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Comparison of Patient-Reported Outcome Measures and Mobile and Stationary Gait Analysis Systems for Evaluating a Multidisciplinary Biopsychosocial Rehabilitation Programme for Patients with Hip and Knee Osteoarthritis

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Zusammenfassung

Der Vergleich von Patienteneinschätzungen sowie mobilen und stationären Ganganalysesystemen zur Evaluierung eines multidisziplinären biopsychosozialen Rehabilitationsprogramms für Patienten mit Hüft- und Kniearthrose

Ziel: Es soll ermittelt werden, ob Patient-related outcome measures (PROMs) sowie mobile und stationäre Ganganalysesysteme bei Patienten mit Hüft- und Kniearthrose, die an einem multidisziplinären biopsychosozialen Rehabilitationsprogramm (MBR) teilgenommen haben, Verbesserungen erkennen können.

Design: Die vorliegende wissenschaftliche Arbeit ist ein Teilprojekt der Studie *Multidisziplinäre biopsychosoziale Rehabilitation bei Patienten mit chronischen Erkrankungen des Bewegungsapparates: Eine langfristige beobachtende Kohortenstudie*. Sie hatte ein Prä-Post-Studiendesign mit zwei Untersuchungszeitpunkten: vor der Intervention und am Ende der Behandlung.

Einrichtung: Die Studie fand in einer ambulanten Einrichtung statt.

Patienten: Patienten der Tagesklinik für Arthrose am Hüft- und Kniegelenk, die die Einschlusskriterien erfüllen

Intervention: ein vierwöchiges multidisziplinäres biopsychosoziales Rehabilitationsprogramm mit fünf Behandlungstagen pro Woche und insgesamt 79 Stunden.

Ergebnismessungen und -analyse: PROMs wurden unter Verwendung des Arthrose-Index der Universitäten von Western Ontario und McMaster (WOMAC) und seiner Subskalen für Schmerzen, Steifheit und Behinderungen verfolgt. Der 6-Minute Walking Test (6MWT) und zwei Ganganalysesysteme wurden verwendet, um die Gangparameter objektiv zu messen. Die in dieser Studie enthaltenen Systeme waren ein laufbandunterstütztes System mit Druckmessplatten und ein 3D-Bewegungserfassungssystem. Gangparameter wie Ganggeschwindigkeit, Schrittlänge, Trittfrequenz sowie durchschnittlicher Bewegungsbereich bei seitlicher Bewegung des Gelenks zwischen Lendenwirbelsäulensegment 5 und Sakralwirbelsäule 1 wurden untersucht. Die Auswirkungen wurden mit nichtparametrischen Tests analysiert.

Ergebnisse: Die Daten von 15 Patienten konnten analysiert werden. Das MBR-Programm verbesserte die patientenbezogenen Ergebnismaße erheblich. Der 6MWT (p-Wert=0,272)

und die durchschnittliche Ganggeschwindigkeit gemessen mit dem 3D-Bewegungserfassungssystem (p-Wert=0,165) zeigten eine Tendenz zur Verbesserung.

Schlussfolgerung: Das vierwöchige MBR-Programm war wirksam bei der Verbesserung der patientenbezogenen Ergebnismaße von Patienten mit Hüft- und Knie-Arthrose. Diese Studie konnte bei niedriger Probandenzahl eine geringe Verbesserung der Gangparameter zeigen.

Abstract

Objective: To clarify whether Patient-related outcome measures (PROMs) and mobile and stationary gait analysis systems can detect improvements in patients with hip and knee osteoarthritis (OA) who participated in a multidisciplinary biopsychosocial rehabilitation (MBR) programme.

Design: This study was a subproject of 'Multidisciplinary biopsychosocial rehabilitation in patients with chronic musculoskeletal health-conditions: A long-term observational cohort-study.' It had a pre–post study design with two points of assessment: before intervention and at the end of treatment.

Setting: Outpatient clinic.

Patients: Patients were from the hip and knee OA day clinic programme and fulfilled the inclusion criteria.

Intervention: The MBR programme was implemented over 4 weeks, which included 5 treatment days per week and consisted of 79 hours in total.

Outcome Measures and Analysis: PROMs were followed using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and its subscales for pain, stiffness, and physical function. The 6-Minute Walking Test (6MWT) and two gait analysis systems were used to objectively measure gait parameters. The systems included in this study were a treadmill-assisted system with pressure plates and a 3D motion capture system. The gait parameters included gait velocity, stride length, cadence, and average range of motion in lateral movement of the joint between the lumbar spine segment 5 and sacral spine 1. Effects were analysed with nonparametric tests.

Results: The data of 15 patients were analysed. The MBR programme improved patient-related outcome measures significantly. The 6MWT and the average gait velocity measured with the 3D motion capture system exhibited the tendency to improve (P values=0.272 and 0.165 respectively).

Conclusion: The 4-week MBR programme was effective at improving the PROMs of patients with hip and knee OA. This study was able to demonstrate small improvements in gait parameters despite the low number of participants.

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List of Abbreviations

6MWT	6-Minute Walking Test
LF	Average range of motion in lateral movement (lateral flexion) of the joint between the lumbar spine segment 5 and sacral spine 1
DGOU	*Deutsche Gesellschaft für Orthopädie und Unfallchirurgie* (German Society for Orthopaedics and Trauma)
ESCEO	The European Society for Clinical and Economic Aspects of Osteoporosis, Osteoarthritis and Musculoskeletal Diseases
GC	Gait cycle
IMUs	Inertial measurement units
JSN	Joint space narrowing
KL	Kellgren and Lawrence Scale
km/h	Kilometres per hour
LMU	Ludwig-Maximillian University of Munich
M	Metres
MBR	Multidisciplinary biopsychosocial rehabilitation
MRI	Magnetic resonance imaging
m/s	Metres per second
MS	Milliseconds
N.	Number of participants
NSAR	Nonsteroidal antirheumatic drugs
NYHA	New York Heart Association Functional Classification
OA	Osteoarthritis

P	P value
Pain 1	Item 1 from the Pain subscale of WOMAC – “How much pain do you have when walking on flat surfaces?”
PF 6	Item 6 from the Physical Function subscale of WOMAC – “What degree of difficulty do you have when walking on flat surfaces?”
PRM	Physical and rehabilitation medicine
PPIs	Proton-pump inhibitors
ROM	Range of motion
r *and* r_s	Spearman’s rank correlation coefficient
SL	Stride length
SPM	Steps per minute/cadence
SPSS	Statistical Package for the Social Sciences
TENS	Transcutaneous electrical nerve stimulation
TKA	Total knee arthroplasty
UKA	Unicompartmental knee arthroplasty
V	Gait velocity
WBV	Whole-body vibration training
WOMAC	Western Ontario and McMaster Universities Osteoarthritis Index
WOMAC Pain	Pain subscale of WOMAC
WOMAC Stiffness	Stiffness subscale of WOMAC
WOMAC Physical Function	Physical Function subscale of WOMAC
Xsens™	Mobile Xsens MVN Analyze™ 3D motion capture system by Xsens Technologies B.V.
Rehawalk®	Treadmill-assisted Rehawalk® system by Zebris

1. Introduction

Germany and most other industrialised countries have an ageing society due to increased life expectancy and reduced births. Over the next 2 decades, the proportion of older people in the total population will expand. Today, approximately 20% of the German population are aged over 65 years, but this proportion is predicted to increase to 34% by 2060 (1, 2).

The world's most common chronic joint disease is osteoarthritis (OA), and nearly a third of all adults exhibit radiological signs of OA (3). Postler et al. used 'de-identified claims data from a health insurance fund' to find that in Germany, the overall frequency of hip and knee OA was 21.8% (4). Furthermore, hip OA was found in 6.2%, knee OA was found in 12.1%, and OA in both joints simultaneously was found in 3.5% (4). Several reports on the prevalence of OA have indicated that these figures are going to increase in the coming years because the likelihood of developing OA increases with age (5-10). Today, people wish to function at high levels of vitality at higher ages, which is reflected in the retirement age increasing over the past three decades.

According to Hunter et al. and the Global Burden of Disease Collaborative Network, the number of people affected by OA increased by 48% between 1999 and 2019 (11, 12). This has created more personal, social, and economic challenges in society. The global burden of the disease will continue to grow, and in the future, more resources will be required for treating patients with hip and knee OA.

According to Postler et al., 43.1% of all patients with hip and knee OA receive physical therapy and 5.3% receive total hip or knee replacement (4). Most patients with OA are treated nonsurgically. Physical therapy, including exercise therapy and patient education, is the current best practice in early stages of OA (13). Combined therapies have exhibited positive outcomes, such as less pain, longer distances walked in the 6MWT, and higher quality of life, in patients with hip and knee OA (14-16). Earlier programs have shown positive effects on pain and function in self-assessment questionnaires, but there is no evidence of what changes the programs have on clinically measurable gait parameters. Therefore, determining the effects of a multidisciplinary biopsychosocial rehabilitation (MBR) programme on patients with hip and knee OA, especially using objective data from gait analysis systems, would be interesting.

Patients have high expectations for hip and knee OA treatments (17). In particular, they expect their ability to walk to have improved and their pain to have reduced following an intervention (17). Furthermore, a study indicated that patients with higher outcome expectations have higher self-efficacy and superior results post-intervention (18). To meet these expectations, patients should not only subjectively provide their physicians with feedback through questionnaires but also objective feedback in the form of gait analysis. This may allow physicians to better evaluate specific interventions and improve future treatment for patients with hip and knee OA.

In the following subchapters this work explains what OA of the hip and knee is as well as how it is treated according to different guidelines. I introduce common outcome measures used to assess patients subjectively and objectively with hip and knee OA. Then I define the hypothesis and specific aims of the present study.

1.1 Osteoarthritis of the Hip and Knee

Hip and knee OA is characterised by degeneration of the articular cartilage and subchondral bone (9). Primary and secondary OA are two subtypes of OA. Primary OA, which is the most common type, is mostly related to ageing, whereas secondary OA involves a specific trigger that causes cartilage breakdown. Risk factors that can lead to secondary OA include obesity, repetitive stress on the joint due to a job or physical activity, injury or surgery to the joint, rheumatoid arthritis, and even congenital abnormalities. Both types of OA result in the breakdown of cartilage, which enables smooth and friction-free movement between the joints. When this occurs, the bones that comprise the hip, pelvic acetabulum, and femur head, or the knee, femur, and tibia joint, start to rub against each other. This causes pain, swelling, stiffness, reduction in the ability to move that joint, as well as alterations in gait (19).

OA is often graded radiologically using the scale developed by Kellgren and Lawrence (KL) (20). According to KL, there are 4 grades of OA:

‘Grade 0:

- No joint space narrowing (JSN) or reactive changes

Grade 1:

- Doubtful JSN
- Possible osteophytic lipping

Grade 2:

- Definite osteophytes
- Possible JSN

Grade 3:

- Moderate osteophytes
- Definite JSN, some sclerosis
- Possible bone-end deformity

Grade 4:

- Large osteophytes
- Marked JSN, severe sclerosis
- Definite bone-end deformity’

(20, 21)

To date, many epidemiological studies have used the KL scale to rate OA, defining it according to the presence of a definite osteophyte (Grade ≥2) (8, 9, 22). However, incongruity often exists between radiographic changes and the patient’s self-reported hip or knee pain (23). This means that many patients who feel hip or knee pain may not have a radiographic indication of OA, while patients with a radiographic indication of OA may not exhibit any pain. Several studies have demonstrated that there is an increased desire to use technologies such as histology and magnetic resonance imaging (MRI) to discover early-onset hip and knee OA (24, 25). These technologies have advanced dramatically, and long-standing studies will assist in gaining scientific and regulatory approval for imaging measures as ‘prognostic’ or ‘efficacy of intervention’ biomarkers one day (26-29). Nevertheless, no specific criteria for defining OA using these methods have been established to date. Hence, the radiographic KL scale is still highly relevant in the diagnosis of OA.

Nonmodifiable risk factors for developing OA are age, gender, genetics, and ethnicity (30-32). Diet, obesity, and even lifestyle can be seen as modifiable risk factors for OA (30, 33, 34). According to a retrospective medical record review, OA can also develop post-traumatically and accounts for roughly 10% of all knee OA (9, 22).

Patients with OA often complain about pain while walking (19). They can also adapt their gait and develop a limp to counter their pain. This limping can worsen the more cartilage degenerates (35). The pain can develop suddenly, but it is more likely to develop slowly. OA can cause the hip or knee to swell due to periodic inflammation. Over time, this progressive degeneration can lead to deformities, such as an outward curvature of the knee joint (genu varus). The range of motion in the hip or knee can decrease and both joints can start locking. Furthermore, long-term inactivity due to hip or knee pain usually leads to atrophy of the muscles, which encourages further development of OA (30).

1.2 Treatment of Hip and Knee Osteoarthritis

There are several different approaches for treating hip and knee OA. The main goal of the treatment is to reduce patients' suffering and improve their quality of life. Treatment should aim to stop pain or reduce it significantly, and it should improve joint function and mobility. Furthermore, the treatment should reduce the degeneration of contralateral joints and the lower back. This degeneration could be caused by compensatory movements that cause unequal distribution of the load towards healthy neighbouring joints to reduce pain in joints with OA. The type of treatment given to a patient should be a shared decision between the physician and the patient.

1.2.1 Conservative Therapy

First and foremost, physicians should advise patients who are at risk of developing hip and knee OA to take preventative measures. These recommendations include preventing nonphysiological movements of the joints that are often made due to the patient's profession or sport (36, 37). Repetitive loading of the hip and knee joints during manual labour increases the risk of developing hip and knee OA (37, 38). Football players, high-level long-distance runners, and competitive weightlifters and wrestlers exhibit a higher prevalence of hip and knee OA compared with the general population (36). Patients should participate in sport that is gentle on the joints, such as swimming and cycling (39). Moreover, patients who are obese (BMI >30) are advised to reduce their weight because many studies have indicated that obesity can lead to hip and knee OA (40-42).

Conservative therapy includes several noninvasive methods for treating hip and knee OA. Both the European League Against Rheumatism (EULAR) and the European Society for Clinical and Economic Aspects of Osteoporosis, Osteoarthritis and Musculoskeletal Diseases (ESCEO) published recommendations for the treatment of OA based on evidence in 2018 and 2019, respectively (43, 44). Both referenced several studies on conservative therapies and strongly recommended patient education, weight loss, and an exercise programme. Several studies have demonstrated that physiotherapy and exercise therapy, which include strength, endurance, and mobility training, should be used in primary care for knee OA (45-48). In a review that included 39 articles, Golightly et al. found that aerobic and strengthening exercise programmes – both land- and water-based – are highly useful for reducing pain and improving physical function in patients with hip and hip OA (46). A systematic review by Uthman et al. included 60 trials with a total of 8212 patients that compared the effect of exercise interventions with no exercise control interventions in patients with hip and knee OA (48). These trials led to the conclusion that exercise therapy with a special focus on increased strength, mobility, and aerobic capacity has the highest probability of being the most compelling method for improving the pain and functionality of hip and knee joints (48). Furthermore, one systematic review demonstrated improved balance (49). Physical therapy, such as transcutaneous electrical nerve stimulation (TENS), shock wave therapy, and traction therapy, can have positive effects (50-53). Palmer et al. reported that patient-related outcome measures (PROMs) after a 6-week intervention with TENS and exercise therapy improved in a similar manner to exercise therapy alone (53). Extracorporeal shock wave therapy was the subject of a comprehensive review and meta-analysis by Li et al.; the authors found that said therapy may have a stronger therapeutic benefit than physical therapy, but concluded that larger sample sizes were required to confirm their findings (52). Alpayci et al. were able to demonstrate that traction therapy significantly reduced pain and PROMs in patients with knee OA compared with treatment using only 'hot packs' (50). Occupational therapy and naturopathy, including acupuncture, hydrotherapy, and mud packs, are also used to treat patients with hip and knee OA effectively (54-57).

