CHALLENGING CURRENT EXERCISE PRESCRIPTION FOR OSTEOARTHRITIS OF THE KNEE WITH A YOGA-INSPIRED APPROACH

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EFFICACY OF A BIOMECHANICALLY-BASED YOGA EXERCISE PROGRAM FOR KNEE OSTEOARTHRITIS: A RANDOMIZED CONTROL TRIAL

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Lay abstract

Osteoarthritis of the knee is a debilitating joint disease and a leading cause of disability. Treatment often involves medication to control pain and surgery when drugs fail. Exercise is a conservative approach to improve symptoms and quality of life. Some forms of exercise however can overload the knee and possibly worsen the disease. We have developed a yoga-inspired exercise regimen specifically for knee osteoarthritis that minimizes damaging mechanical loads. To test this program, women with knee osteoarthritis were randomly assigned to receive either 12 weeks of yoga, traditional physical therapy, or no-exercise. Before and after the intervention, pain, physical function, and mobility were measured. The yoga and traditional exercise groups demonstrated improvements in pain, physical function, and mobility; while the no-exercise group did not. In some aspects, yoga even outperformed traditional exercise. These findings suggest yoga is as effective as traditional exercise, and potentially more so, in treating knee osteoarthritis.

Abstract

Background: Knee osteoarthritis is a chronic disease involving the breakdown of joint tissues resulting in pain and disability. Exercise provides equivalent pain relief to medication, improves physical functioning, and ameliorates co-morbidities. However, certain forms of exercise can potentially overload the joint and exacerbate symptoms; the optimal type is unknown. We developed a yoga-based exercise intervention designed for knee osteoarthritis by incorporating postures that minimize a mechanical loading variable implicated in disease progression.

Purpose: The objective was to compare the efficacy of this biomechanically-tailored yoga program as treatment for knee osteoarthritis with the current "gold standard" of physical therapy, and a no-exercise attention control group.

Methods: A single-blinded, 12-week, 3-arm, parallel randomized control trial was conducted. Participants (women 50 years or over, with clinical knee osteoarthritis; n=31) were stratified by disease severity and randomized to receive biomechanical yoga exercise (YE; n=10), traditional exercise (TE; n=11), or no-exercise (NE; n=10). The primary outcome measure was pain; secondary outcomes included patient-reported physical function and mobility performance; and tertiary outcomes included muscular strength, quality-of-life, and symptoms of depression.

Results: The YE and TE groups demonstrated statistically and clinically significant within-group improvements in pain, physical function, and mobility performance ($p<0.017$), while the NE group did not. The YE group reported greater improvements in pain compared to the NE group (p=0.003). The YE group also demonstrated greater improvements in physical function compared to NE (p=0.010). There were no significant between-group differences in mobility performance, strength, quality-of-life, or depression (p>0.05).

Conclusion: Yoga appears as an efficacious and well-tolerated conservative treatment option for women with knee osteoarthritis. The yoga intervention yielded comparable, and in some cases possibly greater improvements in the major burdening symptoms of the disease compared to traditional physical therapy. Future investigations with larger samples are warranted to establish effectiveness and possibly superiority to traditional exercise.

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List of Abbreviations

Abbreviation	**Definition**
(30sCS)	30 Second Chair Stand
(40mW)	40 Meter Walk
(ADL)	Activities of Daily Living
(ANCOVA)	Analysis of Covariance
(BMI)	Body Mass Index
(CESD)	Center for Epidemiological Studies Depression Scale
(COX-2)	Cyclooxygenase Enzyme – 2
(ICOAP)	Measure Of Intermittent And Constant Osteoarthritis Pain
(KAM)	Knee Adduction Moment
(KOOS)	Knee Injury and Osteoarthritis Outcome Score
(LEFS)	Lower Extremity Functional Scale
(MCID)	Minimal Clinically Important Difference
(NE)	No Exercise
(NSAID)	Non-steroidal Anti-inflammatory Drug
(OA)	Osteoarthritis
(OARSI)	Osteoarthritis Research Society International
(PASS)	Patient Acceptable Symptom State
(QoL)	Quality of Life
(RCT)	Randomized Controlled Trial
(SA)	Stair Ascent

(SMW)	Six Minute Walk
(SMD)	Standard Mean Difference
(SR)	Sport and Recreation
(TUG)	Timed Up And Go
(TE)	Traditional Exercise
(YE)	Yoga Exercise

Declaration of Academic Achievement

This thesis is the original work of Master of Science candidate Alexander B. Kuntz. Alexander is the primary author of this document including the enclosed manuscript. Alexander conducted the literature review and was involved in the following aspects of the featured research study: study conception and design, participant recruitment, data collection and analysis, intervention design and conduction, and preparation of the manuscript which will be submitted for publication.

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CHAPTER 1: Introduction

Osteoarthritis

Osteoarthritis (OA) is a chronic joint disease involving the breakdown of all tissues in and around a synovial joint; a result of joint tissues being unable to repair at a rate fast enough to match breakdown. Osteoarthritis is the most prevalent form of arthritis, affecting 1 in 8 Canadians; it is also the most common joint disorder worldwide (Arden & Nevitt, 2006; Bombardier, Hawker, & Mosher, 2011). The Arthritis Alliance of Canada estimated that in 2010, OA resulted in a $10.2 billion dollars direct cost (health care) and a $17.3 billion in indirect cost (lost productivity) to the Canadian economy (Bombardier et al., 2011). This economic encumbrance is anticipated to increase steadily in the near future, due to an aging population that is becoming more obese (Bombardier et al., 2011; Felson et al., 2000). Of greater concern is the individual burden of OA. Persons living with this condition experience debilitating pain and hindered physical functioning that can lead to social isolation and a breadth of co-morbidities. Most commonly affected by OA is the knee joint (E. Badley & Glazier, 2004). Knee OA is a leading cause of chronic disability in older adults and is associated with an increased risk of cardiovascular, gastrointestinal, and metabolic diseases, as well as poor mental health including symptoms of depression and anxiety (Guccione et al., 1994). It also decreases willingness and ability to ambulate, impeding one's ability to perform activities of daily living and those that they enjoy, ultimately leading to loss of independence (E. Badley & Glazier, 2004).

Diagnosis

Knee OA can be identified by symptoms or pathology. Symptomatically, individuals with knee OA may experience pain, swelling, joint stiffness, crepitus, and obstructed joint range of motion (Arden & Nevitt, 2006). Criteria for the diagnosis of clinical (symptomatic) knee OA according to the American College of Rheumatology consists of being 50 years of age or older and satisfying three of the following six conditions: having knee pain on most days of the week, joint crepitus, bony tenderness or enlargement, no warmth to the touch, and knee stiffness in the morning lasting longer than 30 minutes (Altman et al., 1986). It should be noted these criteria are 30 years old; however are still accepted. Pathologically, OA of the knee manifests through joint space narrowing and bony abnormalities that are visible using X-ray imaging (Kellgren & Lawrence, 1957). Radiographic assessment is effective at diagnosing late-stage disease; its usefulness for detecting earlier disease presence is questionable (Cibere, 2006). Knee OA pathology involves the whole joint in what is often a progressive disease process. Prominent pathological features within the joint include degradation of the articular cartilage, as well as changes to the sub-chondral bone involving the development of marginal outgrowths, osteophytes, and bony sclerosis (Kellgren & Lawrence, 1957). Damage to soft tissues surrounding the joint is often characterized by inflammation of the synovium, laxity in the ligaments, and muscle weakness (Felson et al., 2000). Radiographic evidence of knee OA and troubling clinical outcomes are not well correlated (Bruyere et al., 2002). Individuals with pathology confirmed by radiograph can have varying levels of pain, function, and muscle power; and vice-versa (Barker, Lamb, Toye, Jackson, & Barrington, 2004).

