = 0.68-0.80 [T1 and T2]) indicate that the injury had a strong negative impact on the participants. Johnston et al.[47] revealed similar difficulties of athletes in their qualitative analysis with competitive athletes. According to Johnston and colleagues, the athletes' lower performance after injury was associated with lower sport confidence, which was related to a fear of injury or recurrent injury. This fear of injury presented as being hesitant, holding back, not giving 100% effort or being wary of injury-provoking situations.[47] Most likely, athletes underestimated the impact of JK on their physical performance even after treatment had been completed and therefore were not able to cope well with these new circumstances. Moreover, it may be speculated, that the sport coaches did not appropriately progress them into physical activity and had them take on higher training loads and intensity too soon. Gould et al.[48] found that athletes returning after a severe injury identified their lower performance in competition as a source of stress and frustration. An explanation for the lack of significant differences between JK and HC at the two last points of data collecting (i.e., 16 and 20 weeks after the start of the season) may be that athletes had regained confidence in their physical capabilities after realizing that the symptoms were not reoccurring despite performing high-intensity exercises. This theory can be supported by the findings of Smith et al.[49] who measured higher levels of anger and depression after injury, but also reported a swift improvement when the subject approaches full recovery. Thus, it is important to focus on improvements in the process of rehabilitation. Zafra et al.[20] showed a relationship between psychological variables and injuries in tennis players. Especially players with tendinitis showed a significant relationship between a higher number of injuries and lower score in motivation.[20] As a consequence, these findings should lead to further research on the impact of injuries and rehabilitation methods on psychological variables of athletes. For example, psychological counseling and the verification of its effects on psychological and physical parameters could be a field of interest. Moreover, optimizing physical recovery in form of holistic treatment procedures to secure the athletes' belief in their own movement abilities could be another point of interest.

DIFFERENCES IN INJURY- AND PAIN-RELATED CORRELATES

This study showed significantly higher values of non-contact lower extremity injuries, injury-related rest periods, and pain-related training interruptions for soccer players with a history of JK compared to HC over the course of the season. The higher incidence rate of non-contact lower limb injuries may be attributed to the pain-related rest period and limited training load during therapy. It is likely that the subjects' muscle structure and overall physical fitness did not yet adapt to the requirements of competitive sports after only one full load training session. Therefore, it is possible that the players' training intensity was increased too soon. Although Le Gall et al.[50] showed only a few percent (n=29, 7.8%) of the players suffering from tendinopathy. In light of our study's findings this could also lead to the conclusion that players with JK post-rehabilitation are also more susceptible to injuries during competition than HC. In another prospective cohort study, Kucera et al.[10] described a positive association between previous injury and injury incidence in youth soccer players. Participants without previous injuries (2.5 per 1,000 h) showed a significantly lower injury incidence rate than those with two or more injuries (6.9 per 1,000 h). In relation to Table 2, the findings of the present study are in keeping with this report. The longer period of injury-related rest and the greater number of pain-related training interruptions may be indicative of an insufficient rehabilitation procedure. On a professional level, a successful rehabilitation should not only aim for the athlete to be game ready in general, but also rectify any abnormalities that led to the injury in the first place. A further reason might be that regular training and competition were resumed too early. Large effect sizes of d = 2.06 (injury related rest period) and d = 1.35 (pain-related training interruptions) are indicative of clinical meaningfulness and therefore suggest a high impact on the players return-to-competition process. Consequently, further research is necessary to investigate the effectiveness of conventional rehabilitation versus alternative programs targeted for athletes with the diagnosis of JK.

This study design has some limitations that should be considered when interpreting the results. For example, it would be of interest for further studies to measure knee extension torque in order to compare the results provided with recent studies measuring similar performance parameters. Furthermore, a measurement of baseline samples prior to the completion of therapy would provide a considerable amount of data to preclude any mistakes made by coaches or therapists during rehabilitation. Especially, isokinetic strength testing protocols should be added in further studies to combine sport specific tests outside of clinical settings with a more clinical evaluation of muscle strength parameters.

CONCLUSIONS

Differences in physical, psychological, and injury-/pain-related parameters in sub-elite male youth soccer players, who completed physical therapy after JK compared to HC were investigated over the course of a season. The results indicate significantly worse physical (i.e., for measures of CODS and speed) and psychological (e.g., hope for success, fear of failure) performance variables at the expense of players with previous JK, which indicate a specific significance of these components during rehabilitation and training interventions. Moreover, the higher incidence rate of non-contact lower extremity injuries, the longer periods of injury-related rest, and the higher number of pain-related training interruptions in athletes with a history of JK as in HC may be indicative of insufficient rehabilitation and/or training procedures. Thus, further research is required to determine the effectiveness of rehabilitation/training programs that counteract JK-related performance decrements accompanied with an adequate specification of the return to sport.

CONFLICT OF INTEREST

Marc Niering and Thomas Muehlbauer declare that they have no conflict of interest.

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STUDY II – "Effects of physical training on physical and psychological parameters in individuals with patella tendinopathy: a systematic review and meta-analysis"

Purpose and hypothesis: The aim of STUDY II was to investigate the effects of physical exercise interventions on physical and psychological parameters of subjects with PT. It was hypothesised that eccentric and isometric training protocols are superior to other treatment methods.

Results and conclusion: Eleven studies that investigated the effects of physical exercise on physical or psychological parameters were included in the analysis. Compared to other therapy methods, the mainly eccentric strengthening programmes illustrated better effects on symptom severity (*SMD* = 0.12) and pain intensity (*SMD* = 0.61), but worse effects on muscle power (*SMD* = -0.05). Both the general number of studies that investigated psychological parameters and the methodological quality of the included studies were very low. Furthermore, none of the studies investigated the effects of the respective therapy methods on subsequent injuries. The results show that current methods of exercise therapy improve symptom severity and pain intensity, but not physical performance, indicating a need for new intervention approaches, particularly in competitive sports.

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* Note: This erratum was necessary because the condition was incorrectly referred to as patella tendon myopathy, which was added by the editor shortly before publication.

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MDPI

Review

Effects of Physical Training on Physical and Psychological Parameters in Individuals with Patella Tendinopathy: A Systematic Review and Meta-Analysis

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Abstract: The effectiveness of physical training on physical and psychological parameters in individuals with patella tendinopathy has not been investigated in a systematic review and meta-analysis. The aim of the present study was to determine the effects of physical exercise interventions for measures of physical and psychological performance in subjects with patella tendinopathy. A computerised systematic literature search was conducted in the electronic databases PubMed, Medline, and Web of Science from January 1960 to July 2020. Initially, 506 articles were identified for review of which eleven articles met the inclusion criteria. Our results revealed a small effect (weighted mean standardized mean difference (SMD) = 0.12; nine studies) of physical training on the psychological measure Victorian Institute of Sport Assessment–Patellar tendon scale and a medium effect (weighted mean SMD = 0.61; five studies) on the psychological measure visual analogue scale—both in favour of the intervention group. In contrast, a small effect (weighted mean SMD = −0.05; two studies) in favour of the control group was detected for the physical measure muscle power. Compared to the control condition, physical training seems to be an effective means to improve psychological but not physical parameters in individuals with patella tendinopathy; although conclusions on the latter could have been biased by the small amount of eligible studies ($n = 2$). In addition, the predetermined cut-off value of ≥6 for the Physiotherapy Evidence Database scale score (i.e., assessment of methodological quality) was only achieved by six out of eleven studies. Thus, further research of high methodological quality is needed to verify whether there is or is not an effect of physical training on physical parameters in persons with patella tendinopathy.

Keywords: patellar tendinosis; tendinitis; tendinopathy; athletes; physical fitness; intervention

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1. Introduction

Overuse injuries affect adolescent athletes with incidence rates up to 50% [1]. Patella tendinopathy, also known as jumper's knee (JK), is a common overload injury that is frequently observed in young athletes performing high-impact jumping sports, such as soccer, volleyball, or basketball [2–4]. Compared to other common injuries (e.g., anterior cruciate ligament lesions), the prevalence of patella tendinopathy is relatively high affecting approximately 31.9% of basketball players and 44.6% in volleyball players [5], which underlines the relevance of this injury among common sports. Especially within a competitive season, during which athletes are under constant pressure to perform on a high level, treatment of patella tendinopathy can be challenging [6]. Male athletes are affected twice as often as females [7]. Age does not play a significant role with regard to the presentation of symptoms [3].

A variety of extrinsic (e.g., high tendon loads due to exercise or short recovery periods after mechanical overload) and intrinsic factors (e.g., malalignment, muscular tightness, imbalance) have been shown to cause patella tendinopathy [8]. Direct medical expenses of patients with tendinopathy are around £20,000 to £30,000 (currency in 2015) and are comparable to the medical expenses of osteoarthritis and osteoporosis (currency in 2005 and 2004, respectively) [9]. Recent literature reports a loss of work ability by 16%, as well as a 36% decrease in productivity in patients with patellar tendinopathy [10], both adding to the indirect medical costs.

Several treatment options aim to reduce pain related to patella tendinopathy. Apart from surgical interventions, dry needling, extracorporeal shockwave therapy, and a wide range of physical exercise interventions, which have proven useful in the reduction of pain and symptoms, are available. Pain relief interventions using physical training present many benefits for patients. Exercises that improve symptoms of patella tendinopathy and prevent consequential trauma can be practiced with lower pain intensity, therefore improving execution of these exercise [11]. More specifically, eccentric muscle strengthening has proven to be particularly effective when performed on a declined surface [12,13]. Also, a heavy slow resistance training program showed a significant reduction of tendon stiffness and similar effects in treating patella tendinopathy [14]. The main effects of the aforementioned exercise therapies are a reduction in pain with and without stress on the tendon, as well as improved athletic ability, in particular jump height. However, the current literature is sparse with regard to psychological parameters, although pain relief after a long period of injury-related downtime often correlates with higher motivation in sports and everyday activities. The aim of this systematic review and meta-analysis was to determine the effects of physical training on physical and psychological parameters in individuals with patella tendinopathy. Due to the high prevalence of patella tendinopathy in adolescent athletes in particular [4], it is of utmost importance to measure the effectiveness of physical exercise on both outcome categories. More precisely, there is evidence that better values in physical and psychological parameters have an impact on athletes' performance during exercise and competition [15,16].

2. Methods

In the present study, we followed the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement guidelines (see Supplementary Table S1) [17].

2.1. Literature Search

The authors performed a systematic computerised literature search in PubMed, Medline, and Web of Science using the following Boolean search strategy: "(patellar OR patella) AND (tendinopathy OR tendinosis OR "tendon pain" OR tendinitis OR "jumpers knee" OR "jumper´s knee") AND (treatment OR therapy OR exercise OR training)". In addition, the search was limited to the following: full-text availability, publication dates: 1 January 1960 to 31 July 2020, language: English, article type: no review. Moreover, the reference lists of the included articles were screened to identify other suitable studies for inclusion in our analysis.

2.2. Selection Criteria

We considered studies to be eligible for inclusion in our review if they provided enough relevant information with regard to the PICOS (Population, Interventions, Comparators, Outcomes, Study design) approach. For eligibility, we used the following criteria: (a) Population: participants with a diagnosed (by imaging or palpation technique) patellar overuse injury; (b) Intervention: physical training protocols comprising eccentric, concentric, or isometric strength training; (c) Comparator: active or passive control group (i.e., different physical intervention, no training at all); (d) Outcome: at least one measure of physical or psychological performance; (e) Study design: controlled trials with pre- and post-measures. The exclusion criteria were as follows: (a) participants were not diagnosed by a health professional; (b) intervention was not exercise-based (i.e., ultrasound, injection, dry needling, shockwave); (c) reported data did not allow for calculation (i.e., no central tendency and dispersion measure in the results section or upon request); (d) effects were examined without control condition; (e) assessments did not include a physical or psychological outcome measure; (f) cross-sectional study design. Two independent reviewers (MN, TM) assessed the eligibility of the relevant papers by analysing titles, abstracts, and full texts of the respective articles.

2.3. Study Coding

The included studies were coded for the variables listed in Table 1. In our analyses, we focused on different categories of outcome measures. If an eligible article reported multiple variables within one of these categories, we prioritized the most commonly reported outcome for each category in order to reduce heterogeneity between studies. In the case that a study included only similar, but not identical, tests, we selected the test that seemed most relevant with regard to physical or psychological performance outcomes. Jump and reach tests as well as countermovement jumps (with/without use of arms) were considered to be the most important variables of muscle power. Validity and reliability have been shown for both tests [18,19]. Pain at rest was evaluated using the Victorian Institute of Sport Assessment—Patellar tendon (VISA-P) scale or the Visual Analogue Scale (VAS) scale score, whereas pain during exercise was measured using pain during single leg decline squat (SLDS). Validity and reliability have previously been shown for the VISA-P [20], the VAS [21], and the SLDS [22]. Further, we considered the use of training equipment, different types of exercises, the use of closed or open kinetic chain, and the type of underground used. Treatment modality was coded according to the following parameters: training weeks/sessions, number of sets, number of repetitions, exercise duration, and training intensity. If the considered studies did not disclose relevant results, the authors were contacted via email [23–27]. When authors failed to respond to our request, or the requested data was no longer available [24,25], we excluded the respective outcome measure.

2.4. Assessment of Methodological Study Quality

The Physiotherapy Evidence Database (PEDro) scale was used to assess the methodological quality of all eligible studies, as well as to quantify the risk of potential bias. The PEDro scale rates internal study validity and the presence of statistical replicable information on a scale from 0 to 10, with $\geq$6 representing a cut-off score for studies of high quality [28]. Two independent reviewers (MN, TM) assessed the quality of the included studies.

2.5. Statistical Analyses

To determine the effectiveness of physical training on physical and psychological parameters in individuals with patella tendinopathy, we calculated the weighted standardized mean difference (SMD = (mean post-test value for the intervention [INT] group minus mean post-test value of the control [CON] group)/pooled variance) using a random-effects meta-analysis model provided by the Review Manager 5.3 software (version 5.3.5, The Nordic Cochrane Centre, Copenhagen, Denmark). From nine studies [14,25–27,29–33] that only reported the median and range, we calculated the mean and the standard deviation, in agreement with Hozo et al. [34]. For another study [35] that only stated confidence intervals, we used the formula provided in the Cochrane Handbook of Systematic Reviews of Interventions [36] to calculate the standard deviations. The weighting of the included studies was also performed with the help of Review Manager 5.3 software. In accordance to Cohen, effect size values of $0 \leq 0.49$ indicate small, of $0.50 \leq 0.79$ indicate medium, and of $\geq$0.80 indicate large effects. In addition, I^2 statistics was used to assess heterogeneity between studies. In agreement with Deeks et al. [37], heterogeneity can be classified as being either trivial ($0\% \leq I^2 \leq 40\%$), moderate ($30\% \leq I^2 \leq 60\%$), substantial ($50\% \leq I^2 \leq 90\%$), or considerable ($75\% \leq I^2 \leq 100\%$).

Table 1. Included studies examining the effects of physical training on physical and psychological parameters in individuals with patella tendinopathy.