1.2.2 Pharmacological Treatment

According to the DGOOC ("Deutsche Gesellschaft für Orthopädie und Orthopädische Chirurgie" or German Association for Orthopedics and Orthopedic Surgery), and their S2k guidelines for Coxarthrosis and Gonarthrosis published by AWMF ("Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften e.V." or Association of the Scientific Medical Societies in Germany), medicinal therapy is often recommended for patients with hip and knee OA in addition to other conservative therapeutic measures (58, 59). Oral nonsteroidal anti-inflammatory drugs (NSAIDs), which are analgesic and antiphlogistic, should be applied with the lowest effective dose and used as briefly as possible. NSAIDs have a high risk of gastrointestinal, cardiovascular, and renal adverse effects, which occur more frequently in older people and at larger doses. Depending on the patient's comorbidities, co-medication, such as proton-pump inhibitors (PPIs), can be added to lessen the danger of upper abdominal pain, heartburn, dyspepsia, or the development of a bleeding gastrointestinal ulcer. If the oral application of NSAIDs is not sufficient or the risk of unwanted side effects is high, the intra-articular application of corticosteroids or hyaluronic acid can be recommended as a treatment. Furthermore, clinical studies and meta-analyses on slow-acting drugs for OA (SADOAs) such as glucosamine and chondroitin sulphate have reported contradictory data on their symptom-relieving (e.g., analgesic, function-improving) effects (58, 59). Ongoing studies are still debating the effectiveness of hyaluronic acid and glucosamine; however, these treatments can be considered for NSAID-intolerant patients (60, 61). Both the ESCEO and the DGOOC have recommended that opioids can be used to reduce pain and suffering in patients with hip and knee OA if medicinal therapy with NSAIDs is unsuccessful (44, 58, 59). Using weak opioids in the short term can be considered in case of inoperable patients or patients who are briefly accompanied until surgery. The benefit of opioids over NSAIDs, despite the therapeutic effect not differing significantly, is that they have fewer gastrointestinal, cardiovascular, or renal side effects. However, opioids' side effects include central nervous effects such as dizziness and imbalance, leading to an increased tendency to fall, as well as being associated with a high risk of developing addiction.

1.2.3 Multidisciplinary Biopsychosocial Rehabilitation (MBR)

MBR can be defined as a combination of various conservative therapies. MBR programmes acknowledge that pain is not only a result of anatomical and physiological problems but can also be caused by psychological factors, such as anxiety, fear-avoidance, and the tendency to catastrophise (62-64). Social and environmental factors such as physical job demands, workplace social support, and expectations for resuming work affect long-term physical function (65). In addition, research indicated that psychosocial characteristics such as mental health, self-efficacy, and social support, as well as physical activity protect individuals with hip and knee OA from deteriorating joint function and consequential disability over time (66).

Sharma et al. used the Short-Form 36 (SF-36) to measure mental health, the Arthritis Self-Efficacy Scale physical function subscale to measure self-efficacy, and social support was measured using the Medical Outcomes Study Social Support Survey (66). These characteristics were compared to the changes in patients' physical functions over 3 years. It was concluded that patients with 'better baseline mental health, self-efficacy and more social support' are less likely to have poor physical function outcomes over this time period(66). These insights have led to interventions being developed that focus on several factors, including physical, psychological, social, and occupational components, which are delivered by a team of specialised physicians and other health professionals. A variety of venues, including multimodal pain clinics, rehabilitation centres, and outpatient settings, can be used to deliver MBR (62).

Many studies regarding the effectiveness of individual conservative therapies have been conducted, and such therapies can be recommended in the treatment of hip and knee OA (43, 44). However, there are currently very few studies that target multidisciplinary approaches suitable for hip and knee OA in primary care (67). In a systematic review on multidisciplinary approaches, Finney et al. only found four suitable multidisciplinary studies that have used both educational and exercise interventions to improve hip and knee OA (67). Hence, much more research is required to solidify the effectiveness of MBR on patients with hip and knee OA. Nevertheless, some studies have reported that therapies combining exercise therapy and patient education had positive effects on the outcomes (14-16). For example, Hunt et al. (2013) combined exercise and pain-coping skills to treat patients with knee OA in a randomised controlled trial, and demonstrated that the intervention could improve both physical and psychological outcomes, such as 'isometric knee strength, self-reported knee pain and physical function, as well as self-efficacy' (15). This indicates that in theory, the combination of several conservative therapies, such as exercise therapy, occupational therapy, physical therapy, and patient education could have greater positive outcome effects in the treatment of hip and knee OA compared with treatment using single therapies. Also, one might suspect greater outcome effects in the treatment of hip and knee OA in patients who have psychological or social risk factors for more pain.

In any case, MBR can be considered if other, less complex measures such as unimodal conservative therapy and pharmacological therapy have not been successful. However, MBR is difficult to implement for economic reasons. The indication for MBR for patients with hip and knee OA should be made after a thorough clinical assessment. Due to the ongoing demographic changes, higher life expectancy, and patients' need for greater activity levels in their old age, the prevalence of hip and knee OA will increase as will the need for therapy. This will place more pressure on current resources. MBR programmes should aim to educate patients, improve the functionality of their hip and knee joints, and mentally strengthen them so that they feel safer and do not develop advanced hip or knee OA as quickly as they would have done prior to the intervention. Therefore, it can be inferred indirectly that MBR programmes, in which patients learn how to cope with their hip and knee OA sufficiently early, could prevent the frequency of hip and knee surgeries and the unnecessary use of resources.

1.2.4 Surgical Therapy

When conservative treatments fail, surgical techniques are recommended for treating hip and knee OA (58, 59, 68). The indication for hip and knee replacement should be considered if a patient reports a high level of subjective distress through pain, functional restrictions, and limitations in their activities of daily living, despite guideline-compliant conservative therapy for at least 3 months (68). However, hip and knee replacement is only recommended if it is objectively proven through radiological imaging that the patient has advanced hip or knee OA (KL Grade 3 or 4).

Depending on the grade or location of the degenerated cartilage, different types of endoprosthetic joint replacements can be applied. For example, patients with isolated medial or lateral knee OA can be treated with medial or lateral unicompartmental knee arthroplasty (UKA) (69-71). For individuals with advanced knee OA, total knee arthroplasty (TKA) is a highly successful long-term therapeutic option (72, 73). Both types of joint replacements can lead to reduced pain and better function, and therefore, they can lead to improved quality of life for patients. This is reflected by the systematic review by Ethgen et al. which describes several studies that measured an improvement in the health related quality of life with the Short-Form 36 (SF-36) (72). UKA has several advantages compared with TKA, such as quicker recovery and smaller incisions. However, in the long term, the revision frequency for UKA is higher than that for TKA (74-76). Total hip arthroplasty (THA) is another effective treatment in the long term for patients with hip OA (77). Nevertheless, risks and complications that should be considered are postoperative dislocation of the hip, abductor muscle insufficiency, intraoperative fractures, as well as nerve injuries (77). Patients should be accurately informed about the pros and cons of the different joint replacement interventions before deciding what to do.

1.3 Outcome Measures

1.3.1 Patient-Related Outcome Measures

PROMs provide information on a patient's health condition as well as on the impact of interventions and therapies from the patient's point of view. PROMs are systematically recorded and supplemented with evidence-based information to help fit medical care with patients' needs, values, and preferences. PROM data can be used to compare the efficacy of various treatment strategies and determine which approach has the best likelihood of success in the context of the specific goal. Several different PROMs are regularly used. PROMs, such as SF-36, measure general health-related quality of life and can be used regardless of the disease. The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Knee Disability and Osteoarthritis Outcome Score (KOOS), and Oxford Knee Score (OKS) are the most commonly used disease-specific PROMs for hip and knee OA (78). These questionnaires include subscales such as pain, physical function, and quality of life, which define patients' lived experience of hip and knee OA (79). PROMs encourage patient-centred care and enable the provision of care that is most beneficial to the patient, in addition to more objective clinical information such as imaging and gait analysis.

1.3.2 Gait Analysis

Gait analysis is a technique for assessing and treating people who have problems walking. The effect of conservative therapy interventions for patients with hip and knee OA is commonly measured using gait analysis (80-83). Gait analysis usually measures a set of various gait parameters such as speed, step length, stride length, cadence, joint angles, and even pressure distribution of the foot. These parameters can provide objective insights into the walking ability of patients with hip and knee OA.

Many different systems exist for measuring gait parameters. They usually work on the basis of kinetic, kinematic, and dynamic electromyography. The present study used two different systems: the first was Rehawalk®, a static system, which was developed by Zebris (Isny, Germany), and the second was Xsens MVN Analyze™, a mobile system, which was developed by Xsens Technologies B.V. (Enschede, Netherlands). Most of the time, the measurement of gait parameters is highly technical and time consuming. Therefore, it is usually only used for scientific research rather than everyday clinical use. For these methods to be used in everyday clinical life, they would need to be simplified. Spatial parameters (i.e., distance parameters), such as step and stride length, and temporal parameters (i.e., time parameters), such as cadence and gait speed, are examples of spatiotemporal parameters. These parameters are critical when assessing pathologies of the musculoskeletal system and can be measured using both systems that were employed in the present study.

Even though several studies have used different gait analysis systems to measure the effect of conservative interventions, no studies – to the best of my knowledge – have used both static and mobile systems to compare the pre- and post-test effects of an MBR programme on patients with hip and knee OA.

1.3.2.1 The Gait Cycle

A brief introduction of the gait cycle will help understand how the Xsens™ raw data was processed to calculate the gait parameters. During locomotion, one gait cycle (GC) is the time taken for a foot to contact the ground and then to make contact with the ground again. This is referred to as a stride. A GC is split into 'two main phases – the stance and swing phase, as well as eight functional periods – initial contact, loading response, mid stance, terminal stance, pre-swing, initial swing, mid swing, and terminal swing' (84). These phases are presented in Figure 1.

Figure 1: Diagram of the Gait Cycle (Source: Own Illustration & Photography based on Stöckel, 2015 (84)).

The stance phase, accounting for approximately 60% of the gait cycle, takes place when the reference foot touches the floor (85). This Phase is split into 5 subphases, which are described by Perry et al. (1992) and Stöckel et al. (2015) as follows:

- Phase 1 – Initial Contact: The heel contacts the ground.
- Phase 2 – Loading Response (Foot Flat): Starts immediately after the heel's ground contact and then the weight is shifted. It ends when the opposite foot is lifted for the swing.
- Phase 3 – Mid Stance: Starts with the lifting of the opposite foot and ends when the bodyweight is evenly distributed over the forefoot.
- Phase 4 – Terminal Stance: Starts when the heel rises and ends when the opposite heel contacts the floor.
- Phase 5 – Pre-Swing: Starts after the opposite heel contacts the floor and continues until the ipsilateral foot is lifted for the swing. (86, 87)

The swing phase occurs when the reference foot is not touching the floor and swings in the air (85, 88). This makes up about 40% of the gait cycle. This phase is split into 3 parts:

- Initial Swing,
- Mid-Swing,
- Terminal Swing. (86, 87)

1.4 Hypothesis and Specific Aims

Improvements in pain, stiffness, and physical functions after an intervention can be recorded with the validated and commonly used WOMAC. However, WOMAC scores do not explain why people feel better or what is causing their pain and disability. Hence, gait analysis systems could offer physicians more objective insights as well as explain whether altered gait causes these improvements in WOMAC scores. Furthermore, data gathered from gait analysis could be used to more effectively plan an individual treatment programme that is adapted to the patient's specific needs.

The specific aims of this study were as follows:

- To evaluate the effects of a 4-week MBR programme on pain, stiffness, physical function, gait parameters, and 6-Minute Walk Test (6MWT) performance;
- To evaluate the correlations between the WOMAC and gait parameters of two gait analysis systems, namely Rehawalk® by Zebris and Xsens™ by Xsens Technologies B.V.;
- To evaluate the correlations of gait parameters between the Rehawalk® and Xsens™ gait analysis systems as well as between said systems and 6MWT performance;
- To evaluate the correlations among changes pre-/post-treatment of parameters of the Rehawalk® stationary gait analysis system, the Xsens™ mobile gait analysis system, and 6MWT performance.

The remainder of this thesis is organised as follows. Chapter 2 presents the materials and methods and explains how I attained and statistically processed the data. Chapter 3 describes the results, which are discussed in chapter 4. Chapter 5 concludes the thesis.

2 Materials and Methods

2.1 Study Design

This clinical study was a subproject of a study titled ‘Multidisciplinary biopsychosocial rehabilitation in patients with chronic musculoskeletal health-conditions: A long-term observational cohort-study’. It adopted a pre–post design. Recruitment began on 25th June 2018 and data collection ended on 19th March 2019. The study was approved by the Research Ethics Committee of the Medicine Faculty at Ludwig-Maximillian University (LMU), Munich, Germany (Project Number: 632-16). The study was conducted in accordance with the Declaration of Helsinki.

Participants were recruited from an outpatient clinic at the Department of Orthopaedics, Physical Medicine and Rehabilitation (OPMR), University Hospital, LMU Munich, Germany.

A written patient information form was provided to the participants to inform them about the procedure as well as the use and risks of participating in the study. They were also informed verbally and advised not to start any other gait and postural control rehabilitation interventions for the duration of the study as it would ultimately result in their exclusion from the trial. Prior to enrolment, all patients signed informed consent forms.

2.2 Participants

At the assessment, the recommendation of MBR was given based on predefined inclusion and exclusion criteria, the results of standardised assessments and clinical tests, and the appraisal of the results by the treatment team. The team consisted of a specialist in Physical and Rehabilitation Medicine, a physiotherapist, and a psychologist.

The predefined inclusion criteria for participation in the MBR programme were radiological OA of the knee and hip of grade 2 or higher according to KL (20), knee or hip pain, prior outpatient physical therapy that did not provide meaningful gains based on the patient’s responses to oral questions, limits in activities and involvement, no extra pain medication for the duration of the study, and an adequate command of the German language to follow instructions during the MBR.

Exclusion criteria for participation in the MBR were severe somatic or mental illnesses that would limit one’s capacity to participate in the MBR (e.g., major depression, schizophrenia, and dementia).

Additional criteria for inclusion in this study were a signed informed consent form and the ability to perform the gait analyses.

2.3 Assessments

Each participant was evaluated for a variety of outcome measures before the intervention (pre-test = T1) and on the penultimate day of the 4-week exercise programme (post-test = T2). After a 6-month (T3) follow-up period, participants were sent a stamped addressed envelope that contained questionnaires as well as a letter that reminded them to return the completed questionnaires. Table 1 lists the measures and their application at each assessment.