Risk factors

Numerous factors affecting risk of development or progression of knee OA have been identified and can generally be divided into modifiable and unmodifiable factors. Modifiable factors are those that can be addressed via conservative measures, such as obesity and muscular dysfunction (Felson et al., 2000). Unmodifiable factors are those that cannot be readily altered without invasive procedures like surgical intervention, such as age, sex, trauma, and lower extremity alignment (Felson et al., 2000). The focus of this thesis is on treatment of knee OA rather than etiology; nonetheless two non-modifiable risk factors (age and sex) are elaborated upon to rationalize the selected study sample population.

Knee OA rarely affects young adults and it is well documented that the risk of developing of knee OA is associated with increasing age (Arden & Nevitt, 2006). This effect is likely mediated by multiple systemic and local risk factors such as muscle weakness, joint laxity, impaired proprioception, and reduced physical activity that are also associated with older age (Arden & Nevitt, 2006). Female sex is also a risk factor; compared to men, women are two times more likely to develop knee OA, generally experience worse symptoms and greater disability; and are less likely to access to specialists and surgical intervention (E. M. Badley & Kasman, 2004; G. A. Hawker et al., 2000). The prevalence and incidence of the disease is significantly greater amongst women over the age of 50 years compared to men (Oliveria, Felson, Reed, Cirillo, & Walker, 1995).

Clinical impact of knee osteoarthritis

Osteoarthritis of the knee can be characterized in multiple ways and is studied from varying standpoints. From a clinical perspective, some aspects of the disease are more relevant than others. A study that interviewed individuals with OA, family physicians, and practical nurses revealed the general consensus from these different viewpoints to be that greater attention is owing to the disability and pain that results from the disease (Rosemann et al., 2006). Pain and physical function are paramount outcomes in knee OA rehabilitation; other factors such as muscle strength and psychological health are also important aspects contributing to quality of life in those living with the disease. Although these factors are not independent, they are explored individually and will be the focus of this thesis.

Pain

Pain in knee OA manifests itself in two forms: chronic dull aching and transient periods of superimposed pain. The constant ache is predictable and does not usually affect lifestyle (G.A. Hawker et al., 2008). The bouts of additional overlaid pain appear to be related to physical activity in the early stages of the disease, and are less predictable later in the disease (G.A. Hawker et al., 2008). Knee OA related pain is not well understood. Articular cartilage, the primarily affected tissue in OA, is an aneural tissue; thus the nociception is likely originating elsewhere. The likelihood of experiencing pain increases with radiographic disease severity (Felson et al., 1987) however the correlation between pain intensity and radiographic indication of joint damage in knee OA is often poor. This was demonstrated in a study consisting of 273 individuals with knee pain and 240 without. Radiographic evidence of OA was only found in 53% of persons with pain and in 17% of asymptomatic individuals (McAlindon, Snow, Cooper, & Dieppe, 1992). There are likely multiple structures potentially contributing to the pain associated with knee OA, including the fat pad, subchondral bone, synovium, ligament, and meniscus (K. Bennell, Hinman, Wrigley, Creaby, & Hodges, 2011). However, plastic changes of the peripheral (Schaible, Ebersberger, & Banchet, 2002) and central (Kosek & Ordeberg, 2000) nervous system, as well as psychosocial factors (Summers, Haley, Reveille, & AlarcOan, 1988) are also likely sources of pain which may introduce considerable variability in pain patterns observed in groups with knee OA.

Physical function

Physical function can be defined as "the ability to move around" (Bellamy et al., 1997) and "the ability to perform activities of daily living" (Terwee, Mokkink, Steultjens, & Dekker, 2006). Physical function is a multi-faceted construct and is therefore not straightforward to measure (Wright, Hegedus, Baxter, & Abbott, 2011). Both self-reported and performance-based measures are used to evaluate different aspects of physical function. Performance-based measures objectively assess what an individual is capable of doing on a selected task. Self-reported measures evaluate what individuals perceive they are capable of, providing a more intimate perspective on how function impacts the individual's life (Terwee, Mokkink, Steultjens, & Dekker, 2006). While self-report measures have been considered superior by some, both methods are valid and should be used complementarily to obtain the truest representation possible (Stratford & Kennedy, 2006; Wright et al., 2011).

Knee OA can have a profound impact on physical functioning. Most often, functional limitations and disability manifest in a slowly deteriorating manner (van Dijk, Dekker, Veenhof, van den Ende, & Carpa Study Group, 2006). A three-year prospective study of community-dwelling adults with knee OA was conducted to investigate the factors involved in slowing versus progressing the functional decline. Factors that appeared to exacerbate functional disability over time were age, body mass index (BMI), pain intensity, joint laxity, and proprioceptive impairment (L. Sharma, Cahue, et al., 2003). Factors that seemed to protect against the functional decline included muscular strength, self-efficacy, psychological health, and activity level (L. Sharma, Cahue, et al., 2003). The importance of psychosocial well-being for preventing physical dysfunction is further supported by a cross-sectional study of 54 individuals with knee OA where the relative contributions of various psychosocial (self-efficacy, anxiety, and depression) and mechanical (BMI and knee musculature strength) variables on mobility performance were explored (Maly, Costigan, & Olney, 2005). While strength and BMI appeared important to mobility performance, which makes sense from a biomechanical perspective; self-efficacy (one's confidence in their own ability) proved to have the greatest influence.

Strength

Muscular strength of the lower limb is an important factor in the management of knee OA and its well documented that individuals with knee OA exhibit muscle weakness, especially in the quadriceps muscle group (K. Bennell et al., 2011). It is not clear why this weakness is present; it may be due to reduced physical activity resulting from the disease or could have preceded and perhaps been involved in the genesis of the disease, or a combination of both (K. Bennell et al., 2011). Regardless, strength appears to be the main factor associated with physical function in older adults with knee OA (Chun et al., 2013) and is a better determinant of functional impairment compared to radiographic indication of knee OA (McAlindon, Cooper, Kirwan, & Dieppe, 1993). It is also possible that muscle weakness may accelerate the disease process. In a study of 2254 of women, greater isokinetic quadriceps strength, relative to body mass, was associated with a decreased risk of knee joint space narrowing (Segal et al., 2010). Furthermore, quadriceps muscle strength has been identified as a protective factor against functional decline in 257 individuals with knee OA (L. Sharma, Dunlop, Cahue, Song, & Hayes, 2003).

There are several factors likely contributing to muscle weakness in knee OA. Muscular strength, which is almost always measured externally using torque at a joint, is largely determined by the tensile force production which is a function of muscle cross-sectional area and the recruitment and firing of alpha motor neurons at sufficient frequencies (Enoka, 2002). Thus, the primary sources of weakness appear to be muscle atrophy and the inability to fully activate muscle voluntarily (K. Bennell et al., 2011).