References	No. of Subjects (Tendons); Sex; Age (Mean ± *SD*, or Range); Training Status; Sport	Diagnosis	Groups (Subjects/Tendons); Treatment Type	Treatment Modality: No. of Training Weeks/Sessions; No. of Sets/Reps/Duration Per Exercise; Training Intensity	Test Modality, Outcome Measures	PEDro
van Ark et al. [29]	29 (45); 2 F, 27 M; 23.0 ± 4.7 yrs; sub-elite; volleyball, basketball	Palpation	INT (n = 13/20); strength training (isometric quadriceps training, leg extension machine) CON (n = 16/25); strength training (concentric quadriceps training, leg extension machine)	4 wk/12 sessions; 5 sets of 45 s hold at 60° flexion at 80% MVIC 4 wk/12 sessions; 4 sets of 8 reps (4 s eccentric, 3 s concentric) at 80% 8 RM	*Physical:* NT *Psychological:* VISA-P (score), SLDS (Numeric Rating Scale 0–0) at pre-/post-intervention	5
Rio et al. [27]	20 (28); 2 F, 18 M; ≥16 yrs; elite and sub-elite; volleyball, basketball	Imaging, SLDS test	INT (n = 10/15); strength training (isometric quadriceps training, leg extension machine) CON (n = 10/13); strength training (concentric quadriceps training, leg extension machine)	4 wk/12 sessions; 5 sets of 45 s hold at 60° flexion at 80% MVIC 4 wk/12 sessions; 4 sets of 8 reps (4 s eccentric, 3 s concentric) at 80% 8 RM	*Physical:* NT *Psychological:* VISA-P (score) at pre-/post-intervention	6
Biernat et al. [30]	28 (NR); M; 17.0 ± 0.1 yrs; recreational; volleyball	Imaging	INT (n = 15/NR); volleyball training + strength exercises (eccentric) CON (n = 13/NR); volleyball training only	4 wk/daily; 3 sets of 15 reps on decline board followed by 20 wk/daily; 3 sets of 15 reps on unstable decline board 24 wk/12 sessions; 5 sets of 45 s hold at 60° flexion at 80% MVIC	*Physical:* Isokinetic leg strength; CMJ (cm, W) *Psychological:* VISA-P (score) at pre-/mid-/post-intervention	5
Dimitrios et al. [35]	43 (NR); 12 F, 31 M; 27 ± 5 yrs; recreational; NR	Palpation, SLDS test	INT (n = 22/NR); strength (eccentric) and stretching (static) exercises CON (n = 21/NR); strength (eccentric) exercises	4 wk/20 sessions; 3 sets of 15 reps on decline board, weight increased when pain-free, static quadriceps/hamstrings stretching before and after the eccentric training, 4 exercises of 30 s 4 wk/20 sessions, 3 sets of 15 reps on decline board, weight increased when pain-free	*Physical:* NT *Psychological:* VISA-P (score) at pre-/post-intervention	5
da Cunha et al. [26]	17 (14); 3 F, 14 M; 25 ± 8 yrs; recreational; volleyball, soccer, athletics, basketball, handball, capoeira, jiu jitsu, triathlon, skating	Imaging	INT (n = 10/8); strength (eccentric) training, maximum pain CON (n = 7/6); strength (eccentric) training, pain-free	12 wk/36 sessions; 3 sets of 15 reps, weight increased when reps possible, pain mandatory 12 wk/36 sessions; 3 sets of 15 reps, weight increased when pain-free	*Physical:* NT *Psychological:* VISA-P (score), VAS (0–10) at pre-/mid-/post-intervention	7
Kongsgaard et al. [14]	25 (25); 25 M; 32 ± 8 yrs; recreational; running, soccer, basketball, floorball, handball	Palpation, imaging	INT (n = 12/12); strength (eccentric) training CON I (n = 13/13); strength (dynamic) trainingCON II (n = 12/12); peritendinous corticosteroid injections	12 wk/168 sessions; 3 sets of 15 reps on 25° decline board, pain-acceptable, weight increased when pain diminished 12 wk/36 sessions; 4 sets of 6–15 reps, pain-acceptable ultrasound-guided injections of 1 mL of 40 mg/mL methylprednisolon	*Physical:* MVIC *Psychological:* VISA-P (score), VAS (0–100) at pre-/post-intervention and 6 months post-intervention	6

Table 1. *Cont.*

References	No. of Subjects (Tendons); Sex; Age (Mean ± *SD*, or Range); Training Status; Sport	Diagnosis	Groups (Subjects/Tendons); Treatment Type	Treatment Modality: No. of Training Weeks/Sessions; No. of Sets/Reps/Duration Per Exercise; Training Intensity	Test Modality, Outcome Measures	PEDro
Bahr et al. [25]	35 (40); 5 F, 30 M; 30 ± 8 yrs; recreational; running, soccer, handball, martial arts	Palpation, imaging	INT (*n* = NR/20); eccentric decline squat, sports from wk 8+ CON (*n* = NR/20); surgical treatment, sports from wk 8+	12 wk; 9.3 ± 4.1 sessions per wk; 3 sets of 15 reps on 25° decline board to 90° knee flexion, moderate pain mandatory (VAS = 4/5), weight increased when VAS < 3 12 wk post-operative training; sessions increased weekly; 10.1 ± 4.3 sessions per wk; wk 1: isometric quadriceps exercises, wk 2: adding walking, wk 3: adding cycling and high squats, wk 4: adding step-ups to a low (5–6 cm) step, wk 5: step-downs from a low (5–6 cm) step, wk 6: adding eccentric squat training similar to INT group but without any pain	*Physical:* Leg press strength (kg); CMJ (cm) at pre-intervention only *Psychological:* VISA-P (score) at pre-/post-intervention and 6 and 12 months post-intervention	7
Jonsson and Alfredson [31]	15 (19); 2 F, 13 M; 25 ± 9 yrs; recreational; running, soccer, basketball, floorball, handball	Palpation, imaging	INT (*n* = 8/10); strength (eccentric) training CON (*n* = 7/9); strength (concentric) training	12 wk/168 sessions; 3 sets of 15 reps on 25° decline board, pain mandatory, weight increased when reps not painful 12 wk/168 sessions; 3 sets of 15 reps concentric knee extension from 70° knee flexion on 25° decline board, pain mandatory	*Physical:* NT *Psychological:* VISA-P (score), VAS (0–100) at pre-/post-intervention	4
Visnes et al. [23]	29 (29); 10 F, 19 M; 27 ± 4 yrs; elite; volleyball	Palpation	INT (*n* = 13/13); strength (eccentric) training CON (*n* = 16/16); volleyball training only	12 wk/168 sessions; 3 sets of 15 reps on 25° decline board to 90° knee flexion, 2 s eccentric phase, weight increased when VAS < 5 volleyball training as usual without information on training load	*Physical:* CMJ (cm), SJ (cm) *Psychological:* VISA-P (score) at pre-/post-intervention and 6 and 24 wk post-intervention	7
Purdam et al. [32]	17 (22); 4 F, 13 M; 25 yrs; recreational; floorball, soccer, volleyball, running, ice hockey, high jump, skiing	Palpation, imaging	INT (*n* = 8/12); strength (eccentric) training, decline squat CON (*n* = 9/10); strength (eccentric) training, flat-surface squat	12 wk/168 sessions; 3 sets of 15 reps on 25° decline board to 90° knee flexion, some pain mandatory, weight increased when reps not painful 12 wk/168 sessions; 3 sets of 15 reps on flat surface to 90° knee flexion, some pain mandatory, weight increased when reps not painful	*Physical:* NT *Psychological:* VAS (0–100) at pre-/post-intervention	5
Cannell et al. [33]	19 (NR); 6 F, 13 M; 26 ± 7 yrs; recreational; basketball, soccer, running, volleyball, tennis, squash, rowing, American football, gymnastics	Palpation	INT (*n* = 10/NR); progressive strength (eccentric) training, drop squats CON (*n* = 9/NR); progressive strength (concentric) training, leg extension/curl	12 wk/60 sessions; 3 sets of 20 reps, pain mandatory, weight increased when reps not painful; activity (running) added when reps not painful 12 wk/60 sessions; 3 sets of 10 reps with 5 kg each leg extension/leg curl exercise, weight increased when reps not painful; activity (running) added when reps not painful	*Physical:* Isokinetic leg strength *Psychological:* VAS (0–10) at pre-/mid-/post-intervention	7

CMJ: countermovement jump; CON: control group; F: female; INT: intervention group; PEDro: Physiotherapy Evidence Database scale; M: male; MVIC: maximum voluntary isometric contraction; NR: not reported; NT: not tested; RM: repetition maximum; SJ: squat jump; SLDS: single leg decline squat; VAS: visual analogue scale; VISA-P: Victorian Institute of Sport Assessment–Patellar tendon scale; wk: week; yrs: years.

3. Results

Figure 1 summarizes the process of the systematic literature search, which identified a total of 506 studies. After removing duplicates, screening titles, and excluding ineligible articles, eleven studies remained and were included in our meta-analysis.

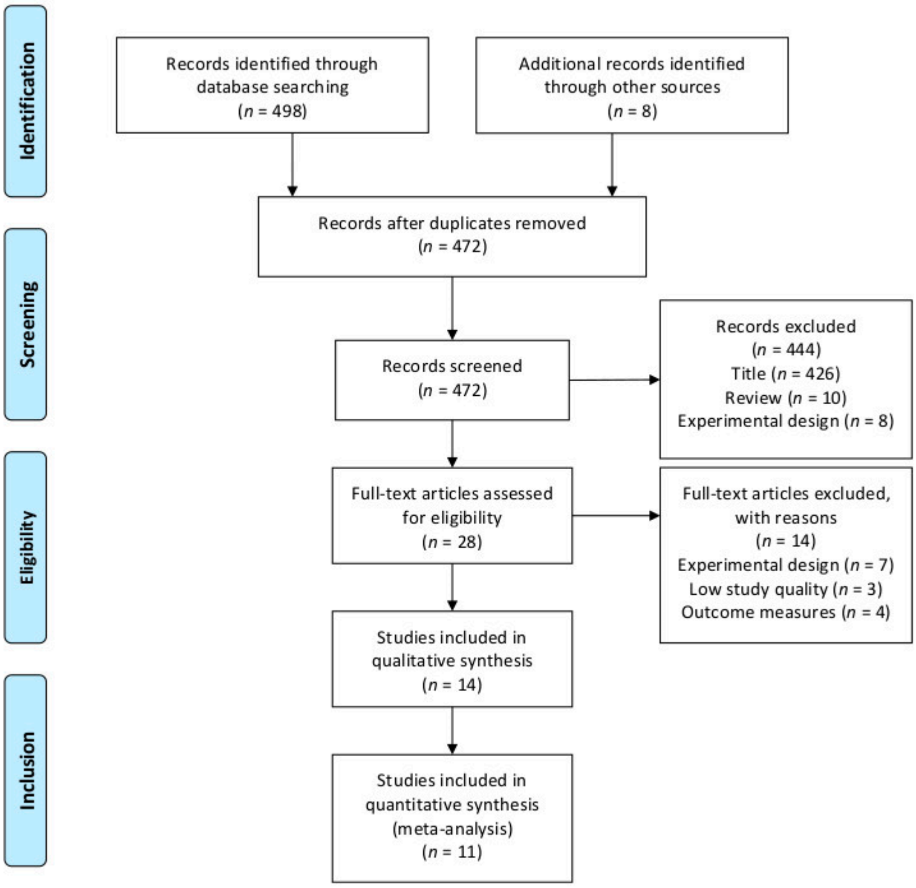

Figure 1. Flowchart illustrating the different phases of the literature search and study selection.

3.1. Characteristics of the Included Studies

Table 1 displays the characteristics of the eleven included studies. Two studies [23,30] reported data for both physical and psychological variables, eight studies [14,26,27,29,31–33,35] reported data for only psychological variables. A total of 277 subjects participated in the eleven trials; 155 of them received eccentric strength training, 42 concentric strength training, 23 isometric strength training, 13 dynamic heavy slow resistance training, 29 sports training, and 20 tendons were surgically treated. The sample size of the included studies ranged from 15 to 43 subjects, and participants had a mean age of 16–32 years. Training periods ranged from 4 to 24 weeks, with the respective training frequencies ranging from 0.5 to 14 sessions per week. Training protocols comprised unilateral/bilateral squats on a decline board/flat surface/unstable surface, leg extensions, leg curls, leg press, as well as static stretching. All eleven studies analysed outcomes of pain assessment (1 × VISA-P, 2 × VAS, 3 × VISA-P/VAS, 1 × VISA-P/SLDS) [14,23,25–27,29–33,35]. Three studies reporting physical data examining strength variables (2 × CMJ, 4 × leg strength) [23,25,30].

3.2. Methodological Study Quality

The median PEDro score of the included studies was six, which equals the predetermined cut-off value of ≥6 and was achieved by six out of eleven studies (Table 1).

3.3. Effects of Physical Training on Physical Parameters in Individuals with Patella Tendinopathy

Figure 2 shows the effectiveness of physical training on measures of muscle power in individuals with patella tendinopathy. The weighted mean SMD amounted to −0.05 (2 studies; I^2 = 0%, Chi^2 = 0.22, df = 1, p = 0.85), which is indicative of a small-sized effect in favour of the CON group.

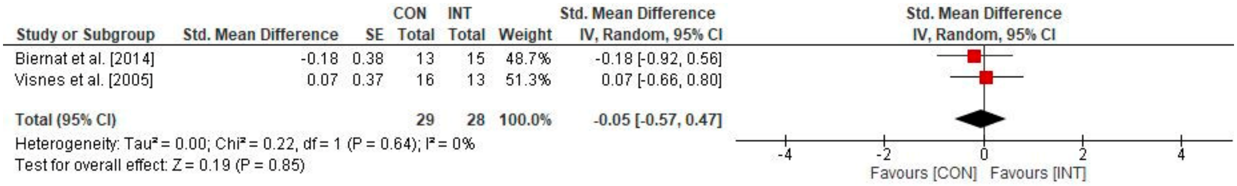

Figure 2. Effects of physical training on physical parameters (i.e., muscle power) in individuals with patella tendinopathy. CI: confidence interval; CON: control group; *df*: degrees of freedom; INT: intervention group; IV: inverse variance; *SE*: standard error; Std.: standard.

3.4. Effects of Physical Training on Psychological Parameters in Individuals with Patella Tendinopathy

Figure 3 illustrates the impact of physical training on the psychological measure VISA-P in individuals with patella tendinopathy. The weighted mean SMD yielded 0.12 (9 studies; I^2 = 64%, Chi^2 = 22.17, df = 8, p = 0.005), indicating a small-sized effect and favouring the INT group.

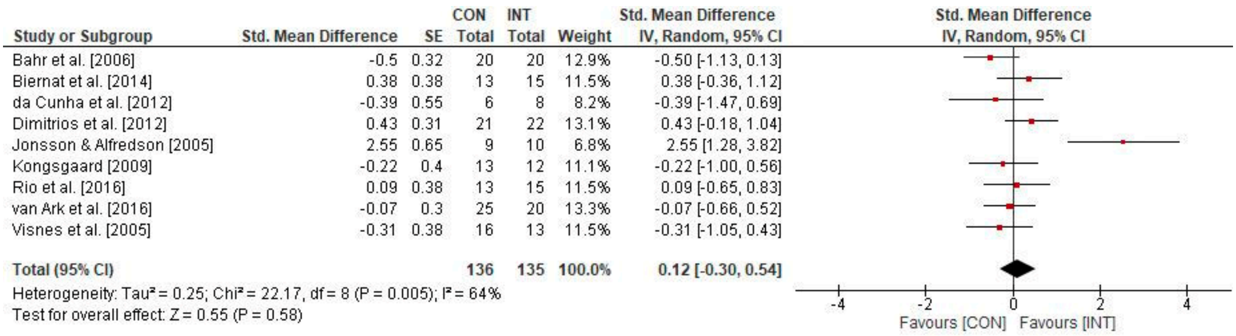

Figure 3. Effects of physical training on psychological parameters (i.e., VISA-P) in individuals with patella tendinopathy. CI: confidence interval; CON: control group; *df*: degrees of freedom; INT: intervention group; IV: inverse variance; *SE*: standard error; Std.: standard.