Table 1: Measures

Measure	Baseline	End of Treatment	6-month Follow-Up	Outcome Domains
Questionnaires				
Sociodemographics	X	--	--	Sociodemographic data
SCQ	X	--	--	Comorbidities
HADS	X			Depression and Anxiety
SF-36	X	X	X	Generic health status
WOMAC	X	X	X	Pain, stiffness, and function
Clinical Tests				
6MWT	X	X	--	Endurance and walking ability
Xens™	X	X	--	Gait speed (V) and lateral flexion
Rehawalk®	X	X	--	Gait speed (V), stride length (SL), and steps per minute (SPM)

Legend: SCQ = Self-administered Comorbidity Questionnaire, HADS = Hospital Anxiety and Depression Scale, SF-36 = Short Form 36, WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index, 6MWT = 6 Minute Walk Test, Xsens™ = gait parameters assessed with the Xsens system, Rehawalk® = gait parameters assessed with the Rehawalk® system, V = average gait velocity, Lateral flexion = average range of motion in lateral movement of the joint between lumbar spine segment 5 and sacral spine 1, SL = average stride length, SPM = step per minute (cadence).

2.3.1 Gait Analysis

Spatial-temporal parameters of the participants' gait cycle were obtained through gait analysis performed on a treadmill with an embedded pressure plate (Rehawalk® Zebris, Isny, Germany) as well as mobile 3D motion tracking sensors (Xsens MVN Analyze™ by Xsens Technologies B.V., Enschede, Netherlands), as described in the following subsections.

2.3.1.1 Treadmill-Assisted Rehawalk® System

The treadmill assisted Rehawalk® system is designed for analysing and treating gait disorders in neurological, orthopaedic, and geriatric rehabilitation. This system consists of a treadmill with an embedded pressure plate. It uses pressure measurements and can provide insights into pressure distribution, contact area, centre of force movement, and symmetry between sides. Furthermore, it can provide spatiotemporal data. The reliability of the spatiotemporal and kinetic parameters measured with the Zebris Rehawalk® system has been tested (89, 90). Since its release, the system has been used in several studies on Parkinson's disease, multiple sclerosis, and total hip or knee arthroplasty (91, 92). The pressure plates detect when each foot touches the ground during gait and then automatically calculate the rest of the gait parameters from this information. The treadmill assisted Rehawalk® system is seen in action in Figure 2.

Figure 2: Treadmill-Assisted Rehawalk® System.

Patients were asked to choose their preferred speed while the speed display was covered. They were given 2 minutes to familiarise themselves with the treadmill and find their preferred speed. A recording on the treadmill took 30 seconds and the computer program automatically calculated the average gait parameters. These data were entered into the Statistical Package for the Social Sciences (version 24; IBM®, Chicago, USA) for further analysis.

The gait parameters recorded using the Rehawalk® system in this study were gait velocity, stride length, and cadence (i.e., steps per minute). Cadence indicates how many times per minute the feet contact the ground.

6.3.1.2 Mobile Xsens™ 3D Motion Capture System

Xsens MVN Analyze™ (Xsens™) was introduced in 2009 as MVN BIOMECH and was later renamed in 2017. During this period the system was further developed and updated to simplify its use. Xsens™ is a 3D motion capture system that is increasingly used in research (93-95). It is a relatively new form of inertial measurement unit (IMU) based on micro-electro-mechanical system technology, which has caused a rush of research in recent years. The IMU collects 3D accelerometric data, which are used to calculate the angles, acceleration, and speed of individual body parts and joints of a patient. These data can be used to calculate spatiotemporal gait parameters (96). Xsens™ uses 17 inertial and motion wireless tracking sensors and data from them are sent over a wireless connection to a computer, where they are processed and further visualised (97). A few studies have used this system to analyse gait (93-95, 98). Between 2016 and 2019, Karatsidis et al. and Konrath et al. published several studies to demonstrate how Xsens™ could be used in ambulatory settings for patients with hip and knee OA. Each study included 10 or fewer healthy participants. The study from 2016 aimed to find estimates 'of ground reaction forces and moments during normal gait' in healthy subjects (93). In 2019, Konrath et al. used Xsens™ to find an 'estimation of the knee adduction moment and joint contact force during daily living activities', such as walking upstairs (98). However, no study using Xsens™ has been conducted to measure improvements or changes in gait after an intervention for patients with hip and knee OA.

In this study, body dimensions had to be measured for each participant. These included 'body height, shoe or foot length, arm span, ankle height, hip height, hip width, knee height, shoulder width, shoulder height, and extra sole height' (99). Descriptions of these dimensions are provided in Table 2.

Table 2: Xsens™ Dimensions of Measurements (from the Xsens MVN User Manual) (99)

Dimension	Description
Body height	Ground to top of head when standing upright
Foot size	Length of feet or length of shoes if wearing shoes
Arm span	Top of right fingers to top of left fingers in T-pose
Hip height	Ground to most lateral bony prominence of greater trochanter
Knee height	Ground to lateral epicondyle on the femoral bone
Ankle height	Ground to distal tip of lateral malleolus
Hip width	Right to left anterior sup. iliac spine
Shoulder width	Right to left distal tip of acromion (acromial angle)
Shoulder height	Ground to C7 spinal process
Extra sole height	Additional thickness of soles below normal shoe sole height. Use for stilts, platform soles, etc.

Sensors were attached to the participants' feet, lower and upper limbs, pelvis, sternum, shoulders, upper and lower arms, and head. Figure 3 presents an example of this setup. The foot sensors were secured with extra tape. Once the sensors had been applied, the system had to be calibrated to each patient. The calibration was repeated 2–5 times depending on the compliance of the patient.

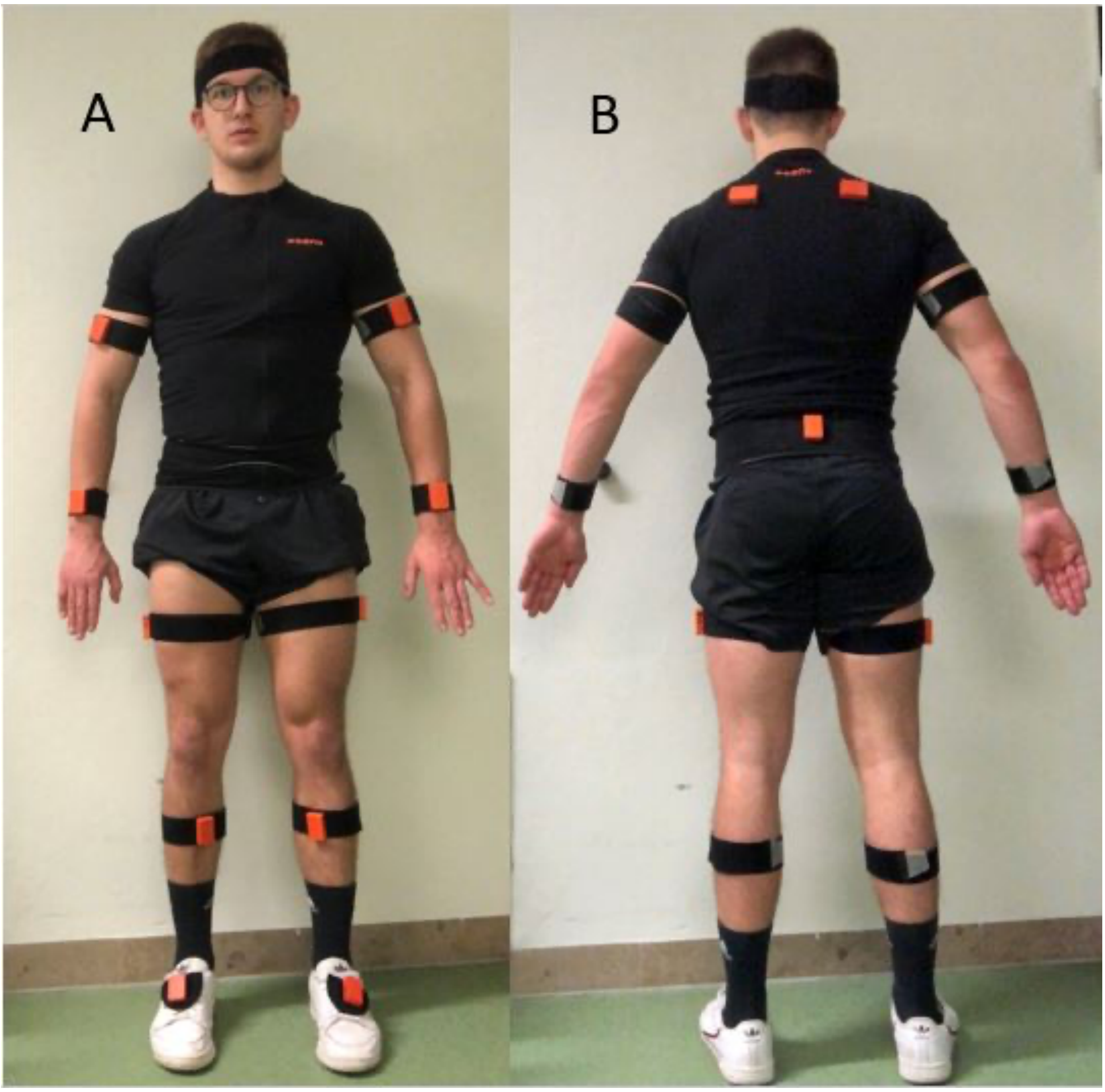

Figure 3: Xsens™ 3D Motion Capture System: A: Front; B: Back (Source: Own Illustration & Photography).

When wearing the 3D motion tracking sensors, patients were instructed to find their preferred speed by walking up and down a 30-metre track at least once. Patients walked for 30 metres, turned at the end, and walked back to the start. When patients were confident about their preferred speed, the recording was started. One recording was the length of the 30-metre track and back to the start. The Xsens™ raw data from the recordings were then converted to usable data in the computer program Excel.

In this study, Xsens™ data were used to measure gait velocity and stability. The parameter for gait stability was lateral movement (in degrees) in the joint between lumbar spine segment 5 and sacral spine 1, which was measured using Xsens™. This parameter was intended to reveal the compensatory movements in patients caused by pain, stiffness, and reduced physical functions.

6.3.1.3 System Comparison

Both the Xsens™ and Rehawalk® systems measure gait velocity. Xsens™ data provided gait data that other gait analysis systems would not be able to provide, because the patients were not constricted to walking on a treadmill and could therefore move more naturally. Xsens™ is a system unlike Rehawalk® in that it is not confined to an external infrastructure (100). This means that one can freely move around when wearing the sensors and every twitch of the body is recorded.

Gait parameters recorded with Rehawalk® offer insights into the gait patterns of the patient by breaking down the gait cycle. However, unlike Xsens™, the treadmill-based pressure plates of Rehawalk® cannot provide information about joint angles and limb acceleration.

Rehawalk® did not require any calibration, input of any extra body dimensions, or further processing of raw data, which were necessary for every patient when Xsens™ was used. Table 3 presents a comparison of the Xsens™ and Rehawalk® systems.

Table 3: System Comparison

	Rehawalk®	**Xsens™**
Gait Parameters Measured	• Gait velocity • Stride length • Steps per minute	• Gait velocity • Lateral flexion
Where?	Gait lab: treadmill	Corridor: free walking
Assessment Duration (s)	30	30-60
Calibration necessary?	No (not for every new patient)	Yes (for every new patient)
Data entered into Software	None	Body dimensions
What measures?	Embedded pressure plate	Inertial measurement unit
Data Recorded	Pressure measurements	3D accelerometric data
Data Processing	Automatically computed	Raw data – manual computation

Legend: Lateral flexion = average range of motion in the lateral movement of the joint between lumbar spine segment 5 and sacral spine 1.

2.3.2 Six-Minute Walking Test

The basic mobility of the participants was assessed using a previously validated clinical test, namely the 6MWT, which is frequently used in assessments for patients with pulmonary diseases as well as for OA of the lower extremities (101-106). Kennedy et al. demonstrated that the 6MWT has excellent test–retest reliability for patients with OA (107). Further conditions where the 6MWT can be used with high test–retest reliability are geriatrics, multiple sclerosis, Parkinson's disease, and stroke (108-110). In this test, the patient is asked to walk as far as possible in 6 minutes. He or she walks up and down a 30-metre walkway for 6 minutes or until they need a break. The distance in metres covered in 6 minutes is used as the outcome. This test can be used to detect changes in basic mobility between pre- and post-intervention; a greater distance walked in 6 minutes would mean an improvement in basic mobility. In healthy adults, the 6-minute walk distance varies between 400 and 700 metres. (111).

2.3.3 The Western Ontario and McMaster Universities Osteoarthritis Index

The WOMAC questionnaire is a fully standardised OA index that records the symptoms and physical functions of patients with hip and knee OA in everyday life. Bellamy et al. developed the WOMAC in 1988 (112). Stucki et al. evaluated the German version of the WOMAC in 1996 (113). Since then, validations of the questionnaire have been conducted in several countries, including Sweden (114), Italy (115), Turkey (116), Spain (117), and others (118, 119).

This questionnaire was developed purely for patients with knee and hip OA. It has been used in studies on hip and knee OA for many years now (45, 80, 120). This makes it easy to compare the results with those of other studies. According to Bellamy, the WOMAC is a reliable, valid, and multidimensional instrument that accurately reflects the therapeutic effect on patients with hip and knee OA (121-123).

The WOMAC was used to assess the pain and physical function of the patients in their everyday life. It comprises 24 items that can be used for either hip or knee OA. The questionnaire is split into 3 subscales. Subscale A (WOMAC Pain) has 5 items for pain during specific movements and positioning of the patient; subscale B (WOMAC Stiffness) has 2 items for stiffness of the affected joint; and subscale C (WOMAC Physical Function) has 17 items for physical function. Patients should respond to the questions based on how they have felt over the previous 2 days. The questionnaire takes roughly 5-10 minutes to complete. This is a valid and reliable questionnaire that is available in several countries and has been translated into more than 100 languages. It comes in a variety of formats, including a 5-point Likert scale, a 100-mm visual analogue, and an 11-box numerical rating scale. In this study, the German version of the WOMAC was used, which was translated and evaluated by G. Stucki et al. (113). This version of the WOMAC uses the 11-box numerical rating scale format with values ranging from 0 to 10.

The WOMAC is scored as described by G. Stucki et al. and Bellamy et al. (113, 124, 125). Each subscale is scored by calculating the mean of the item scores, which causes the results to equal standardised WOMAC scores (124). Each sum of the subscale item scores was divided by the number of items. This meant that the sum of the pain subscale was divided by 5, the sum of the stiffness subscale was divided by 2, and the sum of the physical function subscale was divided by 17. A composite score was calculated by dividing the sum of the total WOMAC score by 24 (124). The subscale scores as well as the composite score range from 0 to 10 (124). Higher scores on the WOMAC indicate higher pain and stiffness as well as reduced physical functions (112, 122, 123).

The most crucial questions for this study were those that specifically ask about pain or limitations during gait. These include Item 1 in the pain subscale (Pain 1) and Item 6 in the physical functions subscale (PF 6). In the Appendix, an example of the original questionnaire used in this study is attached.