The tensile force production of the muscle then acts in conjunction with the moment arm (distance from joint axis of rotation to tendinous insertion on bone) to create torque or a moment about the joint, which gives rise to angular displacement of body segments and subsequently joint movement. Therefore, slight perturbations to the mechanical environment of the joint due to the disease process can also yield substantial changes in torque production (muscle strength) (K. L. Bennell, Wrigley, Hunt, Lim, & Hinman, 2013). Other factors suggested to play a role include pain and joint effusion, which are not necessarily independent (K. L. Bennell et al., 2013). Pain can indirectly affect muscle strength by creating neural inhibition; this was demonstrated by a study using anaesthetic injections to alleviate OA associated pain resulting in acute increases in voluntary muscle activation (Hassan, Mockett, & Doherty, 2001). Joint effusion is also often associated with knee OA pain; experimental models of which have demonstrated this effusion to acutely affect gait parameters (Rutherford, Hubley-Kozey, & Stanish, 2012).

Psychological health

The consequences of knee OA on overall physical health are well established. This condition can also have a severe impact of psychosocial well-being. This being said, the genesis of OA and subsequent psychological distress may not be the case for all, it is possible that mental health concerns can precede or develop simultaneously with OA. Individuals with knee OA often experience symptoms of depression, anxiety, poor self-efficacy, and insomnia, more so than persons without OA (E. Badley & Glazier, 2004). Unfortunately, the functional disability associated with knee OA can give rise to social isolation (Maly & Cott, 2009) possibly creating some of the psychosocial health concerns.

It is a self-perpetuating cycle given depression and anxiety are associated with poor self-reported functional ability (Summers et al., 1988), and this very lack in self-efficacy can further hinder function (Rejeski, Ettinger, Martin, & Morgan, 1998), leading to greater social isolation, and furthermore exacerbating psychological distress. It is also likely that the depression observed so frequently with OA is a downstream result of the pain and fatigue associated with the disease (Gillian A. Hawker et al., 2011). This was demonstrated by a longitudinal study where participants with knee or hip OA were followed over two years to inquire about symptoms of depression and how they relate to pain, disability, and fatigue (Gillian A. Hawker et al., 2011). While the depressive symptoms were mediated by pain, depressed mood was also found to further augment the worsening of pain and disability, further supporting the negatively self-perpetuating cycle. What is concerning is that these debilitating mental health issues, namely depression and anxiety, are frequently missed by health care providers (Memel, Kirwan, Sharp, & Hehir, 2000). This highlights the importance of an integrated approach to OA management where mind and body are not treated distinctly to address the burdening symptoms of knee OA that are both physical and psychological in nature.

Treatment

Osteoarthritis is thought to be an irreversible disease process; thus the goal of treatment is to manage pain and maintain or improve physical function with the ultimate goal in improving health related quality of life (Felson et al., 2000). Expert opinion and evidence-based guidelines published by the Osteoarthritis Research Society International (OARSI) suggest optimal management of knee OA involves a combination of non-pharmacologic and pharmacologic treatment modalities (Zhang et al., 2008). Some of these non-pharmacologic options include but are not limited to disease education and self-management, regular social engagement, exercise, weight reduction, walking aids, bracing, and modified footwear. Some of the pharmacologic recommendations include administration of acetaminophen, non-steroidal anti-inflammatory (NSAID) agents, selective cyclooxygenase enzyme-2 (COX-2) inhibitors, topical NSAID and capsaicin ointments, intra-articular injections, and glucosamine and/or chondroitin for symptom relief. When pain management and functional improvement is no longer attainable via these conservative measures, surgical intervention (i.e. total joint replacement) is considered (Zhang et al., 2008). Adherence to non-pharmacological interventions are often low (Li et al., 2004); and side effects of pharmacological treatments are possible and potentially severe (Wallace, 2013). In practice, it would appear as though initial conservative treatment typically involves drug administration to mitigate pain until physical function declines sufficiently for consideration of surgery (Li et al., 2004). In Canada, the average wait time for joint replacement is 4.4 years from diagnosis (Canadian Institute for Health Information, 2014), and this wait is greater for women and individuals of low socioeconomic status (Rahman et al., 2011). This is a substantial period of time from diagnosis until surgical intervention that could be used in a more proactive and effective manner. The treatment guidelines from OARSI clearly state that initial management approaches should emphasize patient-driven self-help strategies and therapies, rather than passive treatments lead entirely by health care professionals (Zhang et al., 2008). This notion is consistent with qualitative research exploring the standpoints of both patients and health care providers, that has concluded patients must not simply be labelled as chronically ill and prescribed pharmacologic agents to mitigate pain but rather educated about their condition and equipped with proactive self-help strategies to complement mainstream treatment (Rosemann et al., 2006). Thus, conservative interventions that are empowering to the individual and restore the responsibility of health back into the hands of the patient are of utmost importance in optimally managing OA of the knee.

Traditional exercise for knee osteoarthritis

Exercise as a conservative treatment approach for knee OA produces pain relief that is equivalent to commonly prescribed medications, improves physical functioning, and health related quality of life; and is associated with relatively few and minor side effects (or adverse events) (Fransen et al., 2015). Similar to medications, not all exercise is equal and effectiveness can vary depending on the nature of the intervention. It is essential to distinguish various forms of exercise, as important differences do exist, especially in knee OA. Certain types of exercise may be more effective in alleviating symptoms than others. Examples of exercise types that appear to be suitable for knee OA include strength training (weight and non-weight bearing; land and aquatic based), endurance training (walking, cycling, and swimming), and flexibility based programs (emphasizing joint range of motion) (K. Bennell et al., 2011). Response to various forms of exercise will also depend on "dose". Exercise dosage refers to frequency, intensity, and duration. The majority of studies evaluating the efficacy of exercise in knee OA do not relate exercise type and dosage to effectiveness thus it is not clear what type or amount is optimal (K.

Bennell et al., 2011). The effectiveness of an exercise intervention also depends on the mode of delivery. Exercise can be supervised, either individually or in a group setting; or unsupervised (e.g. home-based program). While all delivery methods are efficacious at improving pain status and physical function, a meta-analysis reviewing land-based exercise interventions for knee OA revealed the largest effect sizes for supervised exercise programs, either individual or group-based (Fransen & McConnell, 2009).

Pain

The benefits of physical exercise on pain status in knee OA are well documented, and have been reviewed by numerous meta-analyses of randomized and controlled exercise trials for knee OA. Land-based exercise reliably produces small to moderate effect sizes for pain management (Fransen & McConnell, 2009; Fransen et al., 2015). A meta-analysis of 44 land-based exercise interventions involving 3537 participants, concluded that exercise reduces pain by a standard mean difference (SMD) of 0.49 (95% confidence intervals (CI) = 0.39 – 0.59) compared to not exercising (Fransen et al., 2015). In other words, individuals with knee OA who complete an exercise program generally rate their pain 12% less following the intervention, compared to baseline. While the magnitude of these effects are considered small to moderate, it is important to note that exercise produces similar effects to those reported for the use of analgesics and NSAIDs (Zhang et al., 2010). Relative to land-based, aquatic exercise yields much smaller effect sizes for pain management in knee OA (Zhang et al., 2010). A recent meta-analysis reviewed 48 randomized control exercise trials for knee OA aiming to provide insight on the influence of exercise type and dosage on pain status (Juhl, Christensen, Roos, Zhang, & Lund, 2014). With respect to exercise type, the authors found aerobic exercise, resistance exercise, and "functional" (exercise designed to bear functional relevance to activities of daily life) exercise to be equally effective for pain relief. Despite the apparent equality of exercise type, exercise interventions with a single focus (i.e. aerobic condition or quadriceps strengthening) were more effective, relative to those addressing multiple treatment goals. Regarding dose, supervised programs consisting of at least three sessions weekly were most effective. Exercise session duration, intensity, patient characteristics (age, sex, BMI), and disease severity (radiographic evidence and baseline pain) do not appear to influence the efficacy of the intervention (Juhl et al., 2014).