The effect of physical training on the psychological measure VAS in individuals with patella tendinopathy is displayed in Figure 4. The weighted mean SMD amounted to 0.61 (5 studies; I^2 = 80%, Chi^2 = 20.07, df = 4, p = 0.22), which indicates a medium-sized effect in favour of the INT group.

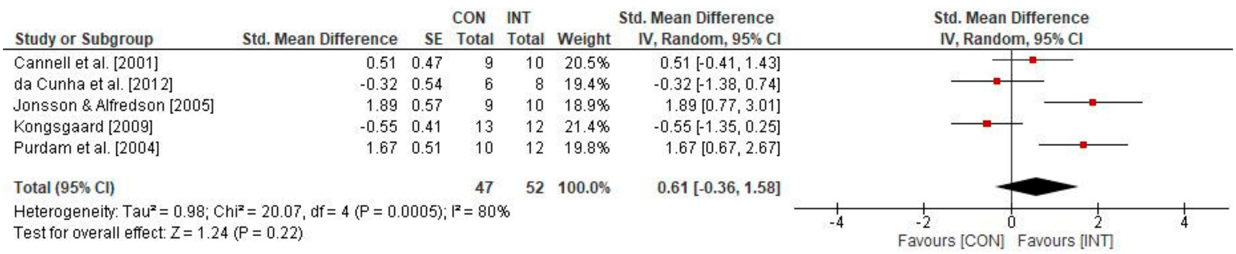

Figure 4. Effects of physical training on psychological parameters (i.e., VAS) in individuals with patella tendinopathy. CI: confidence interval; CON: control group; *df*: degrees of freedom; INT: intervention group; IV: inverse variance; *SE*: standard error; Std.: standard.

4. Discussion

To the best of our knowledge, the present systematic review with meta-analysis is the first to examine and quantify the effects of physical training on proxies of physical and psychological parameters in individuals with patella tendinopathy. The analyses of the data of eleven studies revealed mixed results with (i) small-sized but better effects on muscle power for the CON group, (ii) small-sized but better effects on VISA-P for the INT group; and (iii) medium-sized effects on VAS in favour of the INT group.

4.1. Effects of Physical Training on Physical Parameters in Individuals with Patella Tendinopathy

Physical training displayed only minimal positive effects on variables of muscle power. Eccentric training intervention, in particular, which had been considered useful in previous reviews [38,39], showed only small effects on muscle power compared to team training. However, it is important to bear in mind that Biernat et al. [30] and Visnes et al. [23] both implemented a very high training volume (two sessions daily) in comparison to other studies. The eccentric training protocol was performed on a decline board, a method which had shown positive results in previous studies. While both studies examined volleyball players, Visnes et al. [13] included both adult males and females and Biernat et al. [30] included adolescent male athletes only. The subjects in the above-mentioned studies also took part in all team practices and matches regardless of pain intensity, therefore resulting in a much higher training load than the CON group, which only took part in team practice. Furthermore, on days with intensive team practice, the subjects were permitted to decide whether or not to take part in the training intervention on their own, which may have led to inconsistent training. Both studies only included subjects with a high burden of symptoms, which may have further affected the impact of the intervention and the volleyball practice. It can be assumed that the high training intensity resulted in an immense burden on the knee joint and the patella, especially as a result of the frequent jumps in volleyball, therefore causing further strain inhibiting the positive effects of training on muscle power.

Overall, a complex, high-intensity physical training intervention should not be combined with intensive team practice and competitive matches. In this regard, further research is required in order to prove the different effects of combined versus single-mode physical exercise interventions on muscle power. Moreover, the investigation of different strength training methods (isometric, eccentric, concentric) in combination with team training may be able to provide insights into the efficacy of therapy.

4.2. Effects of Physical Training on Psychological Parameters in Individuals with Patella Tendinopathy

We were able to detect a small-sized effect concerning pain reduction, which was verified by the VISA-P test. Previous reviews [38–40] revealed a significant relief of pain and symptoms using eccentric and isometric training in comparison to other treatment methods. In Bahr's et al. [25] randomized study, it must be considered that the CON group received surgical treatment and, post-operation, the same eccentric intervention as the INT group. It is therefore not possible to ascribe their results to either surgical or conservative intervention. The results of da Cunha et al. [26] must also be interpreted carefully, since both groups received an eccentric training intervention; while the INT group performed the exercises at maximum pain level, the CON group trained without any pain. No significant group differences could be determined, but both groups reported an improvement in the pain and symptoms. Of the studies examined, Jonsson and Alfredson [31] showed the clearest advantages of eccentric training in contrast to concentric training. However, this study was lacking in terms of sample size and study quality, so these outcomes need to be interpreted accordingly. More specifically, this study only included 15 patients and showed a rather low methodological quality because no information was provided for some criteria of the PEDro scale (i.e., concealed allocation; blinding of subjects, therapists, and assessors; adequate follow-up or intention-to-treat analysis). While our systematic review with meta-analysis reported only a medium-sized effect of VAS favouring the INT group, Jonsson and

Alfredson [31] showed the most significant improvement of the INT group in comparison to the CON group. Similarly to da Cunha et al. [26], Purdam et al. [32] compared two eccentric exercises with one another; while the CON group performed the exercises on a flat surface, the INT group used a decline board. Therefore, this study cannot make claims pertaining to the effectiveness of eccentric training per se, but only to a variation of eccentric training, which relaxes the calf muscles and in doing so exerts a greater load on the knee extensor muscles. Regarding the time frame of pain reduction, Purdam et al. [32] as well as Jonsson and Alfredson [31] reported a significant pain reduction after twelve weeks in the eccentric group. Further, Bahr et al. [25] did not examine or describe any change in pain reduction before the first testing after twelve weeks. Lastly, da Cunha et al. [26] described an improvement in pain reduction after only eight weeks in both treatment groups—results which are similar to those of Rio et al. [27] and van Ark et al. [29], who found a significant improvement in both treatment groups after four weeks.

In sum, there are slight advantages of eccentric and isometric training compared to other treatment methods in terms of pain management, and these exercises can also be performed using simple equipment. Since all the investigated studies implemented similar intensities and extents of eccentric/isometric training, but none of them combined both methods, it is not possible to draw an adequate conclusion as to what an effective conventional therapy entails. Furthermore, the question whether withdrawing from sports and activities is beneficial for pain and symptom management remains unanswered. The studies presented in this systematic review only vaguely comment on this without describing in detail the intensity/duration of activity, so it is impossible to determine the effect of this variable on the study outcomes.

4.3. Limitations

The heterogeneity among the included studies with regards to the implemented training modalities (i.e., eccentric, concentric, or isometric training) is a strong limitation of this systematic review and meta-analysis. Thus, it remains unclear which type of strength training produces the greatest effect on physical and psychological parameters in individuals with patella tendinopathy. By using equal load dimensions (i.e., training duration, frequency, volume), future studies should directly compare the effects of different physical training programs (i.e., eccentric vs. concentric vs. isometric strength exercises) on physical and psychological parameters in individuals with patella tendinopathy. Another limitation is that only active CON groups (i.e., a different type of physical training) were used in the included studies. This circumstance most likely led to the fact that the effects in the INT groups were only small (muscle power and VISA-P) to medium (VAS) compared to the CON groups.

5. Conclusions

Unlike previous reviews, the present systematic review and meta-analysis detected only small (muscle power and VISA-P) to medium (VAS) effects among both physical and psychological parameters when comparing eccentric and isometric training protocols to other treatment methods. We therefore conclude that further research is needed to establish the optimal treatment modality in order to reduce pain and symptoms in athletes with patella tendinopathy. Although eccentric and isometric training seem to be useful in pain management, we did not find any study that combined different methods in order to find benefits when used synergistically. Moreover, we were unable to find a study that examined the post-interventional effects on performance in training and competition. The studies included in this review mainly used isolated exercises, such as eccentric leg extension, that were not combined with other treatment methods as training intervention. In addition, only active CON groups were used and compared with the treatment groups. This likely contributed to the fact that only small (muscle power and VISA-P) to medium (VAS) effects were found.

Supplementary Materials: The following are available online at https://www.mdpi.com/2075-4663/9/1/12/s1, Table S1: PRISMA Checklist: transparent reporting of systematic reviews and meta-analyses.

Author Contributions: Conceptualization: M.N.; methodology: M.N.; formal analysis: M.N. and T.M.; writing—original draft preparation: M.N.; writing—review and editing: M.N. and T.M. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the Faculty of Educational Sciences at the University of Duisburg-Essen, Germany (date of approval: TM_29.11.2018).

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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4.2 STUDY III – "Changes after a conventional vs. an alternative therapy program on physical, psychological, and injury-related parameters in male youth soccer players with patellar tendinopathy during return to competition"

Purpose and hypothesis: The STUDY III investigated the effects of a conventional compared to a multimodal progressive dual-task therapy programme on physical, psychological, and injury/pain-related parameters in adolescent male soccer players (15–16 years) with PT during their return to competition. The hypotheses were that after therapy, compared to the conventional group, the alternative group would demonstrate significantly better physical and psychological performance, as well as lower injury-related or pain-related parameters over the course of a soccer season.

Results and conclusion: The alternative versus the conventional group required a shorter programme duration (47.1 ± 15.6 days vs. 58.2 ± 24.6 days) and achieved the same (muscle power, speed, endurance) or greater (change of direction speed) improvements in physical performance, the same improvements in psychological measures (achievement motivation), and better results for injury/pain-related correlates (injury frequency, pain-related training interruptions). Results indicate that both programmes are effective in improving relevant outcome parameters in players with PT. The alternative therapy seems to be more efficient due to the shorter programme duration and should therefore be considered for a quicker return to competition phase, as well as minimizing the risk of subsequent injuries.

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Abstract

Changes after a conventional (CON) versus alternative (ALT) therapy program on physical, psychological, and injury-/pain-related parameters in soccer players with patellar tendinopathy (PT) during return to competition were examined. Thirty-four male youth soccer players (15-16 years) with PT were randomly assigned to a CON (n=18) or ALT (n=16) program. The ALT program consisted of 60 minutes of balance training, eccentric and isometric exercises, static stretching, and a dual-task progression. The CON program consisted of 30 minutes of eccentric and isometric exercises and static stretching. Both programs were conducted until painlessness was reported during full training load. Assessments of muscle power (drop jump, jump-and-reach), change of direction speed [CODS] (acyclic sprint), speed (tapping, 30-m linear sprint), endurance (Yo-Yo intermittent recovery test level-1), the Achievement Motives Scale Sport, and injury-/pain-related correlates were performed immediately, 6, 16, and 20 weeks after the respective therapy program. Players in the ALT group required a shorter program duration (ALT: 47.1±15.6 days, CON: 58.2±24.6 days) and achieved the same (muscle power, speed, endurance) or greater (CODS) improvements in physical performances, the same enhancements in psychological measures (achievement motives), and better values for injury-/pain-related correlates (injury incidence, pain-related training interruptions). Results indicate that both programs effectively improve relevant outcome parameters in players with PT. The ALT therapy is more time efficient than the CON therapy. Therapists should consider this multimodal training program for effective treatment of athletes to shorten their return to competition time and minimize the risk of secondary injuries.
Keywords: Jumper's knee; young athletes; physical fitness; intervention

INTRODUCTION

Overuse injuries in soccer show incidence rates up to 46.8% among young athletes (23), therefore necessitating further attention in research and treatment methods (6). Rommers et al. (35) demonstrated an increased risk of injury in adolescent soccer players with special stresses of growth and slow adaptations in the tendon structures. In addition, higher training volumes and more frequent competitions lead to overuse injuries like patellofemoral syndrome, patellar tendinitis, and patellar tendinopathy (PT) (15). Occurring in 11.7% (14) to 13.0% (8) of adolescent soccer players, PT in particular causes long periods of absence and performance regression in young athletes. Not much is known about the long-term prognosis of PT, yet it is proven that many athletes suffer from long lasting symptoms and are often forced to end their athletic career (14). Further, the frequent recurrence of symptoms after initially having subsided can result in a psychological burden of the athlete, which can lead to secondary injuries (4). One third of the patients are not able to return to play for more than six months, and even with current treatment methods, only 31.5% of athletes are able to return to their sport at a similar level as before the injury (5).

With regards to rehabilitative and preventive measures, studies recommend a stage-adapted therapy and progressive loading based on the patient's complaints (26,28). Evidence-based therapy methods of treating PT include stretching, eccentric resistance training of the quadriceps muscles, as well as painful progressive tendon-loading exercises (1,5,22,36). However, experiencing higher levels of pain during workout can result in insufficient loading of the tendon and therefore mitigate improvements using this treatment method (30). In comparison to the previously mentioned outcomes of eccentric exercise, concentric quadriceps strength training showed a significantly lower score in the Victorian Institute of Sport Assessment (VISA) pain score, hence more severe symptoms and a higher likelihood of surgery (17). In this regard, Cannell et al. (7) divided PT patients into two groups performing different training interventions. One group (*n*=10, age: 26±3.0 years) performed eccentric drop squats and the other group (*n*=9, age: 26±7.0 years) progressive concentric leg extension/curl exercises. After twelve weeks, the drop squat group showed a significant increase in hamstring moment of force, whereas the leg extension/curl exercise group did not show any improvements.

However, studies that have measured the long-term effects of therapy as a follow-up are rare in the literature on PT (24), making it difficult to draw conclusions about long-term changes in athletic and psychological performance as well as subsequent injuries. Jonsson and Alfredson (17) showed in a comparison of eccentric (*n*=10, age: 26±9.9 years) and concentric (*n*=9, age: 24±6.4 years) exercise therapy that six PT patients in the eccentric group had fully returned to their previous activity at 32.6 months after treatment and were satisfied with the pain reduction. These findings are supported by Young et al. (44) who showed a significant decrease of pain and symptoms over a 12-month period in patients (*n*=9, age: 27.3±1.8 years) participating in eccentric squatting exercises on a "decline board" inducing moderate tendon pain in comparison to patients (*n*=8, age: 27.3±1.8 years) exercising painlessly on ground level. Furthermore, Agergaard et al. (1) reported that in a comparison of two groups with heavy slow resistance training (*n*=21, age: 29±5.1 years) and moderate slow resistance training (*n*=21, age: 32±4.9 years), the pain level improved only minimally in both groups within 40 weeks after the end of therapy and the tendon structure did not normalize. In addition, participation in sports was significantly lower at this time compared to before the start of therapy in both groups, which showed an unsuccessful return to competition. However, in all three aforementioned studies, no conclusions could be drawn about subsequent injuries or physical performance.

In sum, it can be observed that most studies trying to provide a treatment suggestion only focused on either eccentric or concentric training exercises (1,7,17,22,36,44), investigated small sample sizes (7,17,44), examined the patients in a relatively short time period (<12 weeks) (7,17), and did not investigate long-term effects on physical and injury-related parameters through follow-ups (>6 weeks) after the end of the intervention (1,7,17,22,36,44).