2.4 Interventions Protocol

All participants participated in the 4-week MBR programme at the Osteoarthritis Day Clinic at the OPMR, in the LMU Clinic in Munich, Germany. Details of the MBR programme, which comprised 5 treatment days per week and 79 hours in total, are presented in Table 4. The table was adapted from a study that evaluated the chronic neck pain-specific MBR programme of the department (126) and changed for hip and knee OA-specific content. Patients were treated in small groups of 5 to 8 patients. On the first day of week 1 and the penultimate day of week 4, assessments were scheduled.

Patients were motivated to practice exercises at home. This was intended to help with the internalisation of the exercises. They were also taught to avoid overloading of the hip and knee joints in everyday life. The treatments were administered by a specialist in physical rehabilitation medicine (PRM), a physiotherapist, an occupational therapist, a psychologist, a medical massage therapist, and a balneotherapist. Patients received a folder with therapeutic information, reassurance, and regular support from the physician and other health professionals, as well as developed individual long-term goals by applying the SMART technique (Specific, Measurable, Achievable, Realistic/Relevant, and Timed) (127). These measures, similar to the study conducted by Letztel et al., were aimed at increasing the sustainability of the MBR programme (126).

Table 4: Treatment Programme

Types of Therapy	Content	Goals	Profession	Total frequency (duration), frequency per week
Assessment at entry	Physical examination, clinical tests, individual goal setting including the patient's perspective	Evaluation of health status, definition of treatment goals, motivation of the patient	Specialist in PRM, physiotherapist, occupational therapist	1 (135 min) week 1, 1st day
Physiotherapy exercise	Hip- and knee-specific strengthening and stretching, general strengthening and stretching exercises, task-oriented training, teaching and encouragement of home exercises, handouts	Strengthening of hip abductor/adductor and knee flexor/extensor muscles, global muscle strengthening with a focus on the back and lower extremity, improvement of mobility of the hip and knee joints, improvement of postural control, reduction of tension of painful muscles, ability to perform home exercises	Physiotherapist	20 (30min) week 1: 4 week 2: 6 week 3: 6 week 4: 4
Physiotherapy theory	Theoretical introduction to the anatomy of the leg muscles and the principles of hip abductor/adductor and knee flexor/extensor muscle exercises	Knowledge of principles of leg muscle stabilisation exercises	Physiotherapist	3 (60min) week 1: 1 week 3: 1 week 4: 1
Nordic walking	Instructions on correct walking technique, walking outdoors in groups depending on endurance	Reduction of overloading of the hip and knee joints, improvement of endurance, improvement of walking distance	Physiotherapist	3 (60min) week 1: 1 week 2: 1 week 3: 1
Gym training (group)	Training with weight machines, treadmill training, vibration training	Improvement of strength of back muscles and lower extremity muscles, improvement of general endurance and postural control	Physiotherapist	7 (60 min) week 1: 2 week 2: 2 week 3: 2 week 4: 1
Pool exercises (group)	Aquatic exercises and swimming	General endurance and strength training, strengthening of hip abductor/adductor and knee flexor/extensor muscles through leg exercises, mental relaxation	Physiotherapist, balneotherapist	7 (60 min) week 1: 2 week 2: 2 week 3: 2 week 4: 1
Occupational training (group)	Work and PC ergonomics, household ergonomics, advice for structuring daily activities, instructions on bearing weights, recommendations for mattresses and cushions, recommendation for ergonomic bicycles	Adaptation of activities in the workplace, household, garden, as well as in leisure time	Occupational therapist	14 (30 min)* week 1: 2 week 2: 6 week 3: 4 week 4: 2
Psychological lessons (group)	Relaxation techniques (Jacobson technique), learning of how to enjoy, teaching of how to overcome fear-avoidance behaviour, teaching of strategies for adhering to goals	Learning of relaxation techniques, reduction of depressive symptoms through learning how to enjoy, reduction of fear-avoidance behaviour, increase of adherence to personal goals	Psychologist	12 (30 min)* week 1: 2 week 2: 4 week 3: 4 week 4: 2
Self-help techniques (group)	Instructions on self-help techniques such as warm packs, Kneipp hydrotherapy	Improvement of coping strategies without the intake of medication	Medical massage therapist	10 (60 min) week 1: 1 week 2: 3

	(repeated cold-water stimulation), self-massage techniques, TENS device			week 3: 3 week 4: 3
Ward round, individual appointments on demand	Questioning of each patient about pain, functioning and health; clinical examination if necessary	Recognition of individual problems of patients; documentation of the course of pain; motivation	Specialist in PRM	16 (30 min) week 1: 3 week 2: 5 week 3: 5 week 4: 3
Patient education (group)	Interactive presentation of background information; topics: causes of knee pain; physical activity and pain; pain medication	Improvement of adherence to treatment by providing a theoretical background; reduction of kinesiophobia; avoidance of side effects of pain medication	Specialist in PRM	7 (30 min) week 1: 1 week 2: 2 week 3: 2 week 4: 2
Relaxation exercises	Mindfulness activities	Determination of how to relax muscles that are tense due to anxiety-provoking thoughts	Physiotherapist	7 (60min) week 1: 1 week 2: 2 week 3: 2 week 4: 2
Group discussion with patients at the end of the week	Feedback round of patients and rehabilitation team	Consolidation of knowledge and intentions by reflecting on the last week; definition of goals for next week; peer group support	Rehabilitation team, patient group	4 (30 min) week 1: 1 week 2: 1 week 3: 1 week 4: 1
Team meeting at the end of the week (group)	Discussion of all patients in the rehabilitation team	Recognition of problems of individual patients and definition of solutions	Rehabilitation team	4 (30 min) week 1: 1 week 2: 1 week 3: 1 week 4: 1
Assessment at the end of the rehabilitation	Examination, clinical tests, individual setting of goals after the end of rehabilitation	Comparison of health status before and after treatment, recommendations, motivation of the patient	Specialist in PRM, physiotherapist, occupational therapist	1 (90 min) week 4: 1

2.5 Statistical Analysis

2.5.1 Processing of Xsens™ Raw Data

The Xsens™ raw data were exported to Excel. Each patient's recording had to be exported from Xsens MVN Analyse™ in an '.mvnx' file. This file was imported to an Excel document with a table designed specifically for Xsens™ raw data. In Excel, further editing was performed.

Ten whole gait cycles were selected and cut to the right size according to the time in milliseconds (ms), so that the same cycles could be used for all of the parameters. To identify a gait cycle, graphs were drawn to see the maxima and minima. Figure 4 presents a graph that depicts the flexion (maximum) and extension (minimum) of one patient's left knee created by Xsens™ data for angles. A total of 10 gait cycles can be seen in this graph. One gait cycle is from one minimum to the next, as shown by the red lines. The minima indicate initial contact with the ground.

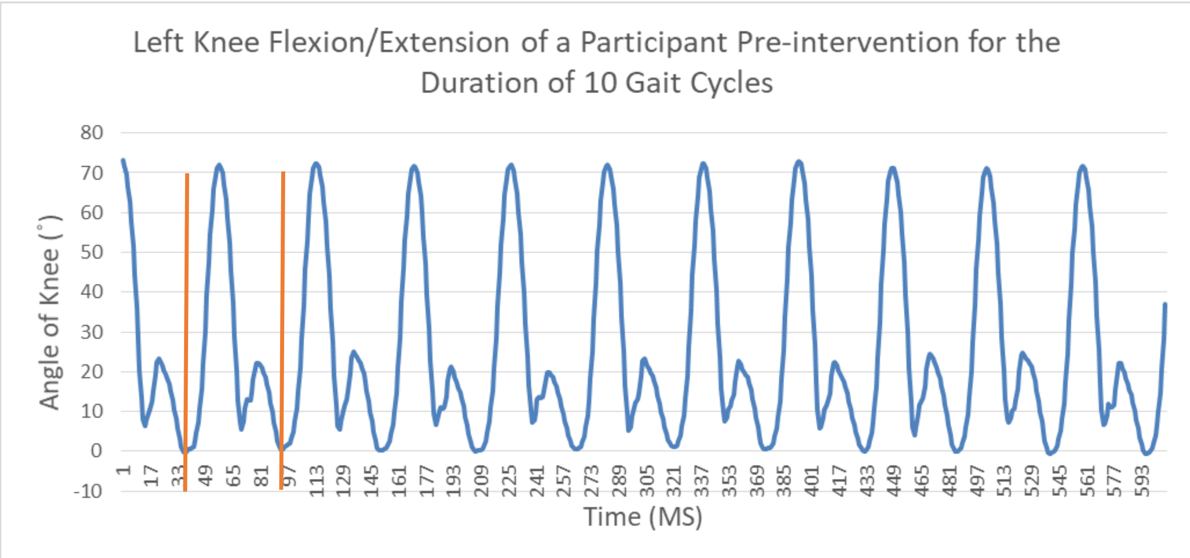

Figure 4: Left Knee Flexion/Extension of a Participant Preintervention for the Duration of 10 Gait Cycles.

To find the average speed of a patient, velocity values from the x- and y-axes recorded with the pelvis sensor were used. The formula $\sqrt{x^2 + y^2}$ was used to find the directional velocity of the patient. A graph was drawn from the calculated velocities to visualise the average speed during the 10 gait cycles. The average of all these velocities was calculated in metres per second (m/s) and multiplied by a factor of 3.6 to obtain the final result in kilometres per hour (km/h). Figure 5 presents an example of a graph drawn from velocity data in m/s, which were calculated using the x and y data recorded by the pelvis sensor.

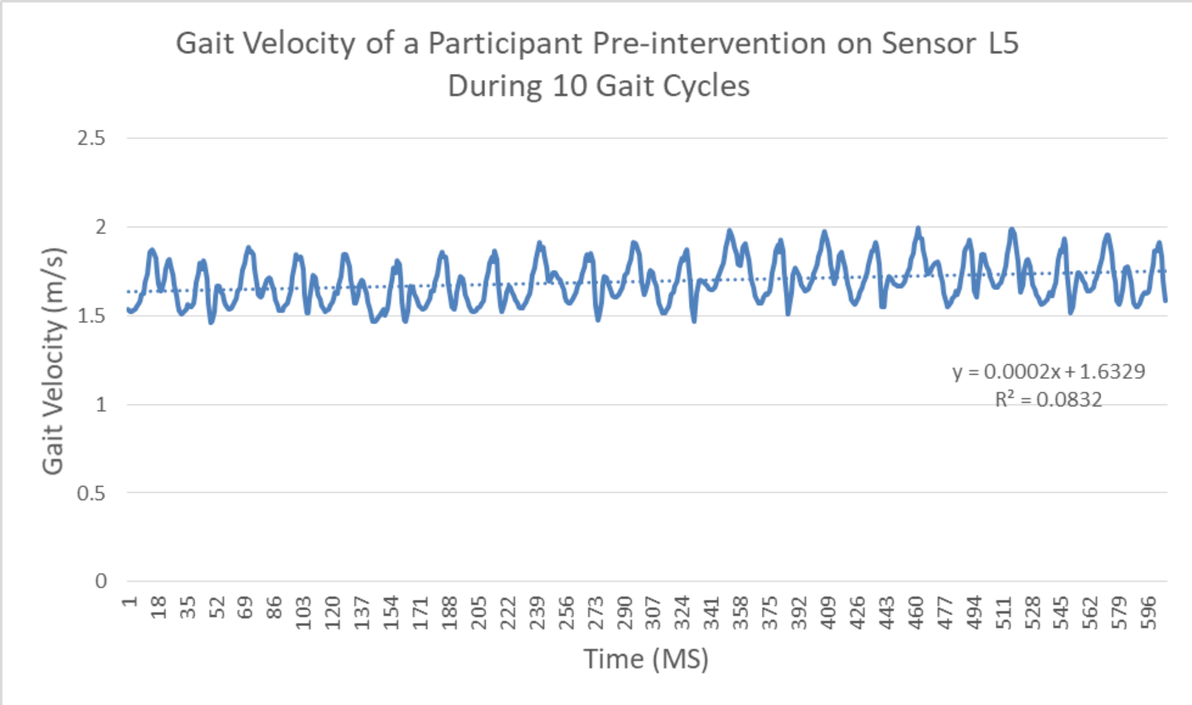

Figure 5: Gait Velocity of a Participant Preintervention on Sensor L5 During 10 Gait Cycles.

To find the average range of motion for the lateral movement of the joint between lumbar spine segment 5 and sacral spine 1 (LF), a graph was drawn using all the 'Lateral Bending Right (+)/Lateral Bending Left (−)' values in the L5/S1 column in the joint angle table. The gradient between each point on the graph was calculated and the 'IF Function' in Excel was used to find the maximum and minimum values. The peaks indicate movement to the right and the troughs indicate movements to the left. Figure 6 presents an example of such a graph. A total of 10 maxima and 10 minima were found and then the range of motion was calculated with the following equation: $ROM = Max - Min$. The average range of motion for the 10 gait cycles was calculated using the following equation: $m = \frac{Sum\ of\ ROMs}{Number\ of\ ROMs}$. This was done for every participant separately. The calculated data were entered into SPSS for further analysis.

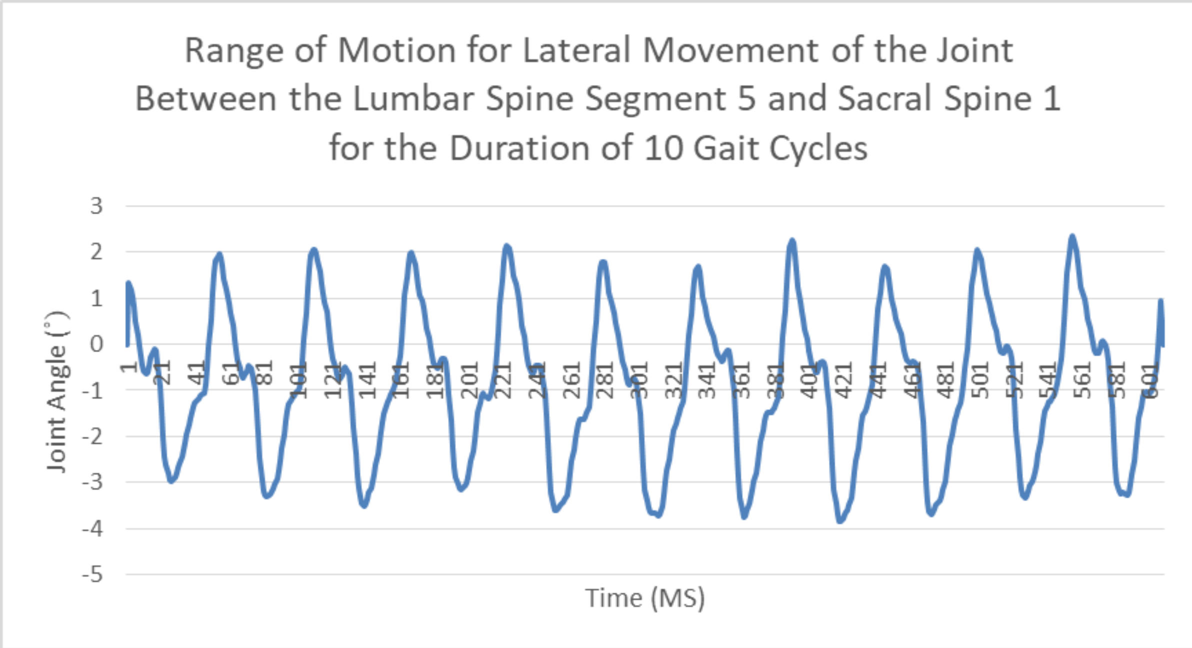

Figure 6: Range of Motion for Lateral Movement of the Joint between Lumbar Spine Segment 5 and Sacral Spine 1 for the Duration of 10 Gait Cycles.