It is not clearly understood how exercise improves OA-related pain, however the mechanism is likely multi-faceted. A qualitative systematic review of the literature on mechanisms underlying exercise-mediated improvements in knee OA pain concluded potential origins to be neuromuscular, peri-articular, intra-articular, general fitness/health, and psychosocial well-being oriented (Beckwée, Vaes, Cnudde, Swinnen, & Bautmans, 2013). Neuromuscular based mechanisms include muscular strength, proprioception, energy absorbing capacity, and stability (Beckwée et al., 2013). Peri-articular mechanisms include bone and other connective tissue adaptations that support healthy joint function (Beckwée et al., 2013). Intra-articular mechanisms could include improvements in cartilage quality, inflammation, and joint effusion (Beckwée et al., 2013; Roos & Dahlberg, 2005). In terms of general health and fitness, improvements in pain from exercise are often credited to improvements in muscle strength, though changes in muscle function are usually not correlated with pain (Beckwée et al., 2013; K. Bennell et al., 2011). A recent systematic review that examined 94 exercise intervention studies for OA, most of which focusing solely on knee OA, attributed the improvements in pain most likely due increases in upper leg muscle strength, increased joint range of motion through alleviation of impaired knee extension, and improved proprioception (Runhaar, Luijsterburg, Dekker, & Bierma-Zeinstra, 2015). With respect to psychosocial elements, proposed mediating factors of pain improvement include increases in self-efficacy, perceived well-being, and symptoms of depression (Beckwée et al., 2013).

Physical function

Physical function of individuals with knee OA appears to respond to exercise treatment similarly to that of pain (K. Bennell et al., 2011). A meta-analysis of 44 land-based exercise interventions involving 3913 participants concluded that exercise improves self-reported physical function by a SMD of 0.52 (CI = 0.39 – 0.64) compared to no exercise (Fransen et al., 2015). Individuals with knee OA who complete an exercise program generally rate their physical function 10% better following the intervention, compared to baseline. The aforementioned meta-analysis that evaluated the efficacy of exercise to improve pain, also examined self-reported physical function using data from 48 randomized and controlled exercise trials for knee OA to determine the impact of exercise type and dosage (Juhl et al., 2014). Aerobic, resistance, and functional exercise were all effective for improving physical function with no differences between exercise types. However, interventions that combined multiple types of exercise were significantly less effective at improving physical function relative to programs consisting of aerobic, resistance, or functional exercise only. Similar to pain, supervised programs consisting of at least three sessions per week were most effective. Exercise session duration, intensity, patient characteristics (age, sex, BMI), and disease severity (radiographic evidence and baseline pain) did not significantly influence the effectiveness of intervention in terms of improving physical function.

Strength

Muscular strength can be modified in those with knee OA with an appropriately selected exercise program (Pelland et al., 2004). The most effective form of exercise for increasing muscular strength is resistance training. A systematic review and meta-analysis of exercise programs designed to improve strength for knee or hip OA reviewed 40 randomized and controlled resistance training interventions (Zacharias, Green, Semciw, Kingsley, & Pizzari, 2014). In the context of resistance training, intensity is the proportion of maximal resistance tolerated by the individual that is prescribed. In knee OA, the intensity may require modification to accommodate pain and perceived exertion in the individual. There was high quality evidence of knee extensor (SMD = 0.47, 95% CI = 0.29 – 0.66) and flexor (SMD = 0.74, 95% CI = 0.56 – 0.92) strength increases following low-intensity resistance training in knee OA populations compared to control groups. There was moderate quality evidence supporting a large strengthening effect of the knee extensors (SMD = 0.76, 95% CI = 0.47 – 1.06) and flexors (SMD = 0.86, 95% CI = 0.40 – 1.32) due to high-intensity resistance training. Experts in the field have suggested higher intensity resistance training will likely result in superior strength gains relative to lower intensities in knee OA but can also overload the joint, aggravating symptoms (pain, swelling, inflammation) and possibly accelerating disease progression

(K. L. Bennell et al., 2013). Given the current state of the literature, more work is needed to explore low-intensity exercise approaches that can perhaps yield similar results with greater tolerability.

Yoga for knee osteoarthritis

In contrast to the intense, repetitive nature of traditional exercise, yoga, as a means of physical exercise, offers a foundation of static poses that involve resisting the force of gravity to maintain form in postures that bear functional relevance to activities of daily life. Work from our laboratory has demonstrated a variety of popular yoga postures that disperse mechanical loads incurred by the knee away from the medial compartment, the part of the joint most often affected in knee OA (Longpré, Brenneman, Johnson, & Maly, 2015). From a biomechanical standpoint, this form of exercise would seem to be a safer approach, in theory at least. We then conducted a pilot study to investigate a 12-week intervention comprised of these yoga-based postures in a single group of women with knee OA and found comparable results to traditional exercise interventions with respect to improvements in pain, function, and muscle strength (Brenneman, Kuntz, Wiebenga, & Maly, 2015). Early evidence of yoga as a therapeutic intervention for knee OA looks promising as an alternative option to traditional exercise.

Background of yoga

The word “yoga” is of Sanskrit origin and can be directly translated to “yoke” in English, referring to union or connection. Yoga, in its truest sense, is a practice that was designed to cultivate harmony within self, society, and nature. Yoga is an all-encompassing lifestyle, and there are numerous aspects to the practice, including those less recognized in Western culture such as rules for conducting oneself in society, self-restraint, and oneness with the universe or the divine (M Sharma & Romas, 2013). Westernized schools of yoga however have focused primarily on physical posture, breathing techniques, and somatic awareness through meditation. A modern view of the ancient system involves physical and psychological practices to integrate mind and body to achieve and maintain health of the individual. In accordance with the bulk of the literature examining the therapeutic potential of yoga for rheumatic conditions, this thesis will focus primarily on Hatha style yoga, a form that emphasizes physical posture.

Scientific evidence

Yoga as a conservative approach for alleviating symptoms of OA has received less attention in the scientific and medical communities relative to traditional forms of exercise. Nonetheless, this practice that has withstood the rigorous test of time, given its roots can be traced as far back as 2200 years ago (Singh, 1983), and is now being investigated in the scientific and medical communities. The 2007 National Health Interview Survey demonstrated yoga to be the sixth most commonly used complementary health practice among adults (Barnes, Bloom, & Nahin, 2008). Systematic reviews of the early stages of evidence suggest yoga may be effective for improving some of the major physical (pain, function) and psychological (depression, anxiety) burdens associated with knee OA (Haaz & Bartlett, 2011; Selfe & Innes, 2009; Manoj Sharma, 2014).

There are numerous studies pointing to yoga as a promising therapy for knee OA; here a few of the more rigorously designed studies are highlighted. A study in *The Journal of Rheumatology* was conducted to investigate the effects of hatha-based (emphasis on posture, breathing, and attention) yoga in adults with knee OA or rheumatoid arthritis. Seventy-five participants were randomly assigned to an 8-week yoga intervention (2x60-minute classes and 1 home based practice per week) or a waitlist control. Following the intervention, the yoga group demonstrated greater improvements in perceived physical and general health, pain, walking performance, and depressive symptoms compared to control (Moonaz, Bingham, Wissow, & Bartlett, 2015). These improvements were still evident nine months after study completion. There were seven adverse events in the yoga group, none of which were attributed to the intervention. A limitation of this study was the inclusion of participants with both knee OA and rheumatoid arthritis. Though this may have afforded a larger sample and greater statistical power, these pathologies and their consequences are considerably different; thus it is reasonable to expect the intervention effect may also differ.