Although current literature proves different therapy methods as successful in reducing pain and increasing physical performance, the effectiveness of these conventional treatments (i.e., CON) is often unsatisfactory in the long term. This can be due to the emotional response to the rehabilitation process and can be improved by engaging the athlete in a series of tasks, forcing the body to experience its current limitations in various performance variables (41). Therefore, an alternative therapy program should not only include the training methods that have been applied in the past but should also be able to increase the level of difficulty to adapt to the individual patients' current needs in order to reach or even outperform the performance requirements of their sport on a competitive level. Recent research shows lower proprioception in athletes with PT (40), which also needs to be addressed when composing an effective therapy program. Although strength training on unstable surfaces is only partially recommended for improving balance and proprioceptive abilities (3), little is known about combining proprioceptive and strength training in adolescents. Since both programs showed positive results in young patients with lower limb injuries (2) it seems reasonable to propose that a combination of both could have positive effects on physical performance.

Current literature suggests psychological variables, in particular confidence and achievement motivation, should always find consideration in a successful return to sports process following an athletic injury (31). Even more, sources of confidence information, observational experiences, and confidence restoration need to be addressed as soon as possible after an injury and are significantly related to a successful outcome of treatment (42). In particular, a recent study by Slagers et al. (38) showed that in players with PT, higher scores on psychological readiness and confidence at return to competition were significantly associated with higher scores on the VISA pain scale and therefore less severe symptoms. To the authors' knowledge, no study has specifically investigated the changes following a combined balance, eccentric and isometric training program with dual-task progression on physical and psychological parameters in the post-rehabilitation period. Thus, the present study was designed to investigate the changes following a conventional (CON) versus a novel alternative (ALT) therapy program on physical, psychological, and injury-/pain-related parameters in male youth soccer players with PT during their return to competition. We hypothesized that following therapy, the ALT-compared to the CON-group will show significantly (i) better physical and psychological performances and (ii) lesser values of injury-/pain-related parameters over the course of a soccer season.

METHODS

Experimental Approach to the Problem

After the previous season of the three participating clubs had ended, participants were randomly assigned to both groups and were not informed about the expected differences between the therapies. To systematically assess the physical, psychological, and injury-/pain-related parameters of both groups during a competitive season, a longitudinal study design was used (Figure 1). Baseline testing before or during the therapeutic intervention was not conducted for ethical reasons, as this would have meant that the participants would have had to perform the physical stress of the test procedures in pain. The subjects' level of pain was analyzed after each therapeutic intervention/training session/competition using a visual analogue scale (VAS; 0–10) by the coaches and the athletic department of the participating clubs. Therapy was only discontinued as soon as the players stated VAS=0, which made it possible to determine the individual time of therapy.

After the individual end of the therapy period, each athlete was tested four times using a variety of physical fitness tests including muscle power (drop jump [DJ], jump-and-reach [JaR]), change of direction speed (acyclic sprint [AS]), speed (15-s foot tapping [FTT15], 30-m linear sprint), and endurance (Yo-Yo intermittent recovery test level 1 [YYIRL1]). Assessments of muscle power, CODS, speed, endurance, achievement motives, and injury-/pain-related correlates were performed immediately (T1), 6 (T2), 16 (T3), and 20 weeks (T4) after the respective therapy program, therefore as soon as an athlete was completely pain-free during full training load or competition. Before each physical fitness testing, a standardized warm-up protocol (i.e., 15 minutes of running, jumping, movement preparation and change-of-direction drills) was applied. In addition, psychological characteristics were obtained using the Achievement Motives Scale (AMS) Sport. Furthermore, injury-/pain-related characteristics were assessed including information on the number of pain-related training interruptions, incidence rate of lower-extremity injuries and non-contact lower-extremity injuries, as well as the period of injury-related rest and overall exposure time of soccer training and competition. An injury was defined as follows: An injury acquired during training or competition within the club that completely prevents the player from continuing soccer for at least one day. In addition to these variables, we measured the program duration, which implied the duration from primary diagnosis to painlessness during training and competition, thus stating the time of therapy. The selection of test procedures was made in order to examine the physical, psychological, and injury-related parameters relevant to soccer performance in the current literature (11,38) with validated tests that were feasible with the available resources.

Subjects

Eighteen young male soccer players with PT that were treated with CON therapy methods (mean age: 15.1±0.8 years, body mass: 60.5±8.5 kg, body height: 170.7±6.6 cm) and sixteen players with PT attending the ALT therapy program (mean age: 15.4±1.0 years, body mass: 59.2±8.1 kg, body height: 172.0±9.6 cm) participated in this study. The players were recruited from youth academies of two clubs in the 1st German Bundesliga and one club in the 2nd German Bundesliga. The diagnosis of pain in the inferior pole of the patella or the proximal patellar tendon by palpation of the tendon and its attachments was completed using ultrasound. Tendons classified as “abnormal” showed a hypoechoic lesion and/or fusiform swelling located in the proximal insertion of the patellar tendon. In case these changes could not be seen, the tendon was considered “normal”, excluding the subject from the study. Additionally, all subjects reported pain during jumping exercises, as well as explosive stop-start movements at the time of diagnosis. Prior to inclusion in the study, participants were made familiar with the testing protocol. Before initiation of a training session, the subjects were asked to analyze their current level of pain using a visual analogue scale. The maintenance of a pain-related rest period (13.3 ± 4.1 days) and performance of limited training load during the duration of therapy (58.2 ± 24.6 days) was advised for subjects within the CON group. Players did not meet the inclusion criteria and were excluded from the study if they had (i) a surgical procedure within in the past twelve months, (ii) any kind of other injury six weeks prior to the start of the study, (iii) complete absence of training or competition load before the start of the study or (iv) been originally diagnosed with patellofemoral pain syndrome, plica syndrome, Osgood-Schlatter, or Sinding-Larsen-Johansson syndrome. Participants were instructed that the use of pain medication, taping or medical insoles was not permitted during the treatment period and until the end of the complete data collection. Compliance was verified verbally before each testing based on a self-report. Participation in testing was only allowed in case no pain was present (visual analogue scale = 0) prior the beginning of the test. Both the players and their parents were informed about the procedure, risks, and benefits before signing a written consent form. Approval for the study protocol was obtained from the Human Ethics Committee at the University of University of Duisburg-Essen, Faculty of Educational Sciences.

Procedures

Assessment of Muscle Power. Players' muscle power was determined using DJ and JaR performed on a gym floor (29,44). For the DJ test, players began standing in an upright position on a box (drop height: 40 cm) with their hands on the hips. Following this starting position, the player stepped off the box with one leg, dropped down and landed on both feet before directly performing a vertical jump. A high reliability (ICC = 0.95) of this test procedure has been reported (27). Jump height was measured by OptoJump photoelectric cells (Microgate, Bolzano, Italy), a device consisting of two juxtapose bars connected to a laptop using the OptoJump software.

For the JaR test, players were instructed to perform a vertical jump starting in an upright standing position and to begin the jumping movement with a downward followed by an upward movement of the leg extensors. This test was clinically acceptable showing a near perfect reliability (ICC = 0.97) (29). A scale marked in 0.5-cm increments for measurement purposes was installed on the wall and the players were asked to touch the wall at their maximal JaR height. The spot was marked with stamp ink. Jump height was assessed by subtracting standing reach height from JaR height. Standing reach height was determined to the nearest 0.5 cm. Each jump test was performed five times (two practice trials proceeding to three data-collection trials). For both jump tests, the greatest jump height value was used for further analysis. A 5-minute and a 30-s break was provided between jump tests and single jump trials, respectively.

Assessment of Change of Direction Speed. The AS time was measured using timing gates (Smartspeed Lite®, Fusion Sport, Brisbane, Australia). The test set-up is similarly to the modified agility t-test that uses shorter distances than the known CODS test and showed a high reliability (ICC = 0.95) (37). In this set of testing, side steps were replaced with sprints because linear sprints are of greater relevance to soccer than side steps. The start of the test was signalized by the tester making a fist with his right hand and was performed on a surface with artificial grass in dry weather conditions. The players then first had to perform the test with a change of direction to the left (AS left) and followed by a second attempt with a change of direction to the right (AS right). The test was repeated three times in both directions with a 60-s break between each attempt. For both directions, the shortest measured time was used for further analysis.

Assessment of Cyclic and Linear Speed. Athletes' cyclic speed performance was measured using the FTT15 test. This test has been considered to be moderately to highly reliable (ICC = 0.69-0.98) (21). Starting point of this test was standing barefoot on a gym floor within OptoJump® bars with their feet hip distance apart. The objective of this test was to perform as many floor contacts as possible within a period of 15 s. The measurement of time started with an athlete's first floor contact and was performed three times with 60-s rest periods in between. Only the highest frequency of taps with both legs combined was used for further analysis.

Players' linear sprinting performance was measured using timing gates (Smartspeed Lite®, Fusion Sport, Brisbane, Australia) after 5, 10, and 30 m along a straight distance. The start was signalized visually by the tester making a fist with his right hand. Testing was performed of an artificial grass surface in dry weather conditions. The test was repeated for a total of three times. The best result (i.e., shortest time) was used for further analysis. Between each sprint trial, the player was allowed a 60-s break. High ICC-values of 0.80 (5 m), 0.87 (10 m), and 0.97 (30 m) have been reported for this test (25).

Assessment of Endurance. Using the YYIRL1, the endurance specific to soccer was determined. The test is composed of 2 x 20-m sprints followed by 2 x 5-m recovery phases performed on artificial grass in dry weather conditions and has been considered to be a reliable test procedure for young athletes (ICC = 0.82-0.94) (10). The increase in velocity is signalized acoustically. Each 40-m distance was followed by a 10-m phase of active rest in which the player jogged slowly for 10 s. After missing the finishing line twice within the given time, testing was stopped. The total distance (m) travelled was measured.

Assessment of Psychological Parameters. Psychological characteristics were measured using the AMS Sport. A questionnaire, which subjects were asked to fill out on their own without further explanation, was used to assess the two achievement motive items "hope for success score" and "fear of failure". Each score was composed of 15 items with answers ranging from 1 (not true for me at all) to 4 (exactly true for me). Net hope was calculated by subtracting the sum of the item "fear of failure" from the sum of the item "hope for success" (12).

Assessment of Injury-/Pain-related Parameters. Injury-/pain-related characteristics were assessed through day-to-day tracking of training data by the coaches and the athletic department of the participating clubs with aid of a visual analogue scale (0-10). Using an online database (SoccerWeb, SoccerCollection oHG, Iserlohn, Germany), any reports of injuries or pain-related training interruptions were continuously documented throughout the 20-week duration of testing.

Description of the Therapy Programs. Following diagnosis, the participants started with the respective therapy program displayed in Figure 2. The start of the intervention was scheduled for the end of the season in May for both groups. Up to this point, all players involved were still participating in training and competitions in a pain-adapted manner. After the initial pain-related rest period (13.3±4.1 days) which lasted until no pain was reported during everyday activities, the CON-group started with unilateral eccentric leg squats (3 x 20 reps per leg) on a flat surface, followed by unilateral eccentric leg squats (3 x 20 reps per leg) on a decline board, both to about 60° of knee flexion. The execution was explained and demonstrated to the participants by a physical therapist, who also supervised the execution. The players were instructed to perform the eccentric phase of the squat on the symptomatic leg and the concentric phase on the asymptomatic leg. In addition, a static quadriceps and hip flexor stretching exercise (3 x 60 s per leg) was performed. This CON training routine has been proven to be successful by previous studies (13,44). The sessions were conducted two to three times a week, lasted about 30 minutes and were supervised by a physical therapist.

The ALT-therapy program was designed with input from previous research (5,20,30,33,34) and expertise in training and rehabilitation therapy. The ALT-group performed the first exercises the day after diagnosis, regardless of experiencing any pain or not. The therapy program started with unilateral balance exercises (4 x 30 s per leg) performed on different unstable devices (Balance Pad, Balance Beam, SoftX coordination rocker, Alcan Airex AG, Sins, Switzerland). After the participants felt comfortable balancing without further difficulties further difficulties like juggling or kicking a soccer ball, as well as unexpected perturbations were added to adjust the exercise to the peculiarities of the sport, simulating its activities (34). The strength training routine started with an eccentric hamstring exercise (4 x 10 reps) on a balance pad, followed by each four sets of 60 s of isometric split squats and isometric sumo squats on different unstable devices, both to about 100° of knee flexion. As with the CON group, an athletic coach explained and demonstrated the exercises to the participants and monitored the conditions under which they were performed. Additional weight (dumbbells 1-6 kg each hand or a barbell 15 or 20 kg) was added if the participant performed the strengthening exercises without any difficulties. The stretching routine started with a static quadriceps and hip flexor stretch (3 x 60 s per leg), followed by a static hamstring stretch (3 x 60 s per leg). These sessions were conducted three to four times a week, lasted about 60 minutes and were supervised by an athletic coach. Based on evidence provided by Kongsgaard et al. (19), participants of both groups were allowed to continue with reduced intensity soccer training, which consisted of soccer specific dribbling and skill exercises at an average of 50% of the maximal heart rate reserve.

Statistical Analyses

Descriptive data are reported as group mean values and standard deviations after normal distribution was examined by the Shapiro-Wilk test ($p > 0.05$). For the physical and the psychological parameters, a univariate analysis of variance (ANOVA) was used to test for significant group differences at T1. Thereafter, a 4 (Test: T1, T2, T3, T4) × 2 (Group: CON, ALT) ANOVA with repeated measures on Test was performed. Parameters that showed significant group differences at T1 were included as covariate in the model. In case of a significant Test × Group interaction effect, differences between the four testings were analyzed for each group separately using the simple main contrast method. For the injury-/pain-related outcome measures, group differences were calculated using a univariate ANOVA. All statistical analyses were performed using the Statistical Package for Social Sciences version 24.0. The significance level was set at $p < 0.05$. To further determine the clinical relevancy of our findings, in addition to the p-value (indicator for statistical significance), we calculated the effect size by converting partial eta-squared to Cohen's d (9). The d-value can be classified as small ($0 \leq d \leq 0.49$), medium ($0.50 \leq d \leq 0.79$), and large ($d \geq 0.80$).

RESULTS

All players received treatments (i.e., CON- or ALT-therapy program) as allocated. The duration of the therapy programs amounted to 47.1±15.6 days and 58.2±24.6 days for the ALT- and CON-group, respectively. The attendance rates during therapy sessions amounted to 89% for the CON- and to 96% for the ALT-group. We detected no statistically significant group differences at T1, except for the YYIRL1 indicating better values for the ALT- compared to the CON-group.

Physical Parameters. Figures 3-6 display the therapy-related changes in physical performance characteristics for the CON- compared to the ALT-therapy group over the course of the soccer season. The statistical analyses indicated significant main effects of Test for DJ height ($F_{(3, 93)} = 55.612$, $p < .001$, $d = 2.82$), JaR height ($F_{(3, 93)} = 36.733$, $p < .001$, $d = 2.29$), AS left ($F_{(3, 93)} = 20.102$ $p < .001$, $d = 1.69$), AS right ($F_{(3, 93)} = 20.327$, $p < .001$, $d = 1.71$), FTT15 ($F_{(3, 93)} = 28.893$, $p < .001$, $d = 2.03$), 5-m sprint time ($F_{(3, 93)} = 5.672$, $p = .001$, $d = 0.90$), 10-m sprint time ($F_{(3, 93)} = 15.607$, $p < .001$, $d = 1.49$), and YYIRL1 ($F_{(3, 93)} = 8.108$, $p < .001$, $d = 1.10$), but not for 30-m sprint time ($F_{(3, 93)} = 1.030$, $p = .384$, $d = 0.38$). In addition, we found a significant Test × Group interaction for AS left ($F_{(3, 198)} = 4.370$, $p = .007$, $d = 0.79$) only. Post hoc analysis revealed significant improvements for the ALT- (T1-T4: Δ2.3%, $.001 \leq p \leq .014$, $1.51 \leq d \leq 3.84$) but not for the CON- (T1-T4: Δ0.5%, $.118 \leq p \leq .886$, $0.09 \leq d \leq 0.89$) group. However, we could not detect any significant main effects of Group.