2.5.2 Processing of Rehawalk® Data

After 30 seconds of walking, Rehawalk® automatically computed the average gait velocity, stride length, steps per minute, and several other gait parameters. The data were exported to an Excel table, which also included the standard deviations. These data were entered into SPSS for further statistical analysis.

2.5.3 Scoring of the WOMAC

The WOMAC was scored in SPSS. The score from each item was entered into the software and the mean score for each subscale in addition to the composite score were calculated according to Stucki et al. (124). This resulted in pre- and post-intervention scores for each subscale and the composite score ranging from 0 to 10.

2.5.4 Descriptive Data Analysis

All accumulated data from the questionnaires and selected spatial-temporal data from Xsens™ and Rehawalk® were evaluated using SPSS. The data were organised in metric and ordinal scales. The accumulated data were evaluated in cooperation with Dr. Michaela Coenen at the Institute for Medical Information Processing, Biometry, and Epidemiology (IBE) at LMU Munich, Germany.

The mean with standard deviation and median with minimum and maximum were calculated for the WOMAC scores and each gait parameter pre- and post-test.

Furthermore, the mean with standard deviation and the median with minimum and maximum of the absolute differences between pre- and post-intervention for the WOMAC scores and each gait parameter were calculated. The mean difference for each parameter between pre- and post-intervention was also calculated as a percentage.

2.5.5 Testing of Significance

The nonparametric Wilcoxon–Mann–Whitney test (also known as the Mann–Whitney U test) was selected for assessing the statistical significance of the difference between pre- and post-test because the sample size was small, and histograms exhibited no normal distribution. The level of significance was set to $\alpha = 5\%$.

Because the sample size was small and the data were not evenly distributed, changes in gait parameters were also tested using the Wilcoxon–Mann–Whitney test for statistical difference.

2.5.6 Correlations of Gait Parameters and WOMAC Scores

The Spearman's rank correlation coefficient (r_s) was calculated to discover relationships between the self-reported pain, stiffness, and physical functioning in the WOMAC and the objective gait parameters. The correlation coefficient was also calculated to evaluate whether improvements in the WOMAC were correlated with improvements in gait parameters. In addition, it was used to reveal whether correlations existed between the gait analysis systems. Positive correlations would mean that both parameters included in the calculation would improve similarly.

The Spearman's rank correlation coefficient is a technique that can be used to describe the strength and direction (negative or positive) of the association between 2 ranked variables. The result will always be between +1 and −1. An r_s of +1 indicates a perfect positive rank association, an r_s of 0 indicates no rank association, and an r_s of −1 suggests a perfect negative rank relationship (128). This correlation is not particularly sensitive to strong outliers, which is because the Spearman's rank correlation coefficient limits the outlier to the value of its rank. Levels of correlation were categorised as low (<0.40), moderate-to-good (0.40-0.75), and very good (>0.75) (129). The formula for calculating the Spearman's rank correlation coefficient is as follows (130):

$$r_s = \frac{\sum_i (R(x_i) - R_x)(R(y_i) - R_y)}{\sqrt{\sum_i (R(x_i) - \overline{R_x})^2} \sqrt{\sum_i (R(y_i) - \overline{R_y})^2}}$$

3. Results

3.1 Participants

Using descriptive statistics in SPSS, baseline patient characteristics were calculated and presented in Table 5. Those on medication continued their treatment throughout the study. No prescribed medication, which might affect pain in the hip or knee, was paused. Of the 18 candidates who provided informed consent, 15 could be included in the short-term analysis. Three patients were excluded from the short-term analysis. Two were not fit enough to participate in the gait analysis during the pre-intervention assessment (T1) and one declined to participate in the pre-intervention gait analysis. After 6 months (T3), all 15 patients had returned their follow-up questionnaires. The mean waiting time from assessment to entry was 81 days.

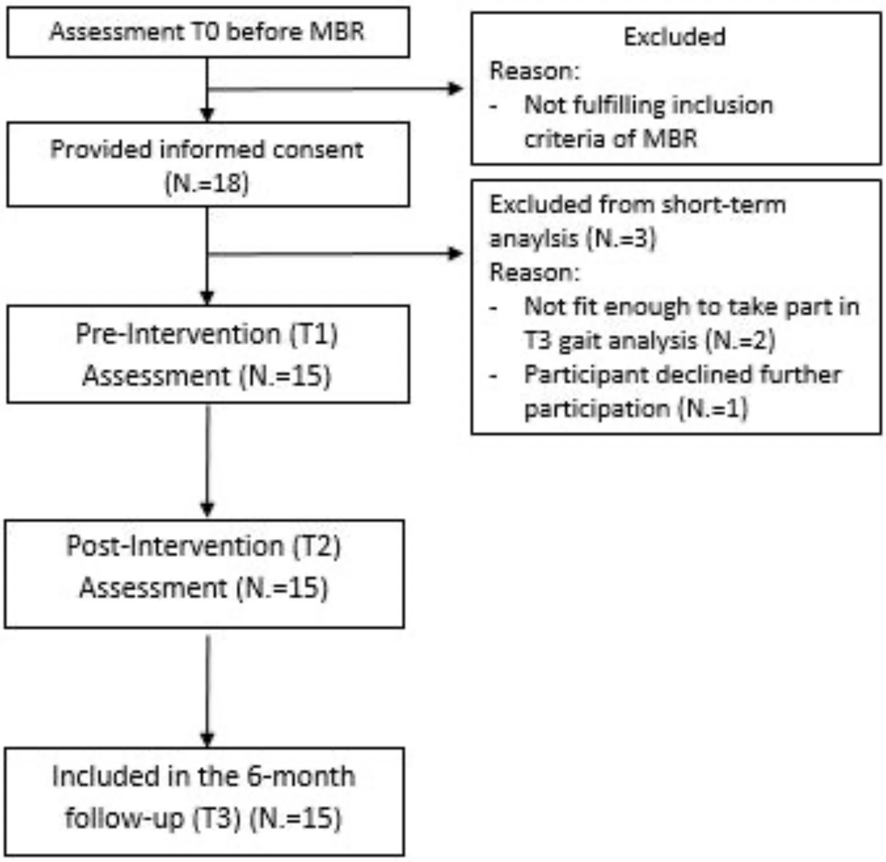

Figure 7: Patient Flow Diagram.

Table 5: Participant Characteristics

Characteristic	N. or mean (SD)	Valid %
Age, mean years (SD)	66.6 (6.7)	
Female/Male	11/4	73.3/26.7
Osteoarthritis hip/knee/both	3/12/0	20/80/0
Comorbidities		
None	0	0
1	3	20
2	2	13.3
3	5	33.3
≥	5	33.3
Missing	0	
Depression (HADS)		
No/Doubtful/Case/Missing	9/1/3/2	69.3/7.7/23
Depression scale mean (SD)	6.69 (5.63)	
Anxiety (HADS)		
No/Doubtful/Case/Missing	5/3/5/2	38.5/23/38.5
Anxiety scale mean (SD)	8.23 (5.09)	
Education		
High school/University	4	30.8
Basic/Middle school (9-11 y)	9	69.2
Missing	2	
Marital status		
Living with partner/Alone	10/4	71.4/28.8
Missing	16.7	
Pain medication		
Yes/No	12/2	85.7/14.3
When necessary/Regularly	8/4	66.6/33.3
Missing	1	
Fell in the last 12 months		
Yes/No	3/11	21.4/78.6
Mean times (SD)	4.33 (4.16)	
Missing	1	
Days waiting time, mean (SD)	81 (47)	

3.2 Outcomes in the WOMAC

Table 6 summarises the pre-test (T1), post-test (T2), and follow-up (T3) results of the WOMAC and its subscales. Figure 8 presents the median and Figure 9 presents the mean WOMAC scores.

Statistically significant differences existed between the pre- and post-test results of the WOMAC, its subscales, Pain 1, and PF 6. The 6-month follow-up WOMAC scores also revealed statistically significant differences from the pre-test scores.

All WOMAC scores decreased, which indicated improvements. These improvements between pre- and post-test are displayed as percentages in Figure 10.

Table 6: WOMAC Scores

	Pre-Test (T1)		Post-Test (T2)					Follow-Up (T3)				
	Mean (SD)	Median	Mean (SD)	Median	Difference to T1 Mean (SD)	% Difference to T1 Mean (SD)	**P value T1 vs. T2**	Mean (SD)	Median	Difference to T1 Mean (SD)	% Difference to T1 Mean (SD)	**P value T1 vs. T3**
WOMAC Total	3.35 (1.85)	2.71	1.76 (1.11)	1.50	−1.59 (1.55)	43.61 (27.02)	**0.001***	1.96 (1.20)	1.88	1.39 (1.66)	37.97 (32.05)	**0.005***
WOMAC Pain	3.64 (1.83)	3.20	1.99 (1.23)	1.60	−1.65 (1.69)	39.77 (36.46)	**0.002***	1.89 (1.21)	1.80	1.75 (1.51)	36.52 (31.52)	**0.001***
WOMAC Stiffness	3.60 (2.27)	3.50	1.83 (1.72)	1.50	−1.77 (2.21)	35.21 (58.88)	**0.01***	2.10 (1.78)	1.50	1.50 (1.70)	35.87 (39.67)	**0.007***
WOMAC Physical Function	3.24 (1.87)	2.82	1.69 (1.04)	1.64	−1.55 (1.52)	43.55 (25.29)	**0.001***	1.96 (1.22)	1.76	1.27 (1.86)	31.31 (46.53)	**0.015***
Pain 1	3.87 (2.47)	3.00	2.27 (1.71)	1.00	−1.60 (2.47)	29.79 (52.73)	**0.026***	1.93 (1.67)	1.00	1.93 (2.12)	47.84 (50.64)	**0.036***
PF 6	3.40 (2.69)	3.00	1.87 (2.13)	1.00	−1.53 (1.96)	33.97 (32.09)	**0.007***	1.93 (1.98)	1.00	1.47 (2.36)	14.64 (93.09)	**0.007***

Legend:

SD = standard deviation (written in parentheses) WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index, Pain 1 = item questioning pain during normal gait in WOMAC Pain, PF 6 = item questioning physical function during normal gait in WOMAC Physical Function

Test for significance: Mann–Whitney U test

* = statistically significant difference

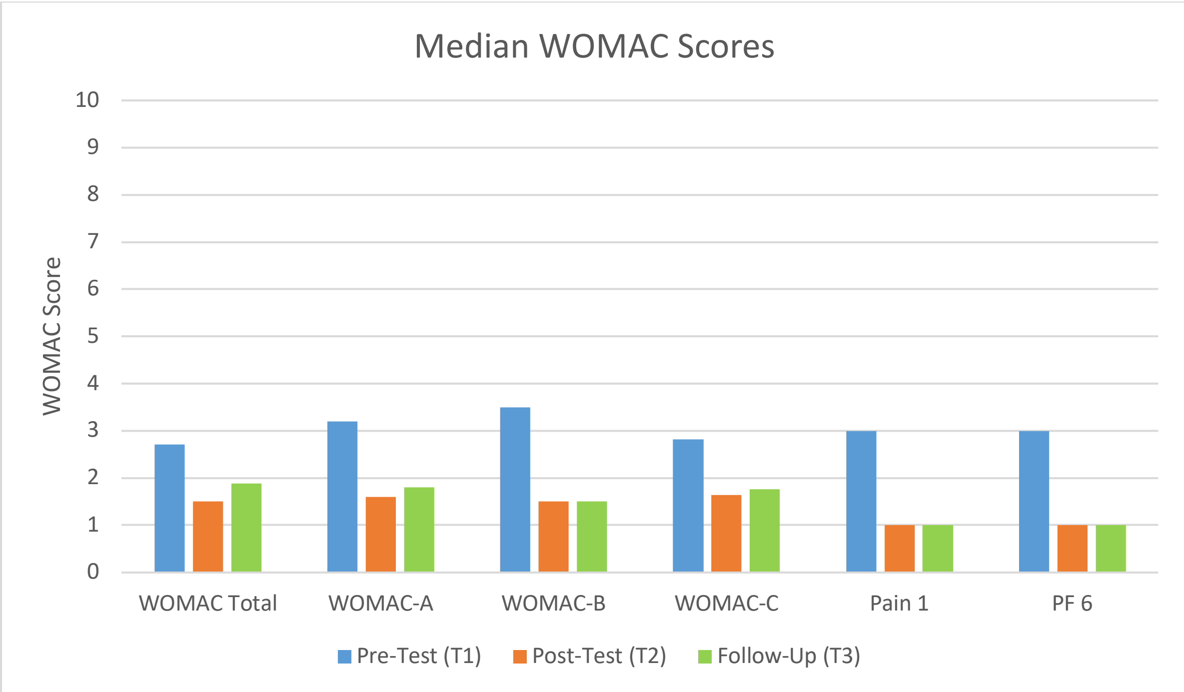

Figure 8: Median WOMAC Scores.

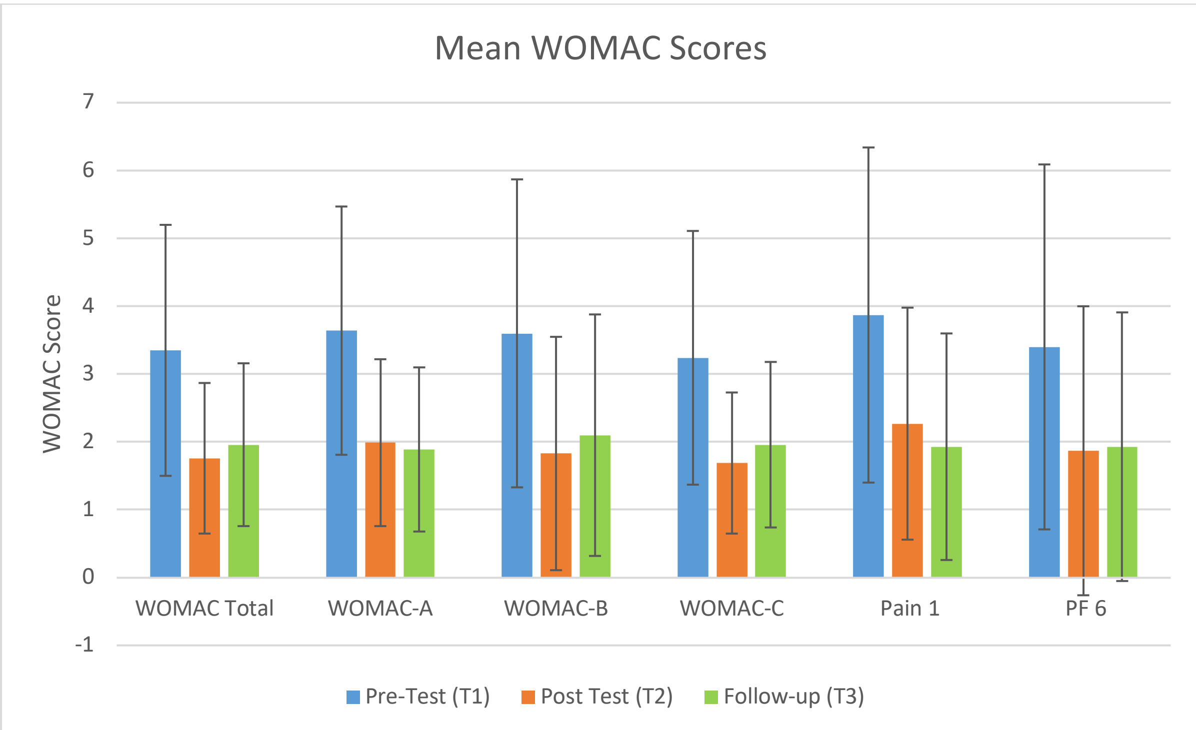

Figure 9: Mean WOMAC Scores.