Specifically for OA of the knee, a pilot randomized control trial of an eight-week hatha yoga intervention in 36 women with knee OA demonstrated improvements in patient-reported pain and function as well as mobility performance compared to waitlist control (Cheung, Wyman, Resnick, & Savik, 2014). Though this was not a blinded study, the results are favourable for the efficacy of a short-term yoga intervention for knee OA. There has also been work investigating the additive effects of yoga to traditional physical therapy for OA of the knee. In a randomized control trial for knee OA, 250 participants (aged 30-85 years) were allocated to a hatha yoga therapy group or traditional therapeutic exercise group. Both groups received transcutaneous electrical stimulation and ultrasound treatment for 20 minutes per day followed by either 20 minutes of yoga or traditional exercise. Fifteen days into the intervention, and following its three month duration, both groups demonstrated improvements in pain, knee range of motion, walking performance, other knee symptoms, and disability with the yoga group yielding greater effects than the active control on all outcomes. All participants were selectively recruited from an orthopaedic clinic; nonetheless this large scale trial supports the efficacy of yoga as a superior adjunct to therapy compared to traditional exercises (Ebnezar, Nagarathna, Yogitha, & Nagendra, 2012b). Published in separate studies, the yoga group of this same sample outperformed the traditional physical therapy group for improving morning stiffness, anxiety, blood pressure and pulse rate, as well as health related quality of life (Ebnezar, Nagarathna, Bali, & Nagendra, 2011; Ebnezar, Nagarathna, Yogitha, & Nagendra, 2012a). The findings of the aforementioned trials are supported by those of less controlled studies (Bukowski, Conway, Glentz, Kurland, & Galantino, 2006; Kolasinski et al., 2005; Park, McCaffrey, Dunn, & Goodman, 2011; Park, McCaffrey, Newman, Cheung, & Hagen, 2014; Tiedemann, O'Rourke, Sesto, & Sherrington, 2013).

The current state of the literature focused on yoga as a treatment strategy for knee OA contains relatively few controlled studies, small samples, and a lack of consistency in reporting of outcomes and intervention protocols. Despite this, there is high consistency amongst study findings suggesting yoga has good potential to be a beneficial therapeutic intervention for improving symptoms of knee OA.

Knowledge gaps

Multiple important areas that are currently lacking in the literature are addressed in this Masters thesis.

1) There is growing evidence to support the efficacy of yoga as a conservative treatment for knee OA. Aside from case studies, only one study has compared yoga to an active treatment (Park et al., 2011). The active treatment intervention was a Reiki program in which there is an uncertain amount of physical exercise and the efficacy of this treatment is not established in the scientific literature. Direct comparisons of yoga and traditional forms of exercise are lacking. These sorts of trials are needed to directly assess efficacy; and whether yoga may be a suitable alternative or adjunct to conventional physical therapy. This thesis will compare a yoga-based exercise intervention to the current "gold standard" of physical therapy for knee OA and no-exercise control group.
2) While higher intensity resistance exercise likely yields greater strength gains, it is possible that the increased resistance relative to lower-intensity exercise could overload the knee joint exacerbating pain, inflammation, and swelling and possibly accelerate the disease process. There is a need to identify tolerable exercises for individuals with knee OA that do not overload the joint but still provide the numerous benefits of exercise. This thesis will aim to examine the efficacy of a low-intensity, resistance-based yoga program designed to alleviate troubling symptoms while avoiding exposure to harmful mechanical loads incurred by the joint.

3) There are numerous proposed mechanisms for how exercise may alleviate debilitating OA symptoms (Beckwée et al., 2013). It is not clear how the attention and the social aspects of a supervised, group intervention in and of itself affect outcomes, particularly self-reported pain and physical function. This thesis will attempt to distinguish the effects of physical exercise separate from those of supervised, group intervention involving the non-physically active elements of yoga.

Purpose and significance

The overarching purpose of this thesis is to test the efficacy of a biomechanically-based yoga exercise intervention as treatment for knee OA by comparison to the current gold-standard of physical therapy for knee OA, and an attention-equivalent no exercise control group. This work will advance our knowledge of non-pharmacologic treatment options for OA of the knee. These findings have potential to provide those living with this challenging condition a safer and possibly more effective and integrative approach to navigating the burdening symptoms of the disease and ultimately improving quality of life and preserving independence.

CHAPTER 2: Manuscript

Efficacy of a biomechanically-based yoga exercise program for knee osteoarthritis: a randomized control trial

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Introduction

Osteoarthritis (OA) is a chronic disease characterized by the degradation of all joint tissues. Osteoarthritis is the most prevalent form of arthritis and the most common joint disorder worldwide (Arden & Nevitt, 2006). Most commonly affected by OA is the knee joint; and knee OA often results in pain and physical dysfunction, and is associated with a variety of comorbidities such as cardiovascular, gastrointestinal, and metabolic disease as well as depression (Badley & Glazier, 2004). First-line treatment recommendations for knee OA include medication for pain management (Hochberg et al., 2012; Yu & Hunter, 2015). This kind of pharmacologic intervention can pose risks of toxicity and dependence over time. Given the vast array of comorbidities associated with knee OA, polypharmacy is a substantial concern (Wallace, 2013). When pain relief and functional improvement are no longer attainable via conservative measures, surgical intervention is considered (Zhang et al., 2008). Arthroscopic procedures appear to be no more effective than placebo (Moseley et al., 2002) and joint replacement surgery, a highly invasive operation, is accompanied with long and growing wait times in North America (Canadian Institute for Health Information, 2014; Kurtz, Ong, Lau, Mowat, & Halpern, 2007). It is for this reason that tolerable conservative treatment approaches are investigated to make meaningful use of this multi-year gap between diagnosis and last resort joint replacement.

Exercise is an effective non-pharmacologic treatment option that provides equivalent pain relief to that of medication while improving physical function, comorbidities, and quality of life (Fransen et al., 2015; Hochberg et al., 2012; Zhang et al., 2008). A variety of exercise types have been tested in knee OA; however it is not clear which form of exercise is optimal for this condition. Examples include aerobic exercise such as walking, cycling, swimming; and resistance exercise (weight bearing or non-weight bearing) which can be land-based or aquatic (K. Bennell, Hinman, Wrigley, Creaby, & Hodges, 2011). Very few studies however have conducted direct comparisons of distinct exercise types; and these kind of trials are needed to establish the optimal exercise prescription for knee OA.

Exercise provides numerous benefits for individuals with knee OA but similar to pharmacologic treatment, it is not entirely risk free. There are certain features of common exercises that can exacerbate symptoms and possibly contribute to disease progression. For example, exposure to elevated magnitudes of the knee adduction moment (KAM), a mechanical variable reflecting the ratio of medial to total knee loading, has been shown to predict disease progression (K. L. Bennell et al., 2011; Chang et al., 2015; Chehab, Favre, Erhart-Hledik, & Andriacchi, 2014; Miyazaki et al., 2002). Therefore, it makes sense to ensure exercise prescriptions for knee OA minimize exposure to this varus knee torque. Highly repetitive exposure to KAM has been linked to pain severity in OA (Robbins et al., 2011). Additionally, the use of running shoes increases the KAM by 38% compared to barefoot (Kerrigan et al., 2009). Repetition and the use of footwear are prominent features in many exercise programs for knee OA, such as walking and resistance training.