Psychological Parameters. Figure 7 illustrates the therapy-related changes in the item "net hope" of the AMS Sport for the CON- compared to the ALT-group over the soccer season. Significant main effects of Test were observed for the items "net hope" ($F_{(3, 93)} = 6.214$, $p = .001$, $d = 0.90$) and "fear of failure" ($F_{(3, 93)} = 5.788$, $p = .001$, $d = 0.86$) but not for "hope for success" ($F_{(3, 93)} = 1.693$, $p = .174$, $d = 0.47$). However, we did not detect any significant main effects of Group and no significant Test × Group interactions.

Injury-/Pain-related Parameters. Table 1 shows injury-related characteristics for both therapy groups. We detected significantly better values for the ALT-compared to the CON-group in terms of lower non-contact lower-extremity injury incidence (p = 0.23; d = 0.82) and pain-related training interruptions (p = 0.002; d = 1.16). For the period of injury-related rest, we did not observe significant differences (p = 0.213; d = 0.44).

DISCUSSION

In the present study, we compared the changes following a CON versus an ALT therapy program on physical, psychological, and injury-/pain-related parameters in male youth soccer players with PT during their return to competition. The main findings of the present study were that players in the ALT-group had a significantly shorter program duration (47.1±15.6 days) and were able to achieve (i) the same (muscle power, speed, endurance) or partially larger (CODS) improvements in physical performances, (ii) the same enhancements in psychological measures (achievement motives), and (iii) better values for injury-/pain-related correlates (injury incidence, training interruptions due to pain) compared to those achieved by players in the CON-group with a longer treatment regimen (58.2±24.6 days).

Therapy-related Changes on Physical Parameters. In terms of physical performance, both groups showed improvements, which correlates with our original hypothesis. However, athletes in the ALT- compared to the CON-group showed partially greater physical performance enhancements. More specifically, there was a significant performance increase with regards to CODS (acyclic sprint performance) at all times of testing within the 20-week period, indicated by large effect sizes of the post hoc analysis (AS left: d = 1.51-3.84). Converted into speed, this means that the improvements for the ALT-group (T1 = 2.66 m/s / T4 = 2.73) were higher compared to the CON-group (T1 = 2.69 m/s / T4 = 2.70 m/s) with regards to running speed, despite the CON rehabilitation process having a longer duration (ALT: 47.1±15.6 days, CON: 58.2±24.6 days).

These differences in efficiency, when considered for their significance in return to competition after injury, may decide if a player regains its position within a team and therefore prevent negative emotions and self-doubt (31) , ultimately increasing the risk of re-injury (41). The results of the ALT therapy program showed that a significantly higher burden of intensity and complexity is necessary in the planning and implementation of the rehabilitative exercises in comparison to treatment with CON therapy. The enhanced performance in CODS is one of the main components of performance during competition (18), so that the improved outcome within the ALT therapy is a considerable advantage opposed to previously described therapy methods. To the best of our knowledge, a training intervention combining eccentric and isometric strength training with additional weights, balance exercises with perturbation and additional coordinative tasks (juggling/kicking a ball), as well as static hamstring and quadriceps stretching has not been tested before, therefore making a comparison with current literature hardly possible. Although previous studies (1,5,7,17,44) described various therapy protocols as successful in treating PT, they focused on injury-related rather than performance-related variables. However, Wilke et al. (43) highlighted that the latter are crucial in assessing the effectiveness of a treatment on return to competition. In their review, they described that without performance-determining factors corresponding to the demands of competition, no reliable statement can be made about an athlete's readiness to return to competition. In support of this notion, Millar et al. (30) stated that in tendinopathies, pain perception variables alone often show a mismatch with the pathological changes in the tendon and thus should not be used as the sole criterion for long-term recovery. Higher CODS performance for athletes receiving the ALT therapy program compared to their conventionally treated counterparts may be due to an improved proprioception as a result of balance training exercises. This could lead to a reinforcement of the athletes' limbs under competitive circumstances (20) and therefore a better ability to cope with the tensorial stress occurring during the acyclic sprint tests. The shorter intervention period of the ALT-group could be explained by the higher intensity and complexity of the exercises, which was achieved by additional weights and the combination of isometric muscle strengthening and proprioceptive challenges. This, in turn, could have improved the eccentric muscle strength, as well as the postural balance ability more quickly and thus made it possible to return to the competition earlier than participants of the CON-group.

Our findings of differences in physical performance were limited to the parameter of CODS. However, measurements of muscle power (i.e., DJ, JaR), endurance (i.e., YYIRL1), and speed (i.e., FTT15) showed no significant differences between the two therapy methods. In order to fully meet the performance requirements of soccer, the ALT therapy program should be expanded to include power, endurance, and speed. In comparison to CON, the ALT therapy program achieved the same and sometimes even better results within a shorter intervention period. Therefore, this method not only seems effective, but also efficient.

Therapy-related Changes on Psychological Parameters. As stated in our hypothesis, athletes being treated with the ALT therapy program showed significantly higher values within psychological performance characteristics (i.e., net hope, fear of failure) in comparison to those being treated with the CON therapy program. Athletes in the ALT-group scored significantly lower in “fear of failure”, whereas the variable “hope for success” showed no significant difference between both groups. These findings contradict those of Elbe et al. (12) stating that the variables of the AMS Sport remain unaltered within an athlete’s life even under changing circumstances. Johnston et al. (16) performed a qualitative analysis of competitive athletes and presented comparable results, finding that the athlete’s decreased level of performance following injury was associated with a lower confidence in their abilities. This appeared to also be related to a fear of injury or re-injury manifesting as hesitancy, retention of full effort, and greater caution of potentially injury-aggravating situations (16).

Related to the aforementioned results are also the findings of Podlog et al. (31) and Zafra et al. (45), which linked an inadequate therapy program to the athletes’ insecurity in movement and in stressful game situations. These outcomes also revealed that athletes returning to sports after having suffered from a severe injury found their lower level in performance to cause stress and frustration. In turn, focusing on improvements in the process of rehabilitation is of great relevance. Similarly, Zafra et al. (45) showed a correlation between psychological variables and the event of injuries in tennis players. Especially players with PT and low psychological readiness in return to sports showed a lower score in the assessment of psychological performance variables (38). Finally, Tufekcioglu et al. (42) showed a significantly higher playing ability in youth soccer players with high achievement motivation compared to players with a lower score in this factor. From the lower scores for "fear of failure" in our results, related to the aforementioned findings, we conclude that athletes in the ALT therapy program felt better prepared for their return to sport and were therefore more confident in their own movement abilities and toughness during competition. Findings such as these show that the rehabilitation process has an impact on psychological variables of athletes, though currently little research is available to the specific effects. Moreover, optimizing physical recovery in form of holistic treatment procedures to improve the athletes' belief in their own quality of movement have proven to be successful and should be considered when establishing any type of therapy program.

Therapy-related Changes on Injury-/Pain-related Parameters. The present study showed significantly lower values of non-contact injuries and pain-related training interruptions for soccer players with ALT compared to CON therapy. The lower incidence rate of non-contact lower-limb injuries can be ascribed to an increased level of the sensorimotor function and the coordination of movements (34). Also, the lower number of pain-related training interruptions, as well as the shorter program duration of the ALT- compared to the CON-group is indicative of an improved return to play process for a competitive soccer player. In the current literature, most studies detected improvements in injury- and pain-related characteristics after only performing (i) eccentric strengthening (7,22), (ii) eccentric and concentric strengthening (1,36), (iii) balance training (3,20,34), or (iv) hip strengthening (32). A recent study of Steinberg et al.

(39) examined two groups of young dancers diagnosed with patellofemoral pain using isometric strength training or balance exercises. Both groups exercised for 15 minutes per day, three times a week, for twelve weeks in addition to their regular training workload and were compared to a control group only practicing normally. Both therapies showed significant pain reduction, but no follow-up data were collected and no overall injury-related variables were measured.

A potential limitation of the current study is the different number of exercises and sets in the respective therapy programs. Due to the low availability of evidence in the current literature, the impact of this limitation cannot be verified. However, in our understanding this limitation does not compromise the comparative value of the study. In recent literature, the exercises of the CON therapy method did not show significantly different outcomes in VISA scores with regards to the amount of training or exercises. In our opinion, the number of sets and exercises of the ALT group was justified due to the intended complexity of the ALT therapy program. Furthermore, the aim of the present study was not only to compare the individual therapy programs or the duration or frequency of exposure to load, but to compare the training methodology/duration/frequency recommended in the current literature by developing an adaptation of different aspects. The fact that this combination of several training concepts results in an increased duration of the training session is due to the practical execution of the exercises alone. In this context, patient compliance was ensured despite the different length of the therapy procedures by not informing the participants about the expected results, which was ethically justifiable as both therapy procedures were promising. As the players were members of youth training centers of German Bundesliga soccer clubs and were used to different training durations and methodologies, no impact on compliance was expected. A further limitation of this study is the unavailability of baseline diagnostic values, which would have improved the contextualization of our findings. This could also have illustrated the possible influence of the decreased time loss from injury on the differences in physical and psychological performance. However, requiring athletes to perform these exercises while experiencing intense pain would not have been feasible. A testing of participants prior to their injury was also not executable due to the unpredictability of this injury and the participation of athletes in different sports teams. However, a second ultrasound examination after the end of the post-rehabilitation phase would have provided information about the changed tendon morphology of the participants. This should be considered for future studies.

PRACTICAL APPLICATIONS

Our new therapy method, which combined isometric and eccentric strengthening with balance and stretching exercises, proved to lead to better outcomes than the conservative treatment that included eccentric strengthening and stretching exercises. We also discovered that a higher intensity and complexity in form of additional weights and balance exercises with perturbation and additional coordinative tasks (juggling/kicking a ball) lead to a more effective and quicker healing process during return to competition than solely adhering to conventional recommendations. The ALT compared to the CON therapy method showed significant performance improvements in CODS, an important component of competition. Therapists aiming to reduce the risk of re-injury and enable a quicker return to prior performance should therefore favor this method. Further research into the effectiveness of each component of the intervention during return to competition could provide insights into more time-efficient therapy sessions.

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Conflict of Interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Ethical Approval

Ethical permission was given by the Human Ethics Committee at the University of Duisburg-Essen, Faculty of Educational Sciences. Before the start of the study, participants' assent and parents' written informed consent were obtained prior to the start of the study.

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Authors' contributions

Author A and author B have given substantial contributions to the conception or the design of the manuscript. Author A developed the methodology and conducted the research, Author B supervised and administered the project. All authors have participated to drafting the manuscript. All authors contributed equally to the manuscript and read and approved the final version of the manuscript.

Trial registration

Current Controlled Trials ISRCTN15532235 (Retrospectively registered 24th June, 2021).

FIGURES

FIGURE 1. Schematic description of the study design, the testing protocol, and the therapy protocols.

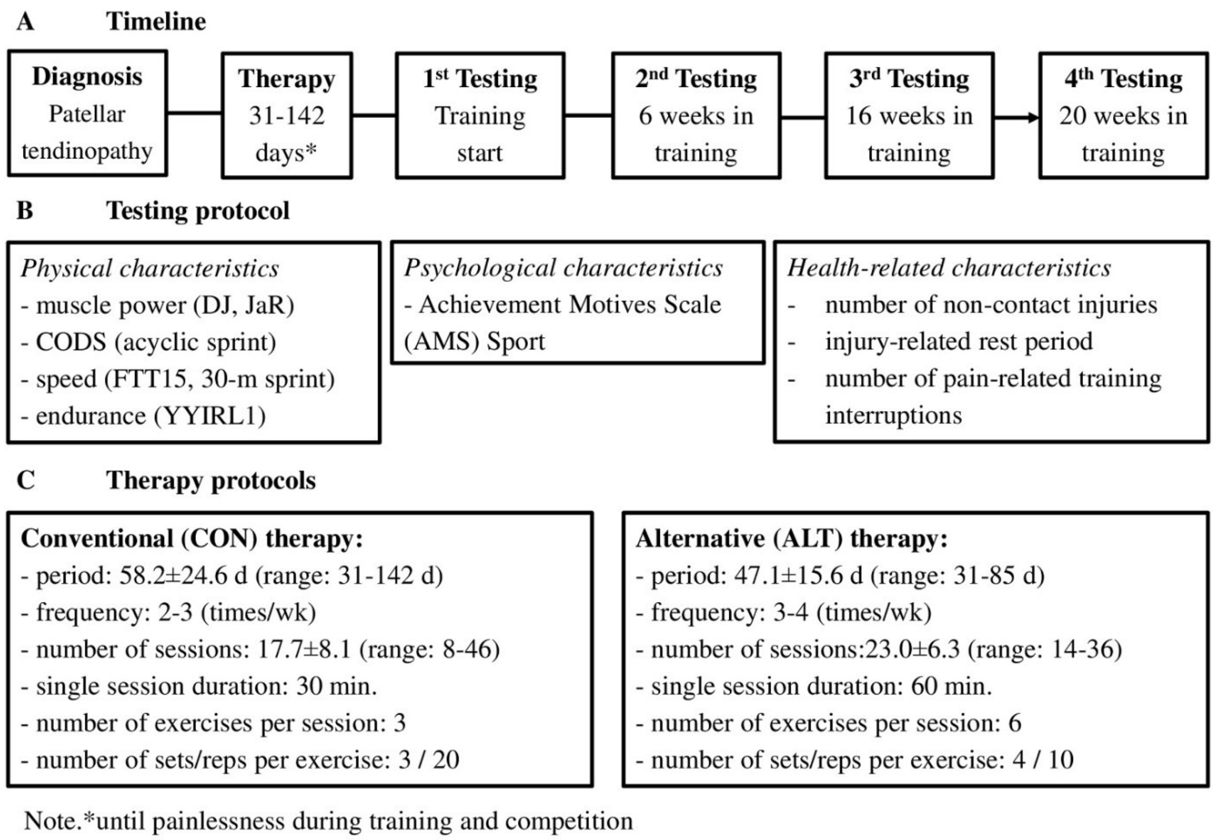


FIGURE 2. Description of the therapy programs.

FIGURE 3. Therapy-related changes in drop jump height (A) and jump-and-reach height (B) for the conventional (CON) compared to the alternative (ALT) therapy group. T1 = immediately after therapy; T2 = 6 weeks after therapy; T3 = 16 weeks after therapy; T4 = 20 weeks after therapy.