Legend for Figures 8 and 9: WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index, Pain 1 = item questioning pain during normal gait in WOMAC Pain, PF 6 = item questioning physical function during normal gait in WOMAC Physical Function

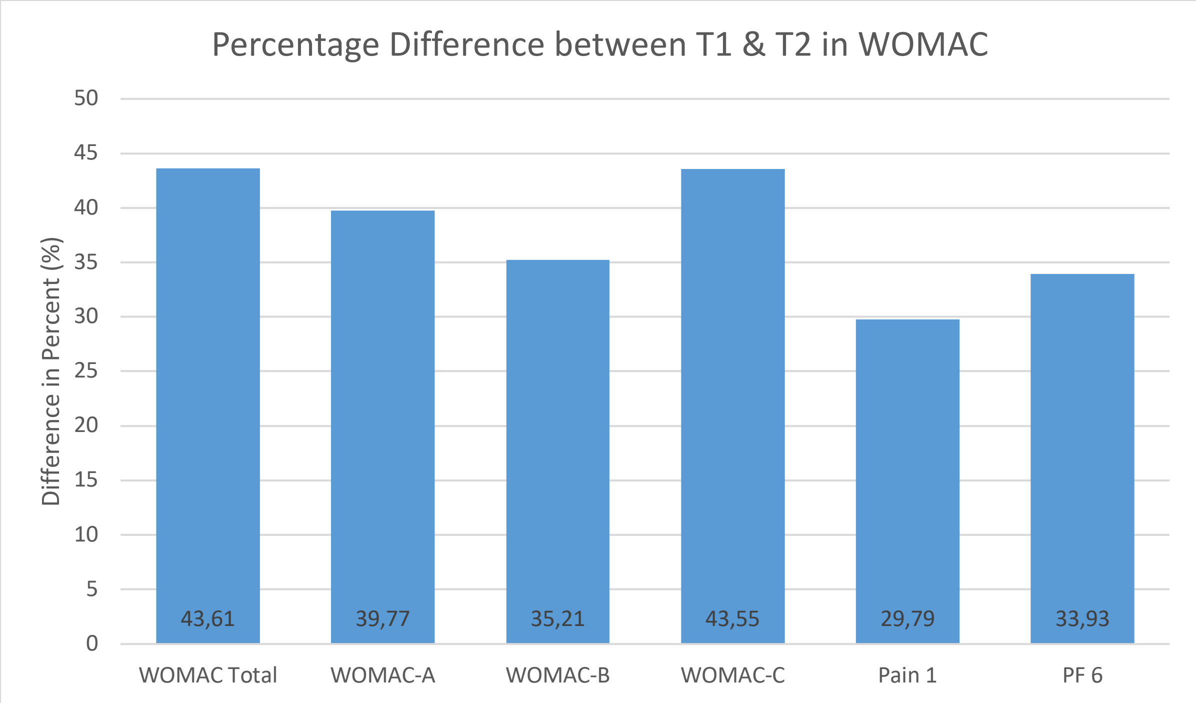

Figure 10: Percentage Difference Between T1 & T2 in WOMAC Scores.

Legend: WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index, Pain 1 = item questioning pain during normal gait in WOMAC Pain, PF 6 = item questioning physical function during normal gait in WOMAC Physical Function, T1 = Pre-Test, T2 = Post-Test

3.3 Outcomes in Gait Parameters

The gait parameters measured pre- (T1) and post-test (T2) are presented in Table 7. Figure 11 provides the percentage changes between the pre- and post-test results.

The largest difference was between the gait velocity measured with Xsens™ before and after the intervention. On average, participants walked at 4.83 km/h before the intervention and 5.21 km/h afterwards. This means that the average gait velocity measured with Xsens™ increased by 0.38 km/h, which is an improvement of 7.9%. Furthermore, the results of the 6MWT indicated that after the intervention, patients could walk an average of 28 metres more than before. This was an improvement of 6.2%. No gait parameter exhibited a statistically significant difference between pre- and post-test.

Table 7: Gait Analysis Results

Gait Analysis	Pre-Test (T1)		Post-Test (T2)		Absolute Difference *Mean (SD)*	Changes in %	P value
	Mean (SD)	Median	Mean (SD)	Median			
6MWT (m)	477 (72)	471	505 (77)	520	28 (33)	6.2	0.272
Xsens™ – V (km/h)	4.83 (0.78)	4.75	5.21 (0.86)	5.04	0.38 (0.29)	7.9	0.165
Xsens™ – LF (°)	5.2 (1.7)	5.5	5.0 (1.9)	4.8	−0.17 (1.00)	3.0	0.648
Rehawalk® – V (km/h)	2.33 (0.61)	2.27	2.37 (0.64)	2.27	0.04 (0.2)	2.0	0.633
Rehawalk® – SL (m)	0.73 (0.20)	0.72	0.74 (0.17)	0.69	0.01 (0.05)	2.6	0.787
Rehawalk® – SPM	107 (14)	107	106 (15)	108	−1 (8)	0.9	0.950

Legend:

SD = standard deviation (written in parentheses)

6MWT = 6-Minute Walk Test, Xsens™ = gait parameters assessed with the Xsens system, Rehawalk® = gait parameters assessed with the Rehawalk® system, V = average gait velocity, LF = lateral flexion – average range of motion in lateral movement of the joint between lumbar spine segment 5 and sacral spine 1, SL = average stride length, SPM = steps per minute (cadence), T1 = Pre-Test, T2 = Post-Test

Test for significance: Mann–Whitney U test

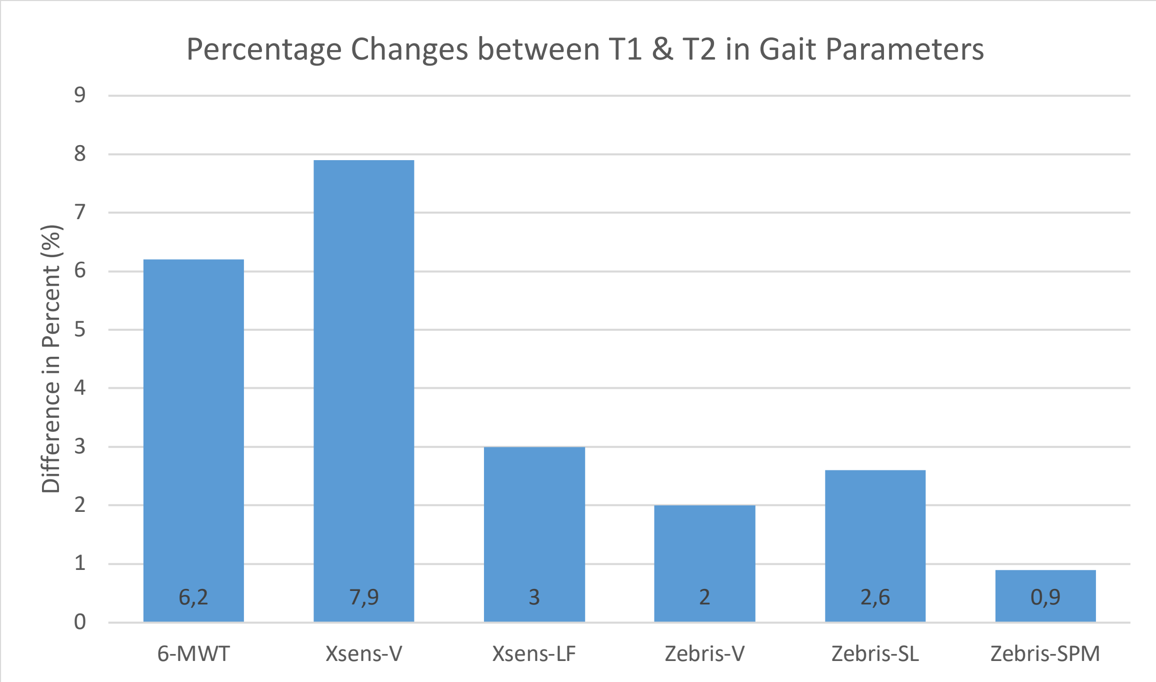

Figure 11: Percentage Changes Between T1 & T2 in Gait Parameters.

Legend: 6MWT = 6-Minute Walk Test, Xsens™ = gait parameters assessed with the Xsens system, Rehawalk® = gait parameters assessed with the Rehawalk® system, V = average gait velocity, LF = lateral flexion – average range of motion in lateral movement of the joint between lumbar spine segment 5 and sacral spine 1, SL = average stride length, SPM = steps per minute (cadence), T1 = Pre-Test, T2 = Post-Test

3.4 Correlations Between WOMAC and Gait Parameters

3.4.1 Pre- and Post-Test Correlations

The correlations between gait parameters and the WOMAC scores are presented in Table 8. These correlations should reveal whether the WOMAC, as a subjective self-report assessment, resembled the participants' actual walking ability, which was measured with the gait parameters of patients with hip and knee OA.

The calculated correlation values between the individual gait parameter results and the WOMAC, including its subscales of Pain (A), Stiffness (B), and Physical Functions (C), revealed that a correlation did exist to a certain degree both for pre- and post-intervention. Twelve absolute Spearman's rank values were r > 0.4, which indicated a moderate-to-good correlation.

Table 8: Correlations Between Gait Parameters and the WOMAC

	Pre-Test (T1)						**Post-Test (T2)**					
	WOMAC											
	Total	A	B	C	Pain 1	PF 6	Total	A	B	C	Pain 1	PF 6
6MWT	0.28	0.18	**0.59***	0.23	−0.10	−0.01	0.28	0.20	0.27	0.24	0.01	0.14
Xsens™ – V	0.29	0.07	**0.52***	0.24	0.02	0.22	0.20	0.20	0.16	0.15	0.09	0.14
Xsens™ – LF	0.33	0.20	**0.56***	0.16	0.27	0.39	**0.57***	**0.44**	0.20	**0.54***	0.33	**0.64***
Rehawalk® – V	−0.03	−0.21	0.10	0.01	−0.12	0.12	0.08	0.12	0.03	0.04	−0.15	0.06
Rehawalk® – SL	0.09	−0.07	0.14	0.12	0.08	0.32	**0.45**	**0.46**	0.30	**0.44**	0.27	0.37
Rehawalk® – SPM	−0.21	−0.30	−0.13	−0.20	−0.26	−0.24	−0.37	**−0.42**	−0.39	−0.39	**−0.45**	−0.18

Legend: WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index, Pain 1 = item questioning pain during normal gait in WOMAC Pain, PF 6 = item questioning physical function during normal gait in WOMAC Physical Function, 6MWT = 6-Minute Walk Test, Xsens™ = gait parameters assessed with the Xsens system, Rehawalk® = gait parameters assessed with the Rehawalk® system, V = average gait velocity, LF = lateral flexion – average range of motion in lateral movement of the joint between lumbar spine segment 5 and sacral spine 1, SL = average stride length, SPM = steps per minute (cadence)

3.4.2 Correlations of the Improvements from Pre- to Post-Test

The correlations between changes in gait parameters and WOMAC scores from pre- (T1) to post-test (T2) are presented in Table 9. These correlations should indicate whether improvements in the WOMAC meant that there were improvements in the gait parameters and therefore the walking ability of patients. Positive correlations revealed that both the WOMAC scores and gait parameters improved.

This correlation analysis revealed weak-to-moderate positive and negative correlations ($-0.45 \leq r \leq 0.58$). The 6MWT correlated with the WOMAC and its subscales with values of $r \leq 0.21$. A moderate correlation existed between the improvement of the 6MWT and the improvement of WOMAC Stiffness ($r = 0.45$) and PF 6 ($r = 0.41$). The improvements in gait velocity, measured with Rehawalk®, revealed moderate correlations with the improvements in WOMAC Total ($r = 0.40$), WOMAC Physical Function ($r = 0.57$), and PF 6 ($r = 0.55$). The improvements in gait velocity, measured with Xsens™, revealed weak positive correlations with WOMAC Total ($r = 0.25$), WOMAC Pain ($r = 0.16$), WOMAC Stiffness ($r = 0.16$), and WOMAC Physical Function ($r = 0.30$). Negative correlations existed between the improvements in gait velocity, measured with Xsens™, and the improvements in Pain 1 ($r = -0.32$) and PF 6 ($r = -0.45$). The improvements in LF revealed weak-to-moderate positive correlations with the WOMAC ($0.06 \leq r \leq 0.40$). Furthermore, a weak positive correlation existed between the improvements in WOMAC Total and steps per minute ($r = 0.21$). Moreover, the improvements in WOMAC Stiffness revealed a moderate positive correlation with improved steps per minute ($r = 0.58$).

Table 9: Correlations Between Differences in Gait Parameters and WOMAC

	WOMAC Total	WOMAC Pain	WOMAC Stiffness	WOMAC Physical Functions	Pain 1	PF 6
6MWT	0.31	0.21	**0.45**	0.25	0.35	**0.41**
Xsens™ – V	0.25	0.16	0.16	0.30	−0.32	**−0.45**
Xsens™ – LF	0.06	0.07	0.15	0.22	**0.40**	0.20
Rehawalk® – V	**0.40**	0.03	0.27	**0.57***	0.08	**0.54***
Rehawalk® – SL	0.04	−0.02	**−0.44**	0.16	−0.11	0.21
Rehawalk® – SPM	0.21	−0.01	**0.58***	0.14	−0.07	0.08

Legend:

WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index, Pain 1 = item questioning pain during normal gait in WOMAC Pain, PF 6 = item questioning physical function during normal gait in WOMAC Physical Functions, 6MWT = 6-Minute Walk Test, Xsens™ = gait parameters assessed with the Xsens system, Rehawalk® = gait parameters assessed with the Rehawalk® system, V = average gait velocity, LF = lateral flexion – average range of motion in lateral movement of the joint between lumbar spine segment 5 and sacral spine 1, SL = average stride length, SPM = steps per minute (cadence)

3.5 Correlations Between Gait Systems

The correlations between the improvements in gait parameters are presented in Table 10. These correlations were used to evaluate whether different gate parameters exhibited similar improvements between pre- and post-intervention. Positive correlations revealed that both gait parameters improved similarly. Little correlation means that improvements in one gait parameter were not detected with the other gait parameter or gait analysis system. Negative correlations revealed that an improvement in one gait parameter was accompanied by a deterioration in another.