Yoga, a form of exercise that has received relatively less attention in knee OA, is a practice in which participants engage in variety of static postures that are performed barefoot. Additionally, if the correct poses are selected, the KAM can be reduced or eliminated entirely (Brenneman, Kuntz, Wiebenga, & Maly, 2015; Longpré, Brenneman, Johnson, & Maly, 2015). Yogic practice also involves cultivating a "mindful" attitude, which can be defined as paying deliberate attention in a non-judgmental manner to one's subjective experience of the present moment (Kabat-Zinn, 1990). Mindfulness practice can ameliorate pain in chronic conditions like arthritis (Fogarty, Booth, Gamble, Dalbeth, & Consedine, 2015; Rosenzweig et al., 2010) and is currently being investigated in persons with knee OA awaiting joint replacement (Dowsey et al., 2014). The English translation of the Sanskrit word *yoga* is *to yoke* or connect, referring to body-mind integration and union. This is an important paradigm for interventions aimed to address the burdening symptoms of OA that are both physiological and psychological in nature (Ferreira et al., 2015; Zambon et al., 2015). Although there is a lack of high quality evidence in the current state of the literature, systematic reviews have concluded that yoga appears to be a safe and promising treatment modality for osteoarthritis (Haaz & Bartlett, 2011; Sharma, 2014). Specifically, it appears to provide relief from the pain, disability, lack of self-efficacy, and depressive symptoms associated with the disease (Haaz & Bartlett, 2011).

Our group tested a series of yoga postures in younger women with healthy knees to identify which poses may be suitable for knee OA (Longpré et al., 2015). To do this, activation of key muscle groups involved in knee OA and mechanical loading of the knee joint were measured using electromyography and three-dimensional motion analysis. A collection of squat and lunge based postures were selected that activated the quadriceps and hamstring muscle groups, while yielding KAMs lower than those experienced during gait. We then developed a 12-week intervention comprised of these postures to utilize the biomechanical alignment and body-mind integrative aspects of yoga (Brenneman et al., 2015). Following the intervention, participants experienced less pain, increased knee muscle strength, as well as improved physical function and mobility performance (Brenneman et al., 2015). This study employed a single cohort design to establish proof-of-principle.

The purpose of the current study was to compare the efficacy of this biomechanically-based yoga exercise intervention to the current gold-standard of physical therapy for knee OA, and an attention-equivalent control group in women with clinical (symptomatic) knee OA. The primary outcome was pain. Secondary outcomes were patient-reported physical function and mobility performance. We also investigated knee muscle strength, depression, and health-related quality of life. It was hypothesized that the yoga group would experience greater improvements in pain, function, and mobility, as well as strength, depression and health-related quality of life, compared to the no-exercise group; and equal or greater improvements compared to traditional physical therapy.

Method

Study Design

This study consisted of a single-blind, three-arm, parallel, exercise intervention trial. In this single-center clinical trial, participants were randomized after stratification for disease severity to receive active treatment or an attention control intervention. After screening, functional limitations of eligible and interested participants were quantified using the Lower Extremity Functional Scale (LEFS) (Binkley, Stratford, Lott, & Riddle, 1999; Hoogeboom, de Bie, den Broeder, & van den Ende, 2012), a 20-item measure with a total score of 80, where higher scores indicate better function. Mild limitation was regarded as LEFS scores between 51 and 65, and those between 30 and 50 were moderate (Kennedy, Stratford, Robarts, & Gollish, 2011). After stratification, participants were randomized to one of three interventions (block size of n=6 and 1:1:1 allocation ratio). The intervention arms included a yoga exercise (YE) experimental group, a traditional exercise (TE) active treatment comparison group (TE), and a no exercise (NE) attention-equivalent control group. Participants received group allocation information in an opaque envelope. This process was completed by an investigator who was not involved in data collection using a custom computer generated sequence (Mathworks Inc., Natick, MA). All data collection was led by an investigator who was blind to group allocation and uninvolved in the interventions. Participants and exercise instructors were blinded to the study hypothesis. This trial (NCT 02370667) was conducted at McMaster University in Hamilton, ON, Canada and was approved by the Hamilton Integrated Research Ethics Board (#15-021) where all participants provided written informed consent.

Sample size

A sample size calculation for an analysis of covariance (ANCOVA) designed to detect significant differences in three primary outcomes between three groups with one covariate (baseline values) was performed. A systematic review of yoga as a therapeutic intervention for adults with chronic pain concluded yoga is capable of reducing pain by a standard mean difference of -0.74 (95%CI, -0.97 to -0.52; $P < 0.0001$). Given the moderate effect size, a high correlation between outcomes, and a 5% chance of type one error, a sample of 60 participants was recommended to yield 80% power to detect between group differences. This calculation was performed using G*Power 3.1.9.2. A convenience sample of 31 participants was selected for feasibility.

Participants

Participants were recruited through rheumatology, orthopedic, and physical therapy clinics, as well as by word-of-mouth in the Hamilton, Ontario, Canada region between April and June 2016. The sample included ambulatory, community dwelling women, 50 years of age or over, who met the diagnostic criteria for clinical (symptomatic) knee OA according to the American College of Rheumatology (Altman et al., 1986). Clinical OA diagnostic criteria were chosen given the main outcomes of this study were pain and physical function, and radiographic disease severity does not appear to influence the effectiveness of exercise (Juhl, Christensen, Roos, Zhang, & Lund, 2014). Exclusion criteria consisted of other forms of arthritis (e.g., rheumatoid, psoriatic), history of osteoporosis related fracture, patellofemoral pain, non-arthritic knee disease (e.g., gout, bursitis, ligament injury), knee surgery (e.g., high tibial osteotomy, joint replacement, ligament repair), unstable heart condition (e.g., physician advised physical activity restrictions), unstable neurological conditions (e.g., stroke), skin allergy to medical tape, lower limb trauma in past three months, ipsilateral hip or ankle conditions, undergoing cancer treatment, and pregnancy. Data collection took place in a clinical biomechanics laboratory at McMaster University in Hamilton, ON, Canada.

Interventions

All three interventions were 12 weeks in duration where participants were asked to attend three of four available supervised one-hour classes each week. The interventions took place between June and September 2016 in Hamilton, Ontario, Canada.

The YE intervention was group format and led by a certified yoga instructor who was trained to deliver the hatha-based program (hatha yoga emphasizes physical posture, yogic breathing patterns, and somatic awareness). The YE program consisted of alignment-based postures deemed biomechanically suitable for knee OA. The selected weight-bearing, static poses were performed barefoot and included a variety of squats and lunges with varying foot, trunk, and arm positioning. The classes began with a body-awareness exercise performed in a supine position followed by the strengthening postures and concluded with a closing deliberate relaxation exercise performed in a supine posture. Exact details of the program including exercise descriptions and figures are previously published (Brenneman et al., 2015) and included in appendix A of this document.