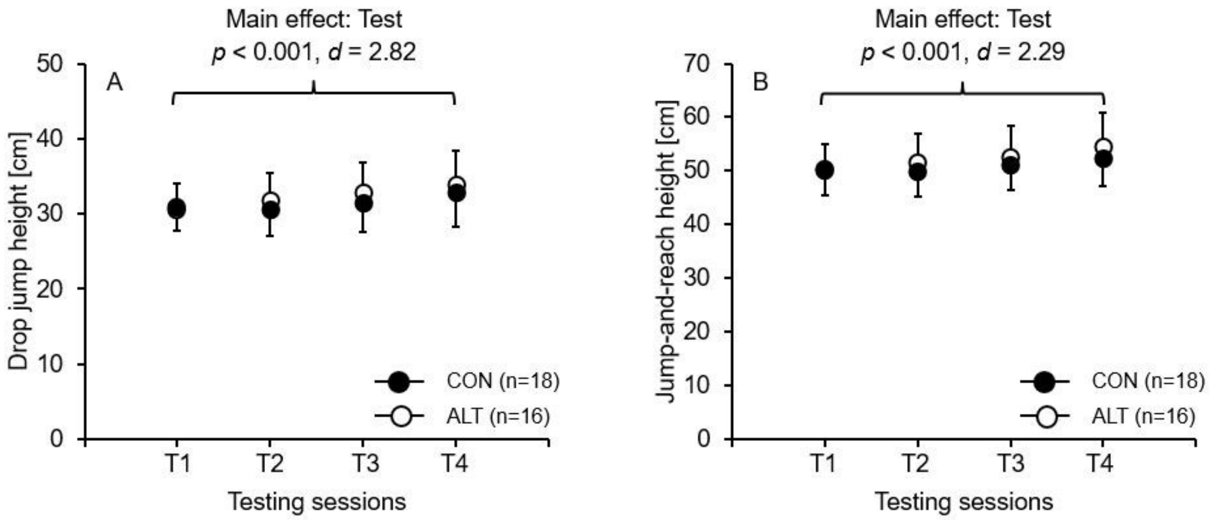


FIGURE 4. Therapy-related changes in acyclic sprint time with first change to the left (A) and right (B) for the conventional (CON) compared to the alternative (ALT) therapy group. T1 = immediately after therapy; T2 = 6 weeks after therapy; T3 = 16 weeks after therapy; T4 = 20 weeks after therapy.

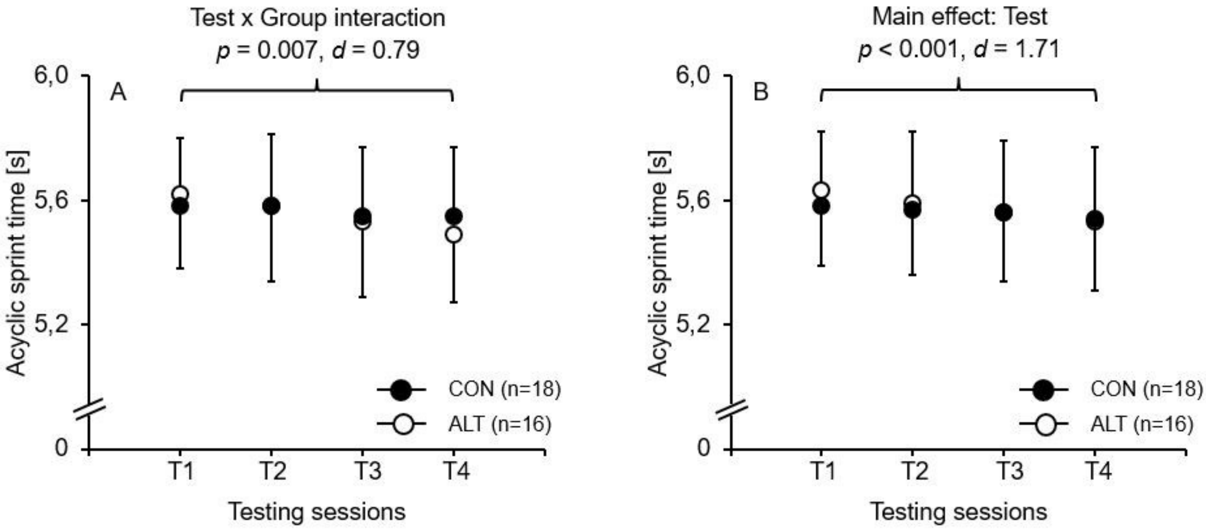


FIGURE 5. Therapy-related changes in 15-s foot tapping (A), 5-m (B), 10-m (C), and 30-m linear sprint time (D) for the conventional (CON) compared to the alternative (ALT) therapy group. T1 = immediately after therapy; T2 = 6 weeks after therapy; T3 = 16 weeks after therapy; T4 = 20 weeks after therapy.

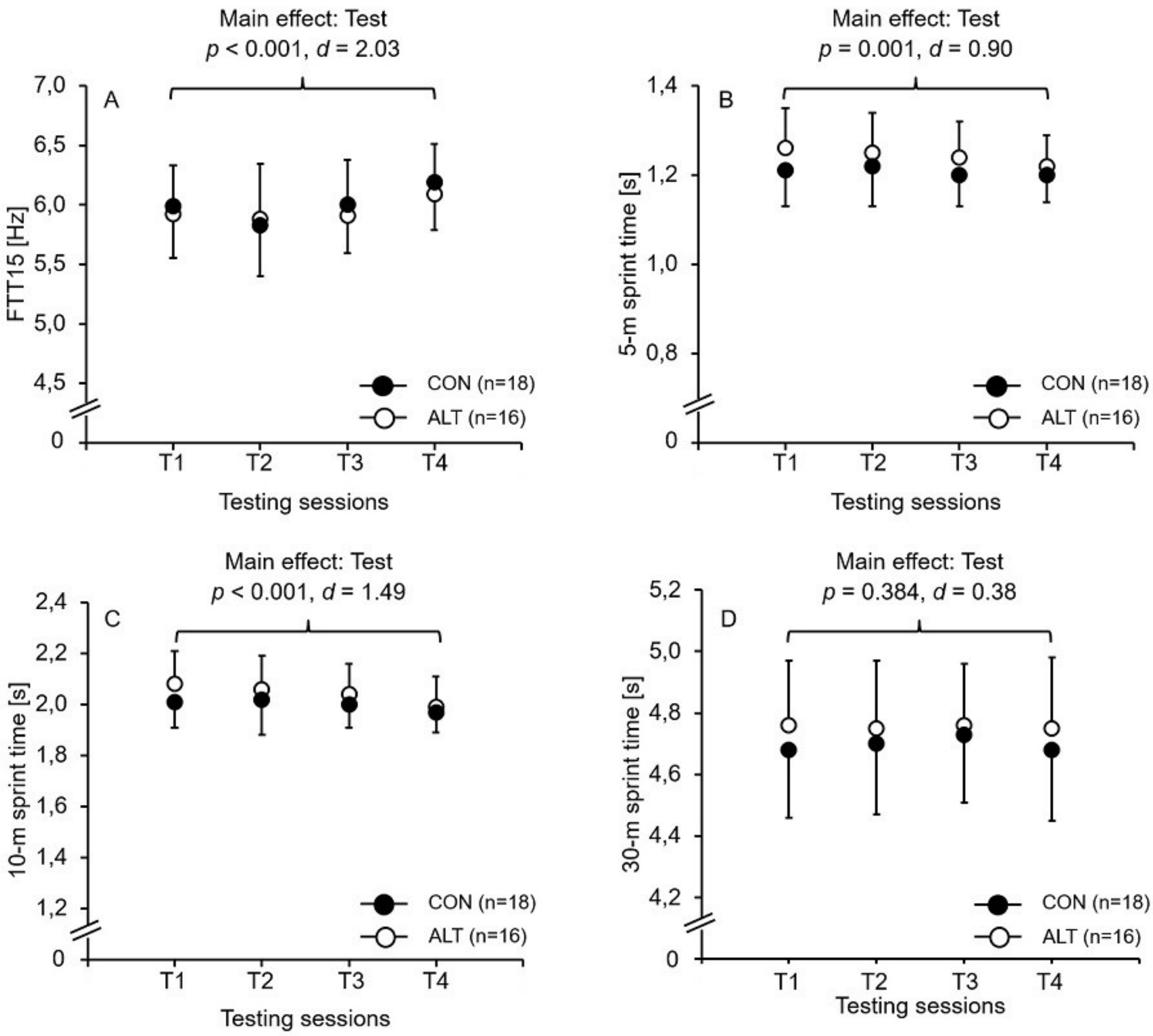


FIGURE 6. Therapy-related changes in the Yo-Yo intermittent recovery test level 1 (YYIRL1) for the conventional (CON) compared to the alternative (ALT) therapy group. T1 = immediately after therapy; T2 = 6 weeks after therapy; T3 = 16 weeks after therapy; T4 = 20 weeks after therapy.

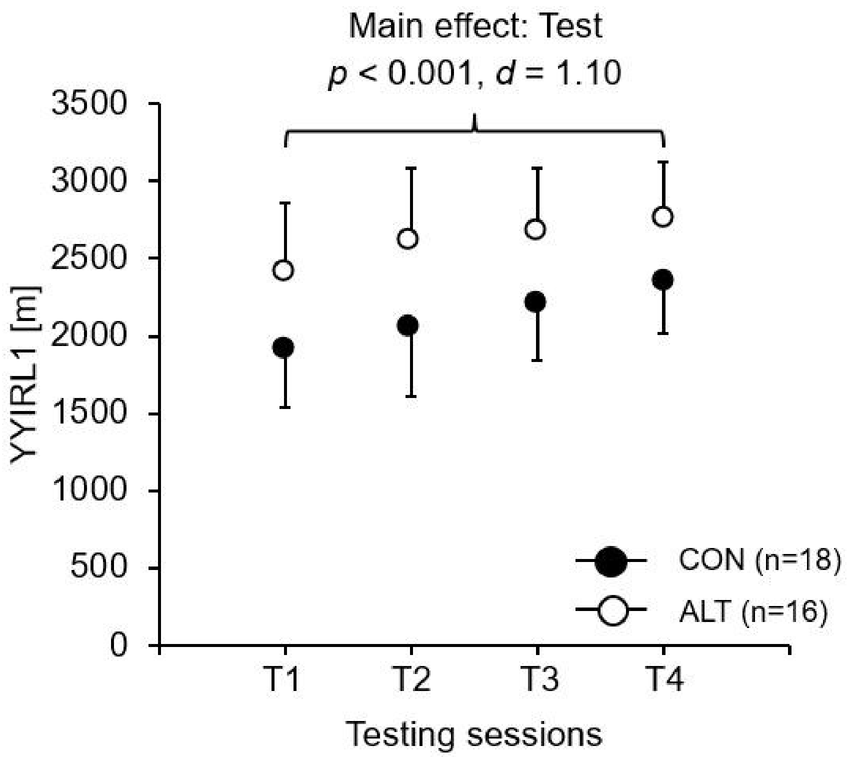
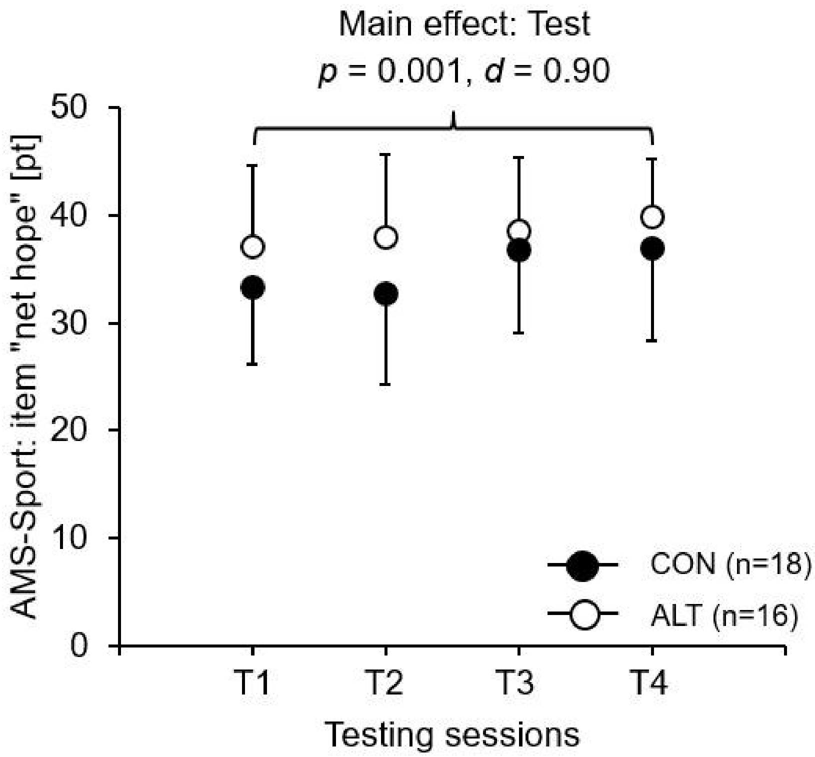


FIGURE 7. Therapy-related changes in the Achievement Motives Scale (AMS) Sport for the conventional (CON) compared to the alternative (ALT) therapy group. T1 = immediately after therapy; T2 = 6 weeks after therapy; T3 = 16 weeks after therapy; T4 = 20 weeks after therapy.


Main effect: Test
p = 0.001, *d* = 0.90
AMS-Sport: item "net hope" [pt]
50
40
30
20
10
0
CON (n=18)
ALT (n=16)
T1
T2
T3
T4
Testing sessions

TABLES

TABLE 1. Differences in incidence of lower-extremity injuries, injury-related rest period, and pain-related training interruptions of male youth soccer players with patellar tendinopathy attending a conventional (CON) or an alternative (ALT) therapy program. Values are means with standard deviations in parentheses.

Variables	CON (n=18)	ALT (n=16)	p- and d-value
Non-contact injuries/exposure time	0.000111 (0.000151)	0.000018 (0.000038)	$p = 0.023$; $d = 0.82$
Period of injury-related rest (days)	14.0 (23.8)	5.9 (9.8)	$p = 0.213$; $d = 0.44$
Pain-related training interruptions (number)	1.3 (1.3)	0.1 (0.3)	$p = 0.002$; $d = 1.16$

Values are means with standard deviations in parentheses.

5. General discussion

Within this dissertation, three original studies, including a systematic literature review with meta-analysis, a cohort study, and an intervention study were conducted to gain a better understanding of the physical and psychological impact of PT and its treatment during return to competition in adolescent athletes. The main findings can be summarized as follows:

(1) In youth soccer players, there are significant differences in physical and psychological performance after physical therapy for PT compared to HC.

(2) After returning to competition youth athletes with PT show significantly higher incident rates for non-contact lower limb injuries, injury-related rest periods and pain-related training interruptions compared to HC.

(3) Only small to moderate effects of eccentric and isometric training on physical and psychological parameters are shown compared to other treatment methods.

(4) A novel therapy approach that combines isometric and eccentric strengthening with balance and stretching exercises results in significant performance improvements, shorter programme durations and lower non-contact lower extremity injury incidence.

The following sections will discuss these findings and place them in the context of the current evidence.