The improvements on the 6MWT had a moderate correlation with the improvements of Rehawalk® gait velocity (r = 0.41). The gait parameters measured with Xsens™ had a weak positive correlation with the 6MWT. A moderate correlation existed between the Rehawalk® measured gait velocity and stride length with a correlation coefficient of r = 0.58. A strong negative correlation was found between the improvements in stride length and steps per minute (r = −0.71), which was observed as the steps per minute increasing as the step length decreased. The improvements in gait velocity and LF measured with Xsens™ had a weak positive correlation (r = 0.35). The gait parameters measured with Xsens™ did not correlate very well with the gait parameters measured with Rehawalk®.

Table 10: Correlations Between Differences in Gait Parameters

	Xsens™ – V	Xsens™ – LF	Rehawalk® – V	Rehawalk® – SL	Rehawalk® – SPM
6MWT	0.20	0.21	0.41	−0.13	0.36
Xsens™ – V		0.35	−0.08	−0.04	0.09
Xsens™ – LF			0.05	−0.16	0.06
Rehawalk® – V				**0.58***	0.39
Rehawalk® – SL					**−0.71***

Legend:

6MWT = 6-Minute Walk Test, Xsens™ = gait parameters assessed with the Xsens system, Rehawalk® = gait parameters assessed with the Rehawalk® system, V = average gait velocity, LF = average range of motion in lateral movement of the joint between lumbar spine segment 5 and sacral spine 1, SL = average stride length, SPM = step per minute (cadence)

4. Discussion

The main results of this study demonstrated that scores on the WOMAC and its subscales improved significantly after the 4-week MBR programme for patients with hip and knee OA. The greatest improvement was found in the physical function subscale (WOMAC Physical Function).

There were also improvements in gait parameters. After the MBR programme, the gait velocity in km/h recorded with the 3D gait analysis system Xsens™ improved most out of all gait parameters. However, the gait parameters improved less than the WOMAC scores.

There was little correlation between the WOMAC and gait parameters. The improvements in the 6MWT correlated moderately with the improvements in the WOMAC. Gait parameters measured with the Zebris Rehawalk® system and the 6MWT were moderately correlated. Xsens™ gait parameters exhibited little correlation with the 6MWT and parameters from the Rehawalk® system.

4.1 Comparison of the Results with Previous Studies

In total, 15 participants successfully participated in the whole 4-week MBR programme. All participants exhibited an improvement in the WOMAC Osteoarthritis Index, whereas not all exhibited improvements in the various gait parameters.

As demonstrated in several physical therapy and exercise therapy studies as well as generally most conservative therapy studies (15, 45, 46, 53, 54, 80, 105), participants' WOMAC scores (including its subscales) improved significantly from before to after the 4-week MBR programme. At the 6-month follow-up, these significant improvements persisted when compared with the pre-test WOMAC scores. This suggests that patients subjectively perceived therapeutic success to have been achieved.

There was little to no evidence that the gait parameters improved significantly after the 4-week MBR programme. Nevertheless, most patients increased the distance walked in the 6MWT and increased their preferred gait velocity when measured with Xsens™. A systematic review by Tanaka et al. (2016) collected data from 28 random controlled studies that researched whether exercise therapy would improve walking ability. The meta-analysis provided low-quality evidence that patients increased the distance travelled in the 6MWT and low-to-moderate-quality evidence that the speed of patients increased after the intervention (82). For example, a randomized, single-blind study by Messier et al. (2004), proved that 80 patients who received exercise therapy over a period of 18 months could significantly improve their 6MWT distance by an average of 48.58m (131). Furthermore, Salacinski et al. (2012)

discovered a significant increase in preferred gait velocity by 7.9 cm/s (0.28 km/h) in a group of 13 subjects who received exercise therapy for 12 weeks compared to a control group of 15 subjects that did not raise its preferred gait velocity(132). These improvements are similar to the 33m increase in patients' 6MWT distance and the 0.38 km/h increase in the patients' preferred gait velocity following the 4-week MBR programme in this study. Even though the improvements in gait parameters were not statistically significant, this shows that the MBR program was beneficial in enhancing the patients' walking abilities.

When the changes from before to after the 4-week MBR programme were compared in terms of percentages in combination with the P values, one can say that these results suggest greater effects in the self-assessment of physical function compared to the effects on the measured gait parameters. This was observed in the low P values calculated for the WOMAC compared with higher values calculated for the gait parameters. This difference in results indicates that different constructs are measured. Therefore, clinical questions are reasonable for both gait analysis and self-assessment questionnaires. Nebel et al. demonstrated that worse WOMAC scores are correlated with shorter walking distance and slower gait velocity (133). Greater pain means shorter distances and slower walking speeds; therefore, hip and knee OA patients in much pain would reduce the load on their joints by walking shorter distances at a slower speed. However, this study may have revealed hints that just because a patient subjectively reports great improvements with the WOMAC after an intervention, this does not mean that his or her gait parameters have improved and vice versa. Similarly to this study, Onodera et al. (2020) found weak correlations between the WOMAC and functional tests, such as the 6MWT, in patients with knee OA (134). This discrepancy in the improvement of the WOMAC compared with the improvement of gait parameters could be due to improved self-efficacy and an enhanced understanding of the disease. According to Hurley et al., patients' beliefs about chronic pain shape their behaviour; they are confused about its cause and scared of 'its variability and randomness' (135). 'Without adequate information and advice from healthcare professionals', patients tend to avoid activity and movement due to the fear of causing more damage (135). Therefore, after the 4-week MBR programme, which included patient education, the patients in this study could have felt more confident in their abilities. This increase in confidence could have contributed to improved WOMAC scores even if their gait parameters did not improve to the same degree. It is possible that their gait parameters will improve in the future because it takes longer for gait patterns to change. To evaluate these improvements, a follow-up would be necessary as well as a control group not exposed to the intervention. Furthermore, each patient had different expectations of what such an intervention should achieve, which could have caused the subjective self-report questionnaires to differ from the actual objective gait parameters.

The correlation between the different assessments and the individual gait parameters, including the 6MWT and WOMAC (including its 3 subscales), was moderate to low in both pre- and post-intervention with absolute Spearman's rank correlation coefficients of $r = 0.64$ or less.

When the correlation coefficients were $r \geq 0.4$, this indicated a moderate correlation, and anything below that indicated a low correlation. Only 12 correlation coefficients exhibited a moderate correlation. High correlation coefficients would have meant that the 2 assessment methods, namely the questionnaire and gait analysis, could be interpreted as equals in terms of the effects of the 4-week MBR programme for patients with hip and knee OA.

It was hypothesised that the gait parameters would correlate with the WOMAC total and its subscales A and C. Most correlations were $r = 0.39$ or less, which suggests that self-reported pain and functionality cannot be directly reflected by gait parameters such as the 6MWT and gait speed.

However, there were individual gait parameters such as LF that exhibited several moderate correlations with $0.44 \leq r \leq 0.64$. This would suggest that the greater the LF, the higher the patient would score on the WOMAC and its subscales. A high LF can be interpreted as compensatory movements during gait. This correlation between WOMAC Total and its subscales A and C suggests that with increased pain and reduced physical function, patients make greater compensatory movements.

Other studies have demonstrated that compensatory movements exist even in early stages of hip and knee OA (136, 137). In 2001, Watelain et al. found that the hip in patients with lower limb OA dropped 2.4 times more than in healthy counterparts during gait (137). Moissenet et al. reported that coronal plane pelvic movement could identify patients with hip OA and differs between mild and severe (patients requiring surgery) conditions (136). It was concluded that as an objective outcome measure, coronal plane pelvic movement can be used for clinical trials. These pelvic movements can be compared with the LF that was measured with Xsens™ in the present study. When patients had higher WOMAC scores, including on subscales A and C, Xsens™ measured a higher LF. This suggests that the calculated LF measured with Xsens™ could be a valuable gait parameter for use as an objective outcome measure, despite there not being significant changes in LF before and after the MBR programme. To strengthen this assumption, more research using the Xsens™ gait analysis system will be required in the future.

Regarding the correlations between improvements in gait parameters and the WOMAC with its subscales, not many are worth mentioning as most correlation coefficients were between r = −0.36 and r = 0.4. A clear, statistically significant correlation between the changes in gait analysis and WOMAC scores could not be demonstrated. However, the gait velocity measured with Rehawalk® exhibited a positive correlation with the functionality score and PF 6 with r = 0.57 and r = 0.54, respectively. This suggests that when patients feel that their physical functions increase, their speed increases and vice versa. Furthermore, the correlation between changes in WOMAC Stiffness, cadence, and the 6MWT indicated that self-reported stiffness reduces the number of steps a patient takes in 1 minute and the distance walked in the 6MWT increases (r = 0.58 and r = 0.45, respectively). Furthermore, a study by Kennedy et al. (2002) reported low-to-moderate correlations (r = 0.37) between a subjective self-report questionnaire of function (Lower Extremity Activity Profile) and pooled objective physical performance measures (which included fast self-paced walk test, stair climb, and timed up and go test) of patients with hip and knee OA (138). Similar to this study, the correlations calculated by Kennedy et al. (2002) were not large enough for the results of one assessment method to mirror the results of the other. Performance and self-report assessments may provide information about different elements of functional status (139). This suggests that the isolated use of either method should be performed with caution and that it would be most beneficial to use both objective and subjective methods to help evaluate the outcomes.

Different assessment methods were used in a conservative therapy study by Eitzen et al. (2015). Gait analysis was conducted 'with a Qualisys pro-reflex motion analysis system (Qualisys AB, Gothenburg, Sweden) and 2 force plates (Advanced Mechanical Technology Inc., Watertown, MA, USA)' (81). This study examined the relationships 'between the number of completed training sessions and changes in each of the kinematic and kinetic variables' as well as the changes in gait that resulted from exercise therapy and patient education(81). The assessments were performed immediately before and after the 12-week intervention. The group receiving both patient education and exercise therapy had a gait velocity of 1.53 metres per second at baseline, and there was no statistical difference in the follow-up ($P = 0.827$). After the 12-week treatment, no significant alterations in joint angles or moments were noted. There were minimal to weak relationships according to the estimated Spearman's rank correlation coefficient, which ranged from −0.007 to −0.383 and from 0.045 to 0.324. This suggested that a 12-week supervised patient education and exercise therapy programme did not cause any evident alterations in gait (81).

Comparing the results of the present study with those of Eitzen et al., both suggested that patient education and exercise therapy have little effect on gait pattern. Eitzen et al. conducted their trial over 12 weeks in a less condensed form. Even though the time intervals between the assessments in the present study and those of Eitzen et al. differed by 8 weeks, there was no difference in results. Furthermore, dissimilar gait analysis systems were used in the present study and that of Eitzen et al.; however, both had similar results. Eitzen et al. only examined differences in gait parameters and did not consider self-reported outcomes unlike other studies, including the present one.

De Matos Brunelli Braghin et al. investigated 'the effect of low-level laser therapy and physical exercise on pain, stiffness, function, and spatiotemporal gait variables' (80). The study included 3 groups, namely a control group, a laser therapy group, and an exercise therapy group, for comparison. Patients participated in therapy programmes twice a week for 2 months. GAITRite® (CIR Systems Inc., Franklin, New Jersey, United States) was used for the gait analysis. Both therapy groups exhibited significant improvements in gait speed after the intervention compared with the control group. The exercise group exhibited significantly reduced pain and improved physical functions scores on the WOMAC (80). Compared with the present study, similar results were found using the WOMAC; however, there were clear differences in the changes in gait speed. This difference in gait speed could be because de Matos Brunelli Braghin et al. used a different gait analysis system. Furthermore, the intervention period was 4 weeks longer than that of the present study, which could have influenced gait parameters despite there being much fewer therapy sessions than in the present study.

Rashid et al. (2019) examined the effect of neuromuscular training compared with conventional quadriceps training. They found that patients significantly improved self-reported physical function (P = 0.011) recorded with the WOMAC as well as stride length (P = 0.009) and gait velocity (P = 0.022) (140). A Stride Analyzer (B&L Engineering, Model SA-VI, software version 6.2, Santa Ana, CA, USA) was used for gait analysis. The difference in the outcomes of gait parameters compared with those in the present study could again be due to the longer intervention period, which also lasted 12 weeks and included 36 supervised therapy sessions for each patient.

Differing from the study, Cheung et al. examined the short-term effect of gait retraining on knee adduction moment (KAM), knee flexion moment (KFM), and WOMAC scores (141). WOMAC scores, as in the present study, as well as KAM exhibited significant improvements after the intervention and at a 6-month follow-up. Again, the sample size in this study was small; nevertheless, these results indicate that KAM could be used in future research as an outcome measure. Furthermore, from Cheung et al. we can learn that it would be beneficial to add a 6-month follow-up of gait analysis to observe long-term effects of the MBR programme on walking ability.

From all the aforementioned studies and their results, it is clear that it is difficult to make a comparison as there is no standard approach used for gait analysis. In addition, these different conservative therapy methods do not allow ideal comparisons with the present study's MBR programme. There is an insufficient number of MBR programme studies for hip and knee OA with similar study designs, which would allow the direct comparison of results. Furthermore, the different outcomes point to the need for studies with longer post-intervention observation periods and follow-ups.

Taking all the different results from the literature into consideration, there is currently no uniform opinion on what an MBR programme for hip and knee OA should include and how long such a programme should last. Furthermore, there is no consistent method for analysing gait parameters to assess conservative therapies, and several studies have used self-report questionnaires other than the WOMAC. As seen in the discussion, several of conservative therapy studies have used gait analysis to measure outcomes; however, it is hard to compare them. This is mainly due to the different durations of the therapy programmes, resulting in different assessment times, and because of the subjective and objective assessment methods differing.

In addition, there has been an increase in the number of studies attempting to find the ideal gait parameters to accurately measure the outcome of conservative and surgical interventions in patients with hip and knee OA (142, 143). This indicates that there is a desire to objectively evaluate post-intervention outcomes reliably. As mentioned previously, this would give the clinician more valuable information about the effects of the MBR programme on patients with hip and knee OA. Nevertheless, in the future, both subjective and objective assessment methods will continue to be used and play a large role in the evaluation.

Since there was very little to no obvious correlation between the WOMAC and the gait analysis, the results indicated that gait analysis can contribute additional information when used as a method for assessing patients with hip and knee OA. This led to the decision to search for a gait parameter that can by itself best describe the walking ability and functionality of a patient before and after a 4-week MBR programme by correlating very little with the other gait parameters.

Furthermore, there were low correlations between several gait parameters. Those measured with the Rehawalk® gait analysis system (gait velocity, stride length, and cadence) correlated moderately with each other. The LF measured with Xsens™ exhibited the lowest correlation with the other parameters ($r = 0.21$ and less), which indicates that it measures a different construct to the other gait parameters. This gait parameter could possibly offer clinicians insights into patients' physical functions.