The TE intervention was designed to reflect the current gold standard of physical therapy for knee OA (Fransen et al., 2015). Exercise programs for knee OA with one primary rehabilitation target tend to produce greater improvements in pain and physical function status (Juhl et al., 2014). Thus the current regimen emphasized knee musculature strengthening but also involved an aerobic warm-up, balance exercises, and stretching. The TE intervention was designed and supervised by kinesiologists and physical therapists and took place at a physical activity center on McMaster University campus. The sessions involved a ten-minute warm-up performed on a treadmill or a cycle ergometer. The lower extremity strengthening followed the warm-up and was performed on pneumatically resisted exercise machines (HUR USA, Inc., Northbrook, IL, USA). Exercises included all major muscle groups of the lower extremity. The quadriceps were targeted at every exercise session. The balance component followed the resistance exercise and involved weight-bearing, balance oriented activities. Lastly, participants engaged in static stretching of the muscle groups involved in resistance training that session. There was a progressive increase in training volume over the course of the intervention (i.e., number of exercise "sets") and participants were continually encouraged to increase their resistance on the strengthening exercises. Complete details of the traditional exercise regimen are included in appendix B.

In both exercise interventions, participants were asked to exercise at an intensity such that their perceived rating of exertion was approximately seven out of ten on the Borg Perceived Exertion Scale (Borg, 1982). Participants were also asked to rate their knee pain on a visual analog scale (Gillian A. Hawker, Mian, Kendzerska, & French, 2011) prior to each session and ensure that pain levels were not exacerbated by more than two points on the measure ranging from zero to ten. In the event that pain increased more than two points during a session, participants were asked to notify the instructor for an appropriate modification.

The NE intervention consisted of group-based, guided meditative relaxation classes involving led by a certified yoga-instructor. These sessions included non-physically active somatic awareness exercises including breath and body-scan meditation practices performed in passive postures fully supported by the use of yoga props.

Strategies to enhance participant adherence included a gift bag (log book, refreshments, and snacks) after the initial data collection visit, rewards for best attendance halfway through intervention (movie passes), and a $50 stipend upon study completion. Session attendance and program adherence was monitored. At follow-up, participants were asked to report any co-intervention or adverse events during the study period.

Outcome measures

All outcomes were measured before and immediately after the 12-week intervention led by the same blinded assessor. The primary outcome was pain. Secondary outcomes were physical function and mobility performance. It has been recommended to assess both patient-reported and performance-based physical function in knee OA to obtain a truer representation of ability (Stratford & Kennedy, 2006). Tertiary outcomes included muscular strength, symptoms of depression, and health-related quality of life.

Primary outcomes

Pain was assessed using the pain subscale of the KOOS (Knee Injury and Osteoarthritis Outcome Score) and the Measure of Intermittent and Constant Osteoarthritis Pain (ICOAP). The KOOS pain subscale yields a score of pain intensity during a variety of movements and activities known to evoke pain in this population. It is a nine-item tool answered on a five-point Likert scale. Scores are normalized out of 100; lower scores indicate more extreme and troublesome symptoms. The KOOS produces valid (Collins, Misra, Felson, Crossley, & Roos, 2011) and reliable (Alviar, Olver, Brand, Hale, & Khan, 2011) data in adults with knee OA. In contrast to the KOOS, the ICOAP provides information on pain intensity and frequency, and the consequent effects on important aspects of life independent of the effects of pain on physical function. The ICOAP is an 11-item questionnaire where higher scores are indicative of more severe pain. The tool was designed to distinguish the OA pain experience into pain that is always present as well as pain that comes and goes, and yields scores for the most troublesome joint and the resulting impact on mood, sleep, and quality of life. The ICOAP produces valid and reliable data in adults with OA of the knee (G. A. Hawker et al., 2008).

Secondary outcomes

Patient-reported physical function was assessed using the function in activities of daily living (ADL) and sport and recreation (SR) subscales of the KOOS. The ADL subscale of the KOOS is a 17-item tool and the SR subset consists of five items; where higher scores indicate better function. Mobility performance measures included those recommended by the Osteoarthritis Research Society International: the six-minute walk (SMW), 40-meter walk (40mW), 30-second chair stand (30sCS), timed up and go (TUG), and stair ascent (SA) tests (Dobson et al., 2012). In the SMW test, participants were instructed to walk as far as possible in a six-minute duration; distance travelled was recorded. Time spent walking the initial 40 meters of the SMW was used as 40mW score. Simultaneous collection of the 40mW and SMW tests was performed to minimize participant burden and fatigue. The number of times participants were able to rise from and return to a chair in 30 seconds was used for 30sCS score. The TUG test involved measuring the duration of time required for participants to rise from a chair, walk around a pylon positioned three meters from the chair, and return to their seat. All of these mobility performance measures produce valid and reliable data in individuals with knee

OA (Cahalin, Mathier, Semigran, Dec, & DiSalvo, 1996; Dobson et al., 2012; Kennedy, Stratford, Wessel, Gollish, & Penney, 2005; McCarthy, Horvat, Holtsberg, & Wisenbaker, 2004). Lastly, time taken to ascend a 9-step staircase as quickly as possible, with or without the use of a handrail, was recorded for the SA test. This stair climbing assessment produced reliable data (ICC 0.72-0.88, SEM <0.4s) in 29 healthy adults in our laboratory.

Tertiary outcomes

Muscle strength was represented by peak torque production of the knee extensor and flexor muscle groups of participants' most symptomatic knee during maximal voluntary efforts. Participants were positioned on a dynamometer (Biodex System 2, Biodex Medical Systems, Shirley, NY, USA) with the knee joint center aligned with the device axis of rotation and in 65° of flexion relative to full extension. Torso, pelvis, and lower leg restraints were used to minimize the contribution of other muscle groups. Apparatus settings were fitted for each participant upon baseline collection and replicated during follow-up for consistency, with attention paid to placement of ankle cuff (immediately proximal to tibial and fibular malleoli). Participants completed five maximal voluntary isometric muscle actions following a submaximal, isotonic warm-up and familiarization. Each effort lasted five seconds in duration with five seconds of rest in between bouts. Participants were verbally encouraged to maximize voluntary effort. The peak torque value obtained during these five efforts was expressed relative to body mass (Nm/kg).

Symptoms of depression were evaluated using the Center for Epidemiological Studies Depression Scale (CESD). The CESD is a 20-item tool inquiring about affect (mood, guilt, worthlessness, helplessness, appetite, and sleep) that produces valid and reliable data in the general population and individuals with rheumatoid arthritis (Blalock, DeVellis, Brown, & Wallston, 1989; Radloff, 1977).

Quality of life was assessed using the four-item knee related quality of life (QoL) subscale of the KOOS.

Statistical Analyses

Descriptive statistics (age, height, body mass, body mass index (BMI), intervention adherence, and analgesic use) were calculated. A per-protocol ANCOVA comparing mean change scores across the intervention (follow-up minus baseline), with baseline data used as covariates in the models were used to detect between-group differences for each outcome. Sidak adjustments were performed to account for multiple comparisons between groups; alpha values of 0.05 were used. Assumptions of ANCOVA were tested and met (Field, 2009). Data distribution was assessed visually and using Shapiro-Wilk tests; homoscedasticity was assessed using Levene's test for equality of error variance; independence of covariate and treatment effect was assessed using a one-way analysis of variance (ANOVA); and homogeneity of regression slopes of covariates versus dependent variables was assessed visually and by testing group allocation by baseline score interactions in an ANOVA. Paired (two-tailed) t-tests between pre and post intervention group means were also calculated to detect within-group differences. A Bonferroni correction was used to adjust for multiple within-group comparisons; an alpha value of 0.0167 was used. Statistical analyses were conducted using SPSS v. 23 (IBM, IL, USA).