5.1 Performance differences in youth soccer players following physical therapy

Significant differences were observed in physical performance among youth soccer players who underwent physical therapy for PT compared to those in the HC group. The physical performance of the PT group was notably inferior to the healthy control group in terms of change of direction speed (CODS) (to the left: $1.37 \leq d \leq 1.51$; $p < 0.001$ / to the right: $1.24 \leq d \leq 1.53$; $p < 0.001$) and linear speed ($0.48 \leq d \leq 1.26$; $p < 0.007$) across multiple testing sessions [T1-T4]. The results of STUDY I support the original hypothesis that individuals with a history of PT would exhibit a significant decline in physical performance over the course of the soccer season. Specifically, soccer players who had experienced PT incidents had noticeably slower metrics in acyclic sprint time (representative of CODS) and 30-meter linear sprint time (representative of speed), with effect sizes ranging from 1.37 to 1.50 for the former and from 0.48 to 1.26 for the latter. Highlighting the differences in CODS performance, the data reveals that the largest gap between PT and HC occurred during the final test. On average, players with PT lagged 0.98 m behind HC in CODS left/right tests (2.7 m/s for PT vs. 2.9 m/s for HC). In the 30-m linear sprint, athletes with PT had an average speed of 6.4 m/s, which is 1.62 m behind the HC group's average speed of 6.7 m/s. These differences can significantly affect in-game situations. These findings align with previous research by Zhang et al. (2018), Silva et al. (2016), and Bolgla et al. (2015), who similarly reported a decrease in physical performance among athletes with PT-related afflictions. On the other hand, several studies have reported enhanced performances (Souza & Powers, 2009) or no significant differences in performance (Cook et al., 2004; Witvrouw et al., 2001). Bisseling et al. (2007) found reduced eccentric muscle activity and a stiffer landing strategy in subjects with a history of PT, stating that residual pain from previous PT-related exercises may be an influencing factor. The decrease in performance among the PT group may also be attributed to heightened tendon stress during sprint assessments. These tests required rapid directional changes and many stops, which resulted in intensified tendon stress. Previous research (Pruyn et al., 2014) linked tendon stiffness to lower performance in rapid movements, which aligns with the results of STUDY I. However, although there were noted disparities in CODS and speed performance, significant differences were not observed in muscle power metrics (DJ and JaR) or endurance (YYIRL1). This incongruity indicates that some performance components may be more impacted by PT than others. While previous research has not extensively examined CODS and speed following rehabilitation, Dauty et al. (2007) found a deficiency in knee extension torque among players with PT. This could potentially contribute to the observed decline in performance in CODS and speed. The lack of muscle power differences could be due to the emphasis placed on strength training over high-velocity exercises in PT therapies. Furthermore, the endurance outcomes may reflect the PT group's prolonged low-velocity training during their therapy phase.

When analysing the psychological parameters of adolescent soccer players with a history of PT, the results of STUDY I showed significant deviations compared to their HC counterparts over the course of the season. The findings revealed notably lower values in achievement motivation (net hope, hope for success, and fear of failure). The lower score in "hope for success" underscores the athlete's inherent insecurity when facing athletic challenges, exposing a reduced confidence in their physical abilities. Furthermore, a significantly higher "fear of failure" score in the PT group indicates an increased apprehension of competitive failures and potential inability to execute certain movements. Contrary to the present results, which showed significant differences in "fear of failure" and "hope for success" only during the first two tests (beginning of the season and six weeks into the season), Elbe et al. (2005) found that such factors remain consistent throughout an individual's athletic career. The significant effect sizes observed during these first two tests (net hope: d = 0.85-0.89, hope for success: d = 0.50-0.65, fear of failure: d = 0.68-0.80) highlight the profound psychological impact. Johnston and Carroll

(1998) identified similar outcomes where performance decreases following injury correlate with reduced athletic confidence, largely due to fear of potential re-injury. This is mostly due to the fear of potential re-injury, resulting in hesitant or restrained performance. Athletes may underestimate the lasting effects of physical therapy on their abilities after treatment, making it hard for them to adjust to their new athletic realities. Additionally, coaches may be a potential source of oversight, returning athletes prematurely to intense training regimens. According to Gould et al. (1997), a significant drop in performance after an injury could cause athletes to experience heightened frustration. It is possible that the absence of psychological disparities between the PT and HC groups during later assessments (i.e., 16 and 20 weeks after the start of the season) could be attributed to the athletes' renewed self-assurance, which was enhanced by the absence of recurrent symptoms during high-intensity activities. This correlates with Smith et al.'s (1993) findings, which identified an initial increase in frustration and sadness following an injury that promptly diminishes as the athlete approaches complete rehabilitation. These findings highlight the significance of prioritizing gradual accomplishments during rehabilitation. Additionally, a study by Zafra et al. (2009) demonstrated a causal relationship between injury volume and decreased motivation scores among tennis players with tendinitis. This calls for further investigation concerning the relationship between injuries, rehabilitation techniques, and the psychological state of the athlete. Possible avenues for future research include studying the effects of psychological counselling on both psychological and physical rehabilitation, as well as optimizing recovery protocols to enhance athletes' confidence in their movement abilities.

5.2 Higher injury-related parameters in athletes after PT

The results of STUDY I illuminate the post-rehabilitation challenges experienced by young athletes who received PT treatment. Upon resuming competition, these athletes exhibited considerably greater incidences of non-contact injuries to their lower limbs, rest periods due to injuries, and training interruptions caused by pain in comparison to their healthy counterparts (HC). The observed incident rate discrepancies for injuries ($d = 0.69$; $p = 0.049$ per 1,000 hours), rest periods linked to injuries ($d = 2.06$; $p = 0.043$), and training disruptions related to pain ($d = 1.35$; $p < 0.001$) have both statistical and practical significance on the athletes’ return-to-play progression and overall performance.

These discoveries support the challenges observed in the physical performance of these athletes, as previously highlighted. The higher incidence of non-contact injuries to the lower limbs could be linked to the lasting impact of PT on the athlete's musculoskeletal system, potentially leading to altered movement patterns and increased risk of injury during high-impact or high-velocity activities, as seen in the CODS and linear sprint tests.

Additionally, the study's results on the physical performance impairments in CODS and speed, such as the PT group having worse acyclic sprint times and 30-m linear sprint times compared to HC, support the observations of increased injury rates. The elevated tendon stress experienced during these activities might account for both reduced performance and heightened injury rates. This agrees with previous studies, such as Dauty et al. (2007), who found deficits in knee extension torque in players with symptomatic PT, suggesting a possible link between the observed performance decrements and injury susceptibility after rehabilitation. Recently, Fendri et al. (2022) showed that the incidence of acute, non-contact lower extremity injuries over a 10-month period was significantly higher in athletes with PT (54%) compared to healthy athletes (21%). This included a variety of injuries such as ankle sprains, hamstring strains, and meniscus injuries. The authors determined that the odds of sustaining an acute lower extremity musculoskeletal injury were 4.24 times higher in athletes with PT compared to controls. These results (OR = 4.24; 95% CI = 0.07, 0.76; $p < 0.05$) align closely with our observations, underscoring a substantial risk of subsequent injuries in athletes post-PT. Further, Fendri et al. (2022) revealed that unilateral patellar tendinopathy was associated with a higher risk of subsequent injury (RR = 1.69; 95% CI = 1.09, 2.63). This finding is critical as it suggests that the presence of PT not only affects the injured limb but may also have repercussions on the overall biomechanical functionality of the athlete. This is further emphasized by their observation that normalized inter-limb asymmetry values were significantly higher in the PT group compared to controls in various directions. Such asymmetries, particularly in the anterior, posteromedial, and posterolateral directions (all $p < 0.001$), could be a contributing factor to the increased injury risk, potentially due to compensatory movement patterns or altered biomechanics.

The evidence highlights the importance of incorporating a wider range of high-velocity activities involving both limbs into rehabilitation protocols. It suggests that current rehabilitation processes, which primarily concentrate on strength training, may not fully equip athletes to meet the dynamic demands of competitive sports. Hence, rehabilitation programmes must target not only the healing of the injury but also the athletes' preparedness for the full range of competitive activities, particularly those involving high-speed and high-impact movements. Furthermore, given the increased likelihood of inter-limb asymmetries, these should be assessed and considered in the treatment programme.

In summary, the aforementioned insights suggest a pressing requirement to broaden the scope of PT rehabilitation, incorporating not only injury recovery but also comprehensive preparation for the physical demands of post-recovery sports. This necessitates a more refined and extensive rehabilitation approach, which acknowledges the intricate interplay between physical recovery, injury prevention, and performance optimization post-PT.

5.3 Limited efficacy of conventional therapy protocols

Systematic reviews by Challoumas et al. (2021), Van der Doelen and Jelley (2020), Mendonca et al. (2020), and Burton (2022) collectively present inconsistent outcomes regarding the efficacy of PT treatment. The meta-analysis of STUDY II revealed inconclusive findings from eleven included studies. In particular, conventional treatments showed small *(SMD* = -0.05) but superior effects on muscle strength. On the other hand, physical training protocols exhibited minor improvements in the Victorian Institute of Sport Assessment-Patella (VISA-P) with a small effect size (*SMD* = 0.12) and moderate benefits in the pain Visual Analogue Scale (VAS) with a medium effect size (*SMD* = 0.61).

The implications of these results are diverse. The slightly favourable impact of conventional protocols on muscle power contradicts the common view that such interventions have universal benefits for patients undergoing physiotherapy. For example, Burton (2022) highlights the potential of resistance training as a general preventive measure for athletes who are at risk of PT. Among the interventions studied, resistance training techniques including eccentric, heavy-slow, and isometric training have been shown to be viable and clinically advantageous during the competitive season. However, the results of STUDY II proved eccentric training interventions, extensively recommended in previous literature (Burton, 2022; Everhart et al., 2017; Visnes & Bahr, 2007), to be less effective. This conclusion is essential, as studies such as those carried out by Biernat et al. (2014) and Visnes et al. (2005) incorporated time-consuming training regimes, with twice-daily sessions. The demanding timetables, accompanied by consistent team practice and matches, may have led to an unproductive overall treatment protocol. This high load may have placed an excessive strain on the knee joint and the patella, especially in sports involving frequent jumps such as volleyball. This could hinder the beneficial effects of exercise on muscle power and tendon pathology.

The variability in training approaches (eccentric, concentric, isometric) in the studies analysed presents significant obstacles, preventing definite conclusions regarding the most efficient form of strength training for PT. Consequently, a distinct research gap has become apparent, indicating a need for future investigative studies to compare different exercise programmes while considering equivalent load dimensions.

Regarding psychological outcomes, the slight improvement in pain reduction, as demonstrated by the VISA-P test, is consistent with previous research showing considerable pain and symptom relief attained via eccentric and isometric training when compared to other techniques (Everhart et al., 2017; Lim & Wong, 2018; Visnes & Bahr, 2007). However, STUDY II discloses that the advantages of eccentric and isometric workouts could be smaller than formerly believed. For example, Bahr et al. (2006) assessed a control group that received surgical treatment followed by the same eccentric intervention as the intervention group. This makes it challenging to attribute the outcomes solely to either the surgical or conservative intervention. Additionally, the study by Cunha et al. (2012) included eccentric training in both groups but with differing pain thresholds, resulting in improvements in both groups without significant differences between them. Jonsson and Alfredson's (2005) study revealed superior results of eccentric training compared to concentric training. However, limitations including a small sample size and lower methodological quality indicate necessary caution in interpreting their findings. Additionally, Purdam et al. (2004) examined two variations of eccentric exercises, primarily differing in the use of a decline board, rather than assessing the efficacy of eccentric training itself. This distinction is significant for understanding the variations in training approaches and their specific impacts on PT.

A heterogeneous study situation is also evident when considering the time required for an improvement. Notably, Purdam et al. (2004) and Jonsson and Alfredson (2005) observed significant improvements in pain reduction after twelve weeks in the eccentric group. However, Cunha et al. (2012) observed improvement in eight weeks, which aligns with the findings of Rio et al. (2017) and van Ark et al. (2016), who noted significant progress in both intervention groups after four weeks. Assessing short-term applications, Van der Doelen and Jelley (2020) present the short-term pain relief and functional improvement effects of multiple interventions, including eccentric exercise, patellar strapping, sports taping, and injections. However, Mendonca et al. (2020) point to the limited superiority of conservative therapy over minimal or invasive interventions in short-term follow-up. This finding is supported by Challoumas et al. (2021), who propose that many proposed interventions do not significantly outperform sham treatments in terms of short-term pain or function. In the development of therapy programmes, the matter of whether refraining from sports and activities is advantageous for pain and symptom management presents an additional layer of complexity. In the absence of detailed descriptions concerning the intensity and duration of additional physical activities in most studies, it is difficult to determine the impact of physical activity levels on treatment outcomes. Thus, the varying durations for pain reduction, as well as an inconclusive impact of continued physical activity, suggest diverse responses to distinct training regimens, emphasising the demand for tailored rehabilitation protocols.

In sum, current literature, in line with the results of STUDY II, indicates a small benefit of eccentric and isometric training compared to other treatment methods for managing pain. It is noteworthy that most studies use comparable intensities and durations of training, but none combine different physical training methods, which can be described as a major research gap. The results of STUDY II, coupled with the constraints highlighted in various systematic reviews, emphasise the requirement for comprehensive research. Subsequent studies should not only investigate the relative impacts of distinct resistance training methodologies but also account for the broader context of an athlete's training schedule, encompassing the relationship between rehabilitation exercises and regular sports participation. Understanding the mechanisms at play is critical to the creation of more efficient and comprehensive treatment plans for individuals who suffer from PT.

5.4 The effectiveness of a progressive multimodal therapeutic approach

In STUDY III, a comparative analysis was conducted between a CON and an ALT therapy programme, focusing on their impact on physical, psychological, and injury-/pain-related parameters in young male soccer players recovering from PT. Consistent with the initial hypothesis this comparison revealed key distinctions in the outcomes of the two treatment approaches. Notably, the ALT group experienced a significantly shorter duration of therapy (47.1 ± 15.6 days) compared to the CON group (58.2 ± 24.6 days). The findings further demonstrated that the ALT group not only matched but, in some aspects, surpassed the CON group in terms of rehabilitation results. These aspects included equivalent improvements in muscle power, speed, and endurance, and notably better enhancements in CODS ($p < .001$, $d = 1.69/1.71$). Additionally, the ALT group showed comparable progress in psychological aspects, specifically in achievement motives ($p = .001$, $d = 0.86/0.90$), and recorded more favourable outcomes in injury and pain-related factors, such as lower incidence of lower-extremity injuries ($p = 0.23$; $d = 0.82$) and fewer pain-related interruptions in training ($p = 0.002$; $d = 1.16$). Therefore, the therapy-related effects of a multimodal therapeutic approach on a) physical, b) psychological performance, and c) injury-/pain-related parameters as well as on d) duration of therapy are presented and critically discussed in the following.

5.4.1 Therapy-related effects on physical parameters

In the evaluation of physical performance within STUDY III, both the CON and ALT therapy groups displayed notable improvements. This aligns with the study's initial hypothesis. Remarkably, the ALT group exhibited more substantial enhancements in physical performance compared to their CON counterparts. This was particularly evident in the context of CODS, a critical aspect of acyclic sprint performance. Throughout the 20-week evaluation period, the ALT group demonstrated significant gains in CODS, as reflected by substantial effect sizes in the post hoc analysis (AS left: $d = 1.51\text{-}3.84$). In terms of running speed, these findings translate to a notable improvement for the ALT group, from T1 = 2.66 m/s to T4 = 2.73 m/s, surpassing the improvements seen in the CON group, which only improved from T1 = 2.69 m/s to T4 = 2.70 m/s. This occurred despite the CON group undergoing a longer therapy period (58.2 ± 24.6 days), in contrast to the ALT group's shorter duration (47.1 ± 15.6 days), suggesting that the ALT therapy programme could be more effective in enhancing certain physical capabilities, particularly in agility and rapid directional changes. This efficiency, particularly regarding the players' return to competition following injury, holds considerable weight in determining their ability to reclaim their position in the team and mitigate negative psychological effects such as self-doubt, a factor linked to increased injury recurrence (Podlog et al., 2020; Tracey, 2003).