In addition, the improvement in gait velocity measured with Xsens™ exhibited low correlations with the 6MWT ($r = 0.20$) and all the Rehawalk®-measured gait parameters ($r = 0.09$ or less). This suggests that in general, Xsens™-measured gait parameters could be used for outcome assessments. However, in a systematic review, Ornetti et al. found that gait velocity alone cannot reliably be used to evaluate post-intervention walking ability (144). Furthermore, as demonstrated in several studies, gait velocity is a parameter that has a direct effect on many different parameters such as stride length, cadence, and knee adduction moment (144-147). Huijben et al. suggested that at higher gait velocities, gait quality improves (147). Since every patient had higher gait velocities before and after the MBR programme while using the Xsens™ system compared with the Rehawalk® system, this means that the results could have been affected.

In summary, the 4-week MBR programme had a positive effect on patients with hip and knee OA, demonstrating significant reductions in pain, stiffness, and functionality in the WOMAC. The MBR programme had no significant effect on gait. However, both subjective and objective assessments are equally crucial for evaluating the outcomes of such an intervention. Even though the WOMAC is critical, it does not directly reflect walking ability. The limitation of this self-report questionnaire is that comorbidities such as lower back pain and intermittent claudication, which lead to limitations in the functionality of hip and knee joints, are not considered. Furthermore, the WOMAC does not take effects of psychological and social factors into consideration.

Gait analysis can offer clinicians extra insights into the walking ability of their patients. Even though the MBR programme did not significantly improve the gait parameters, tendencies of improvement could be observed. Gait velocity measured with the Xsens™ gait analysis system and metres walked in the 6MWT exhibited greater percentage changes before and after the intervention than gait velocity measured on the treadmill based Rehawalk® system. Moreover, the correlations of Xsens™-measured LF with the WOMAC were promising, meaning that this gait parameter should be researched in future studies. Another benefit that the 6MWT and the Xsens™ gait analysis system holds over the Rehawalk® system is that they do not restrict patients to walking on a treadmill and allow gait to be analysed in a more natural environment.

4.2 Limitations of the Study

This study had clear limitations in terms of the sample size and the fact that there was no follow-up on the gait analysis. The following subchapters will discuss these limitations in more detail.

4.2.1 Small Sample Size

As demonstrated in a review by Ornetti et al. (2010), similar to other gait analysis studies, a limitation is the sample size (144). The sample size of N = 15 patients was small. This was a result of the fixed study period, the inclusion and exclusion criteria, and especially the large amounts of effort and time put into assessing the patients' gait. Furthermore, the compliance of some patients and their willingness to participate in the study affected the sample size. Therefore, other factors that could affect the gait parameters as well as the results of the WOMAC were not taken into consideration. These other factors include pain medication, whether patients had hip or knee OA, and their numbers of comorbidities, which can all be seen in participants' descriptions in Table 5 and could have had effects on the results. Nevertheless, all 15 patients that participated in the 4-week MBR programme participated in the 6-month follow-up.

Several other studies that have only used the WOMAC and different questionnaires, including pain and physical function scales, for rating a patient's subjective view of their condition have used much larger sample sizes (45). This was achievable because questionnaires are easier to use, take less time, and place less strain on patients than gait analysis (148). Studies that have also used Xsens™ for their gait analysis, such as that of Karatidis et al., have also used small sample sizes of N = 10 due to the complexity of evaluating the data (93, 95).

Due to the small sample size and the fact that the data from the WOMAC were on the level of an ordinal scale, Spearman's correlation coefficient was used to find possible coherence between the gait parameters and the WOMAC. The advantage of Spearman's correlation is that it is not easily affected by outliers, in contrast to Pearson's correlation coefficient. Nevertheless, Spearman's correlation coefficient is less informative than Pearson's correlation coefficient because data are transformed into ranks, which results in the loss of information (128, 129). More research will be required with a greater sample size to solidify the findings of this study.

Another limitation of this study was that there was no control group. Similar to the study conducted by de Matos Brunelli Braghin et al., a control group could have been used as a reference before and after the intervention, which could have provided us with further statistical proof of the effect of this MBR programme (80). Also, this small sample size is not representative for all patients with hip and knee OA in general clinical practice. Furthermore, examining the effects of the MBR programme over a longer period with a gait analysis follow-up would be beneficial both for long-term outcomes and comparisons with the results of other studies.

4.2.2 Selection of Gait Analysis

No standard for gait analysis has been set for measuring the effects of MBR on a patient's gait. Many different gait analysis systems exist and have been used in various conservative therapy studies conducted for patients with hip or knee OA.

The most common way for a clinician to analyse a patient's gait is through his or her subjective view. Gait analysis is intended to offer the clinician a more objective insight into the real-life effects of an MBR programme.

A limitation of gait analysis is that the assessment conditions do not resemble natural conditions. This results in the assessment situation being a psychophysically disruptive factor. In Zebris' Rehawalk® treadmill-based system, this factor has more weighting than when using the 6MWT or Xsens™. As Xsens™ is less confining, patients are more likely to walk at their preferred gait velocity, which results in a more accurate assessment of their gait. Another limitation of gait analysis is that it can be affected by comorbidities such as lower back pain and neurological disorders.

The 6MWT has been widely used in several conservative therapy studies (82, 149-151). It is a basic method for measuring the effect of such an intervention. Even though it is a simple and reliable method of measuring the outcomes, it does not provide insights into the actual gait pattern.

Inertial measurement units have been tested for validity and reliability in clinical gait analysis (152, 153). The benefit of Xsens™ is that patients can move around more freely, which provides more realistic data for evaluation. However, Xsens™ data are highly time consuming to collect and assess. Much patience is required during calibration of the system, which may result in reduced compliance from patients. Furthermore, calculating the gait parameters that can help the clinician in treating the patient is highly time consuming, which makes it not ideal for everyday clinical use.

Treadmill-based gait analysis systems have also been tested for their validity and reliability (84, 85). Rehawalk® is an efficient way to integrate gait analysis into everyday clinical use, as it immediately gives the clinician calculated gait parameters that can help with a patient's treatment. However, many patients are not used to treadmills, which can affect them psychologically, resulting in them walking slower (154). Slower walking speeds have been shown to cause lower gait quality (147). This would mean that Rehawalk® provides less realistic gait data, which could have affected the results of the present study.

Other studies have started using KAM as an outcome measure in the treatment of knee OA (155, 156). However, Tefler et al. found that speed affects KAM and would need to be controlled to obtain reliable results (146). In this study, the patients were asked to walk at their preferred speed, which means that calculating KAM would not have added extra insights regarding walking abilities.

A factor that could have affected the calculation of the correlation coefficients is that the ordinal scale of the WOMAC was compared with the metric and quantitative values from the gait analysis. The values of an ordinal scale cannot be rated like metric data from the gait parameters since they are different constructs. For example, reporting 8 on an item in subscale A of the WOMAC does not correspond to double the pain represented by a value of 4, whereas for gait parameters such as velocity, 6 km/h is double the speed of 3km/h.

5. Conclusion

In conclusion, this study's 4-week MBR programme as treatment was effective at improving the PROMs of patients with hip and knee OA. Despite the tendency for the gait parameters to improve, the small changes were not significant. This study was not designed to question whether the programme was more effective than other treatments or perform a comparison with a control group.

There was little correlation between the gait parameters and the WOMAC. However, there were a few moderate correlations, such as LF with the WOMAC. A question for future research is how the MBR programme affects LF and gait velocity compared with a control group.

No gait analysis system could be identified with certainty for use in future assessments before and after a 4-week MBR programme.

We drew the following conclusions from this study:

1. The evaluated/designed MBR programme improved the self-reported outcomes recorded with the WOMAC and therefore demonstrated reductions in pain, stiffness, and physical function.
2. The WOMAC was not directly correlated with gait patterns, which were measured at specific times.
3. Both subjective forms of self-assessment and objective assessments such as gait analysis should be used to evaluate post-interventional outcomes.
4. Future research should examine how the MBR programme affects LF and gait velocity compared with a control group.

In the future, gait analysis systems will continue to improve our understanding of the gait of patients with hip and knee OA. If Xsens™ is further simplified for ease of use in daily clinical practice, it could provide physicians and physical therapists with more information about the patient's natural gait patterns. This information has the possibility of being utilized to tailor an MBR program to the patient's individual needs.

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Appendix

The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)

Erfassungsdatum:

☐☐.☐☐.☐☐☐☐

○ Vor Intervention ○ Ende Intervention
○ Verlaufsmessung ○ Follow-up
○ Beginn Intervention

Patientenerkennung
Strichcode-Etikette

Geschlecht PatientIn:
○ weiblich ○ männlich

Geburtsdatum PatientIn:
☐☐.☐☐.☐☐☐☐

Beschwerden der unteren Extremitäten

A Schmerzfragen

Die folgenden Fragen beziehen sich auf die **Stärke der Schmerzen**, die Sie in Ihrem **"Problemgelenk"** haben. Bitte geben Sie für jede Frage die Stärke der Schmerzen an, die Sie in den **letzten 2 Tagen** verspürt haben.

Geben Sie Ihre Wahl an, indem Sie den entsprechenden Kreis ausmalen/ankreuzen.

Wie starke Schmerzen haben Sie ...

1. beim Gehen auf ebenem Boden?

Keine Schmerzen ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schmerzen

2. beim Treppenhinauf- oder hinuntersteigen?

Keine Schmerzen ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schmerzen

3. Nachts im Bett?

Keine Schmerzen ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schmerzen

4. beim Sitzen oder Liegen?

Keine Schmerzen ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schmerzen

5. beim Aufrechtstehen?

Keine Schmerzen ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schmerzen

Nun bitten wir Sie, dasjenige **Schmerzproblem** auszuwählen, das für Sie am **wichtigsten** ist, dass es durch die Behandlung verbessert wird.
Geben Sie Ihre Wahl an, indem Sie **nur einen** Kreis ausmalen/ankreuzen.
z. B. ● 1. Gehen auf ebenem Boden

Bitte wählen Sie **nur ein** Schmerzproblem aus!

○ 1. Gehen auf ebenem Boden	○ 2. Treppenhinauf- oder hinuntersteigen
○ 3. Nachts im Bett	○ 4. Sitzen oder liegen
○ 5. Aufrechtstehen	

B Fragen zur Steifigkeit

Die folgenden Fragen beziehen sich auf **die Steifigkeit** (nicht die Schmerzen) in Ihrem **"Problemgelenk". Steifigkeit** ist ein Gefühl von Einschränkung oder Langsamkeit in der Beweglichkeit, wenn Sie Ihre Gelenke bewegen. Bitte geben Sie für jede Frage die Stärke der Steifigkeit an, die Sie in den **letzten 2 Tagen** verspürt haben.

Geben Sie Ihre Wahl an, indem Sie den entsprechenden Kreis ausmalen/ankreuzen.

1. Wie stark ist die Steifigkeit gerade nach dem Erwachen am Morgen?

Keine Steifigkeit | O O O O O O O O O O O | Extreme Steifigkeit

2. Wie stark ist Ihre Steifigkeit nach Sitzen, Liegen oder Ausruhen im späteren Verlauf des Tages?

Keine Steifigkeit | O O O O O O O O O O O | Extreme Steifigkeit

Nun bitten wir Sie, dasjenige **Problem zur Steifigkeit** auszuwählen, das für Sie am **wichtigsten** ist, dass es durch die Behandlung verbessert wird.

Geben Sie Ihre Wahl an, indem Sie **nur einen** Kreis ausmalen/ankreuzen.
z. B. ● 1. Wie stark ist die Steifigkeit gerade nach dem Erwachen am Morgen?

Bitte wählen Sie **nur ein** Problem zur Steifigkeit aus.

O 1. Steifigkeit gerade nach dem Erwachen am Morgen?
O 2. Steifigkeit nach Sitzen, Liegen oder Ausruhen im späteren Verlauf des Tages?

C Fragen zur körperlichen Tätigkeit

Die folgenden Fragen beziehen sich auf Ihre **körperliche Tätigkeit**. Damit ist Ihre Fähigkeit gemeint, sich im Alltag zu bewegen und sich um sich selbst zu kümmern. Bitte geben Sie für jede der folgenden Aktivitäten den Schwierigkeitsgrad an, den Sie in den **letzten 2 Tagen** wegen Beschwerden in Ihrem **"Problemgelenk"** gespürt haben (falls Sie eine Tätigkeit in den letzten 2 Tagen nicht ausführen konnten, schätzen Sie bitte den Schwierigkeitsgrad so genau wie möglich ein).

Geben Sie Ihre Wahl an, indem Sie den entsprechenden Kreis ausmalen/ankreuzen.

Wie gross sind Ihre Schwierigkeiten ...

1. beim Treppenhinuntersteigen?

Keine Schwierigkeiten | O O O O O O O O O O O | Extreme Schwierigkeiten

2. beim Treppenhinaufsteigen?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

3. beim Aufstehen vom Sitzen?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

4. beim Stehen?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

5. wenn Sie sich zum Boden bücken?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

6. beim Gehen auf ebenem Boden?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

7. beim Einsteigen ins Auto/Aussteigen aus dem Auto?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

8. beim Einkaufen?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

9. beim Socken-/Strümpfeanziehen?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

10. beim Aufstehen vom Bett?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

11. beim Socken-/Strümpfeausziehen?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

12. beim Liegen im Bett?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

13. wenn Sie ins Bad/aus dem Bad steigen?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

14. beim Sitzen?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

15. wenn Sie sich auf die Toilette setzen/aufstehen von der Toilette?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

16. bei anstrengende Hausarbeiten?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

17. bei leichten Hausarbeiten?

Keine Schwierigkeiten ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Extreme Schwierigkeiten

Nun bitten wir Sie, diejenige **körperliche Tätigkeit** auszuwählen, die für Sie am **wichtigsten** ist, dass sie durch die Behandlung verbessert wird.

Geben Sie Ihre Wahl an, indem Sie **nur einen** Kreis ausmalen/ankreuzen.
z. B. ● 1. Treppen hinuntersteigen

Bitte wählen Sie **nur eine** körperliche Tätigkeit aus!

○ 1. Treppenhinuntersteigen	○ 2. Treppenhinaufsteigen
○ 3. Aufstehen vom Sitzen	○ 4. Stehen
○ 5. Sich zum Boden bücken	○ 6. Gehen auf ebenem Boden
○ 7. Einsteigen ins Auto/Aussteigen aus dem Auto	○ 8. Einkaufen
○ 9. Socken/Strümpfeanziehen	○ 10. Aufstehen vom Bett
○ 11. Socken/Strümpfeausziehen	○ 12. Liegen im Bett
○ 13. Ins Bad/aus dem Bad steigen	○ 14. Sitzen
○ 15. Sich auf die Toilette setzen/ aufstehen von der Toilette	○ 16. Anstrengende Hausarbeiten
○ 17. Leichte Hausarbeiten	

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Affidavit

Marka, Alexander Wolfgang

Surname, first name

I hereby declare, that the submitted thesis entitled

Comparison of Patient-Reported Outcome Measures and Mobile and Stationary Gait Analysis Systems for Evaluating a Multidisciplinary Biopsychosocial Rehabilitation Programme for Patients with Hip and Knee Osteoarthritis

is my own work. I have only used the sources indicated and have not made unauthorised use of services of a third party. Where the work of others has been quoted or reproduced, the source is always given.

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Munich, 15.10.2022

Place, Date

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Confirmation of congruency between printed and electronic version of the doctoral thesis

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