While previous studies have successfully employed various therapy protocols in treating PT (Agergaard et al., 2021; Breda et al., 2021; Cannell et al., 2001; Jonsson & Alfredson, 2005; Young et al., 2005), the emphasis has often been more on injury rehabilitation rather than on performance enhancement. However, Wilke et al. (2018) emphasized the importance of including performance-related variables in evaluating the efficacy of treatment protocols, particularly in determining an athlete's readiness for competition. Supporting this perspective, Millar et al. (2021) noted the discrepancy between pain perception and the actual pathological changes in tendons, suggesting that pain alone should not be the sole criterion for assessing long-term recovery. In support of this argument, the ALT group's results in physical performance revealed a need for higher intensity and complexity in rehabilitation exercises compared to the CON approach. This was particularly evident in their superior CODSs, a crucial element of athletic performance in competitive contexts (Kaplan et al., 2009). This enhancement in CODS represents a significant advantage of the ALT method over traditional therapy techniques. Notably, the integration of eccentric and isometric strength training on unstable surfaces, supplemented with additional weights, balance exercises with perturbation, and coordinative tasks (such as juggling or kicking a ball), as well as static stretching for the hamstrings and quadriceps, is a novel approach in this context and lacks direct comparisons in the existing literature. However, incorporating instability strength training into the management of PT, especially when integrated with higher cognitive load, could enhance CODS performance compared to traditional eccentric strength training for several reasons. This method of exercise challenges balance and proprioceptive abilities, essential for effective CODS movements. Training on unstable surfaces necessitates the activation of more stabilizing muscles to maintain dynamic balance, leading to improved proprioceptive responsiveness and joint stability (Behm & Colado, 2012; Behm et al., 2015), especially during dynamic movements (Reneker et al., 2019). Further instability exercises enhance neuromuscular coordination (Kraemer & Knobloch, 2009) and executive functions (Eckardt et al., 2020) by requiring continuous muscle activity adjustments for stability. This improved coordinative functioning can directly impact the ability to perform rapid, precise directional changes, crucial for CODS performance (Mack et al., 2023). It can therefore be concluded that the balance and instability strength exercises in ALT were probably responsible for the improvements in physical parameters, especially CODS.

However, it is important to note that other parameters like muscle power (DJ, JaR), endurance (YYIRL1), and speed (FTT15) did not demonstrate significant differences between the therapy methods. To fully meet the sport-specific requirements in the return-to-performance process, it would be useful to expand the ALT programme to also improve these aspects.

5.4.2 Therapy-related effects on psychological parameters

During the analysis of psychological parameters in STUDY III, it was observed that athletes who underwent the ALT therapy programme demonstrated significantly better scores in psychological performance metrics, such as net hope and fear of failure, compared to those in the CON group. Specifically, the ALT group exhibited significantly lower levels of fear of failure, while the hope for success metric did not show notable differences between the two groups. This result contrasts with the findings of Elbe et al. (2005), who suggested that factors such as net hope and fear of failure remain consistent throughout an athlete's career, even amidst varying circumstances. However, Johnston and Carroll (1998) conducted a qualitative analysis of competitive athletes and found a link between reduced confidence in athletic abilities and diminished performance after injury. This decrease in confidence often resulted in a heightened fear of further injury or re-injury, leading to hesitancy or reluctance to exert full effort in potentially risky situations. This is supported by Podlog et al. (2020) and Zafra et al. (2009), who linked an inadequate therapy programme to an athlete's increased insecurity during movement and in high-pressure scenarios within their sport. Athletes who struggle to regain their previous performance levels after an injury often experience elevated stress and frustration. This emphasises the importance of holistic improvements during the rehabilitation process. Zafra et al. (2009) also found a correlation between psychological readiness and injury incidence among tennis players. They noted that players with PT and lower psychological readiness for sports return tended to score lower on psychological performance assessments. In line with these findings, Tufekcioglu et al. (2014) observed that youth soccer players with higher levels of achievement motivation demonstrated better playing skills than their peers with lower motivation scores. Based on the lower fear of failure scores observed in the ALT group, it can be inferred that athletes receiving this form of therapy felt more prepared for their return to sports. This likely resulted in increased confidence in their movement abilities and resilience during competitive situations, which highlights the influence of rehabilitation on psychological factors in athletes. Therefore, it is crucial to implement holistic treatment strategies that increase an athlete's confidence in their movement abilities to improve physical recovery. A recent study by Tayfur et al. (2023) explained 44% of PT severity variance by quality of life ($\beta = 0.32$) and sports-specific function ($\beta = 0.38$), while Stubbs et al. (2024) identified kinesiophobia, pain beliefs, and fear-avoidance beliefs as the most relevant constructs to include in tendinopathy rehabilitation. Thus, such strategies should be an integral part of any therapy programme designed for athletic rehabilitation.

5.4.3 Therapy-related effects on injury-/pain-related parameters

The investigation conducted in STUDY III compared injury and pain-related parameters between athletes undergoing alternative (ALT) and conventional (CON) therapy for PT. The results showed significant differences, with the ALT group exhibiting a lower incidence of non-contact lower-limb injuries and fewer interruptions in training due to pain compared to the CON group, which according to Reneker et al. (2019) can be attributed to improved coordination and enhanced sensorimotor function. In addition, improved sensorimotor training leads to increased proprioceptive sensitivity, which is crucial for the preventive adaptation of movements and the avoidance of harmful situations in sports (Rössler et al., 2014). Schuermans et al. (2022) and Reneker et al. (2020), who enhanced normal injury rehabilitation with virtual immersive reality and found significantly better results in athletes compared to normal rehabilitation, also showed that more complex, more intensive training improves injury-related parameters.

The reduced frequency of training interruptions and the shorter overall duration of the ALT programme indicate a more efficient return-to-play process for competitive soccer players. However, the current literature predominantly reports improvements in injury and pain-related outcomes following specific types of exercises: (i) eccentric strengthening (Cannell et al., 2001; Lee et al., 2020), (ii) a combination of eccentric and concentric strengthening (Agergaard et al., 2021; Ruffino et al., 2021), (iii) balance training (Behm et al., 2015; Kraemer & Knobloch, 2009; Reneker et al., 2019), and (iv) hip strengthening (Rathleff et al., 2016). A recent study by Steinberg et al. (2020) explored the effects of isometric strength training and balance exercises in young dancers with patellofemoral pain. This study found that both exercise regimens, performed for 15 minutes three times a week over twelve weeks, led to significant reductions in pain. However, it lacked follow-up data and did not measure overall injury-related variables, underscoring a gap in the literature regarding comprehensive long-term outcomes of such therapies. Furthermore, previous studies have used either strength training or balance training as a treatment for PT but have not combined both approaches.

The results from STUDY III, particularly the lower injury and pain-related issues in the ALT group, suggest that a multifaceted approach to PT rehabilitation may offer more substantial benefits than singular exercise modalities. This comprehensive approach could be important in enhancing athletic performance, reducing the risk of re-injury, and expediting the return to competitive sports.

5.4.4 Therapy-related effects on therapy duration

The duration of therapy in the treatment of injuries such as PT significantly impacts short- and long-term outcomes, including physical, psychological, and injury-related aspects (Everhart et al., 2017; López-Royo et al., 2019; Sprague et al., 2021). A key consideration is whether shorter therapy durations, facilitating a quicker return to competition, as shown in STUDY III`s results, positively or negatively influence these outcomes.

A shorter therapy duration might speed up the return to sport but can also increase the risk of insufficient healing and rehabilitation (Magnusson et al., 2010). Especially in the rehabilitation of tendon injuries, the complex pathogenesis of the disease must be taken into account and too early loading can lead to further degenerative changes (Silbernagel et al., 2020) or inflammation (Rees et al., 2014). Also, psychological variables such as kinesiophobia, achievement motivation, fear of re-injury, and performance anxiety in athletes are significantly affected, because the athlete may not feel fully recovered both physically and psychologically. Reduced exercise capacity and caution resulting from this could even increase the risk of actual re-injury during therapy (Ardern et al., 2013). Appropriate duration of therapy can help to reduce the fear of re-injury by increasing the athlete's confidence in the strength and resilience of their body (Feller & Webster, 2013). In addition, positive experiences during rehabilitation can reduce the symptoms of kinesiophobia (Vivekanantha et al., 2023), which affect motor behaviour and lead to an increased risk of injury (Luque-Suarez et al., 2019). However, Slagers et al. (2021) showed that the development of these positive experiences and the readiness to return to sports cannot be achieved in the short term. This approach also helps to improve motivation, as the certainty of having fully recovered increases self-efficacy and reduces performance anxiety (Podlog & Eklund, 2007).

In contrast, extended therapy duration poses the risk of athletes developing a more profound fear of exercise as they gradually reduce their participation in normal sporting activities (Lundberg et al., 2004). In addition, concerns about reduced ability and performance during prolonged absence from sports can lead to increased performance anxiety (Podlog & Eklund, 2007). Christakou et al. (2022) illustrated that psychological outcomes following injury are primarily influenced by the athlete's belief in the effectiveness of therapy. This belief is associated with transparent and realistic communication regarding the duration of therapy (Clover & Wall, 2010), as well as an overall quick return to competition (Saluta & Nunley, 2006).

The majority of all successful exercise therapy interventions are reported to have an average duration of twelve weeks (Aicale et al., 2020; Burton, 2022; Rosen et al., 2022). However, Pearson et al. (2020) and Mayer et al. (2007) highlighted the potential for tendon adaptation over a short 4-week study period, suggesting the need for further investigation into the effects of therapy duration on tendon health and recovery. This is in line with the results of STUDY II, which showed that the included studies had a very heterogeneous treatment period of 4-24 weeks. Even if the pain-related rest period before the start of therapy (13.3 ± 4.1 days) is added to the actual duration of therapy (58.2 ± 24.6 days) in STUDY III's CON group, the total duration of this intervention was only ten weeks on average. The possibility must therefore be considered that a longer duration of therapy in CON could also have led to improved long-term results. However, since the population investigated in this dissertation was adolescent sub-elite soccer players, the comparatively short intervention period of STUDY III's INT group (47.1±15.6 days) until the absence of pain under full training load can be considered advantageous. For this group in particular, longer periods of absence could cause serious problems in terms of mental health (Podlog & Eklund, 2007), as well as in the school and social environment (DiFiori et al., 2014).

In summary, a fast return to competition fulfils the competitive requirements of the athlete and thus strengthens acute motivational components. However, the healing process can be hindered in the long term, whereby the effects of the duration of therapy on psychological factors vary greatly.

6. Practical implications and future directions

The results of the studies conducted in this dissertation lead to a variety of practical applications in therapy and training. In the following sections, these are presented and explained in more detail.

The findings of STUDY I showed significantly poorer physical and psychological performance variables in players with prior PT compared to healthy controls, suggesting the particular importance of these components in rehabilitation and training interventions. Indications of inadequate rehabilitation and/or training procedures may include the higher incidence rate of non-contact lower extremity injuries, longer injury-related rest periods, and a higher number of pain-related training interruptions in athletes with a history of jumper's knee in comparison to healthy controls.

When reviewing the literature (i.e., STUDY II), only small to moderate effects were found for eccentric or isometric training compared to other training methods. The studies mainly used isolated exercises and did not combine them with other effective methods. Furthermore, only outcomes before and immediately after therapy were measured and the significant long-term changes in PT were disregarded.

After performing a new treatment method (i.e., STUDY III) that combined isometric and eccentric strengthening with balance and stretching exercises, better results than conservative treatment that included eccentric strengthening and stretching exercises were observed. Furthermore, higher intensity and complexity in the form of additional weights, balance exercises with perturbation, and coordinative tasks led to a more effective and faster healing process upon return to competition. In addition to the beneficial results of the novel therapy programme, significant performance improvements were also seen in CODS. Therefore, the presented training method should be preferred by therapists who want to reduce the risk of re-injury and enable a faster return to previous performance.

The studies conducted revealed several new research questions and interesting considerations that should be considered in upcoming research:

1. STUDY I and STUDY III applied practical sport-specific testing procedures, with clinical measurements often used in other studies. Future studies should combine clinical measurements (e.g., knee extensor torque) with sport-specific (i.e., modified agility T-test) to improve comparability.
2. The applied test procedures in STUDY I and STUDY III were able to measure changes in physical and psychological parameters, but no structural changes in tendon morphology. Thus, to differentiate whether there were structural changes in addition to functional changes, future studies should perform a second ultrasound examination after the end of the post-rehabilitation phase.
3. The results of STUDY II indicated that the heterogeneity of the strength training methods used is very high, which makes it unclear which training method is the most effective one. Therefore, future studies should examine different forms of strength training for their effects on physical and psychological parameters.
4. STUDY III aimed to investigate short-, medium-, and long-term changes after different treatment programmes and thus did not collect baseline values. However, future studies should also collect baseline values when considering post-therapy changes to ensure comparability of the participants before the start of the intervention.
5. STUDY I to III have revealed that the interaction of physical, psychological, and injury-related parameters in PT is insufficiently assessed and thus should be considered in further studies.
6. STUDY II and III indicated that although multimodal therapy approaches exist, they are not being studied for the efficacy of the individual components. This could provide insight into more time-efficient therapy sessions when returning to competition.

7. Conclusions

The studies in this doctoral dissertation significantly contribute to a better understanding and treatment of the effects of PT on adolescent soccer players. Based on the results, the following conclusions can be drawn:

1. Even after completing PT therapy and feeling ready to return to competition, physical and psychological performance can still be negatively impacted, which highlights the need for improvements in current therapy methods to address these long-term effects.
2. CODS is negatively influenced for an entire season after the completion of a conventional therapy. This suggests a relationship with the significantly increased likelihood of injury, especially in soccer, which involves frequent changes of direction, and should be investigated further.
3. Although current treatment methods in exercise therapy are useful in reducing pain, they have little effect on physical performance. The development of future therapy methods should include the improvement of sport-specific performance factors.
4. The combination of strength training on unstable surfaces, additional cognitive-motor tasks and a progressive increase in therapy intensity improves physical, psychological, and injury-related outcomes in the long term and significantly reduces the overall duration of therapy.
5. Until now, research on the long-term effects of PT and related therapies has focused on clinical symptoms. Future studies should also investigate the impact on physical and psychological performance, especially among elite and sub-elite athletes.

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9. Appendix

9.1 Author Contributions to STUDY I: *"Differences in physical and psychological parameters in sub-elite, male, youth soccer players with jumper's knee following physical therapy compared to healthy controls: a longitudinal examination"*

Conceptualization: Marc Niering

Data Curation: Marc Niering, Thomas Muehlbauer

Methodology: Marc Niering

Formal Analysis: Marc Niering, Thomas Muehlbauer

Writing — Original Draft: Marc Niering

Writing — Review and Editing: Marc Niering, Thomas Muehlbauer

We hereby confirm that each of us contributed to the aforementioned publication as indicated above and acknowledge that the main part of work was carried out by Marc Niering.

9.2 Author Contributions to STUDY II: *"Effects of physical training on physical and psychological parameters in individuals with patella tendinopathy: a systematic review and meta-analysis"*

Conceptualization: Marc Niering

Data Curation: Marc Niering, Thomas Muehlbauer

Methodology: Marc Niering

Formal Analysis: Marc Niering, Thomas Muehlbauer

Writing — Original Draft: Marc Niering

Writing — Review and Editing: Marc Niering, Thomas Muehlbauer

We hereby confirm that each of us contributed to the aforementioned publication as indicated above and acknowledge that the main part of work was carried out by Marc Niering.

9.3 Author Contributions to STUDY III: ***"Changes after a conventional vs. an alternative therapy program on physical, psychological, and injury-related parameters in male youth soccer players with patellar tendinopathy during return to competition"***

Conceptualization: Marc Niering

Data Curation: Marc Niering, Thomas Muehlbauer

Methodology: Marc Niering

Formal Analysis: Marc Niering, Thomas Muehlbauer

Writing — Original Draft: Marc Niering

Writing — Review and Editing: Marc Niering, Thomas Muehlbauer

We hereby confirm that each of us contributed to the aforementioned publication as indicated above and acknowledge that the main part of work was carried out by Marc Niering.