Results

Recruitment, retention, and adherence

Participant recruitment began in April 2016 and follow-up data collection was complete by September 2016. A total of 59 individuals were screened for eligibility; of these, some did not meet the inclusion criteria (n=19), or declined to participate (n=9). Thirty-one individuals were stratified by LEFS score and randomly allocated to either YE (n=10), TE (n=11), or NE (n=10). One participant in TE group completed only two training sessions and was lost to follow-up; therefore data from 10 participants in this group were available for per-protocol analysis. Participant flow is illustrated in Figure 1. Mean ± standard deviation session attendance was 3.0±0.75 sessions per week for YE, 2.7±0.52 for TE, and 2.7±0.62 for NE. One participant in the TE group was unable to complete the intervention due to an unrelated health diagnosis; nonetheless, follow-up data was obtained and included in analysis. Baseline clinical characteristics are presented in Table 1. There were no significant differences ($p<0.05$) in age, BMI, or LEFS scores between groups at baseline.

Table 1. Baseline clinical characteristics (expressed as mean ± standard deviation) of yoga exercise (YE), traditional exercise (TE), and no exercise (NE) groups. The number of participants that self-reported using analgesic drugs is denoted for each group.

Characteristic	**YE (n=10)**	**TE (n=11)**	**NE (n=10)**
Age [years]	65.5±5.6	63.7±8.9	71.1±9.3
Height [m]	1.6±0.1	1.6±0.1	1.6±0.1
Body mass [kg]	75.5±7.0	74.6±21.0	83.0±17.3
Body Mass Index [kg/m^2]	30.1±3.8	28.9±6.4	32.3±5.7
Lower Extremity Functional Scale [/80]	43.1±9.0	41.7±14.8	41.6±14.1

Currently using analgesic drugs [number of participants]	7	5	7

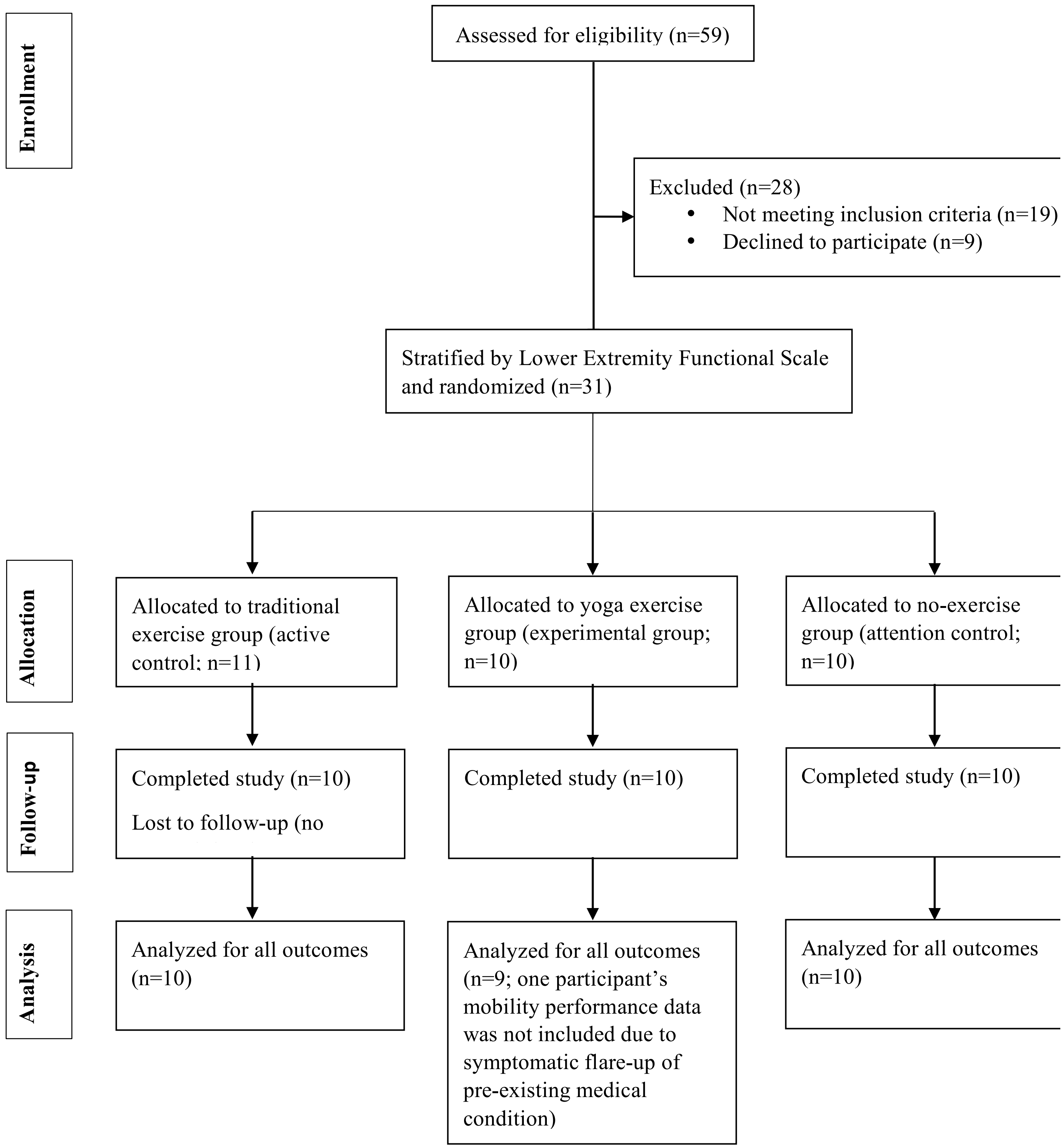

Figure 1. CONSORT (Consolidated Standards of Reporting Trials) diagram of participant flow throughout recruitment, allocation, data collection and analysis.

Adverse events and co-intervention

There were no adverse events related to any of the interventions. There was one case of co-intervention. This participant (in the TE group) received one corticosteroid and two hyaluronic acid injections in the right knee on unknown dates throughout the 12-week intervention. Data from this participant were still included in analysis given this series of injections began prior to study commencement.

Between group comparisons

Pairwise between-group comparisons for all outcomes are presented in Table 2. The YE group reported a greater improvement in pain assessed by the KOOS compared to the NE group (mean difference, 22.9; 95% CI, 6.9 to 38.8; $p=0.003$). The differences in mean change of KOOS pain across the intervention between YE and TE (mean difference, 11.3; 95% CI, -5.1 to 27.6; $p=0.247$), and TE and NE (mean difference, 11.6; 95% CI, -4.45 to 27.7; $p=0.212$) were not significant. The YE group reported a greater reduction in intermittent pain than did the NE group (mean difference, -19.6; 95% CI, -34.8 to -4.4; $p=0.009$). The change in intermittent pain between YE and TE were similar, and there were no differences between TE and NE ($p>0.05$). There were no significant differences ($p>0.05$) in the change of constant pain between the three groups.

The YE group reported greater improvements in KOOS ADL scores compared to the NE group (mean difference, 17.9; 95% CI, 3.8 to 32.0; $p=0.010$). The differences between YE and TE (mean difference, 7.6; 95% CI, -7.0 to 22.2; $p=0.477$); and TE and NE (mean difference, 10.3; 95% CI, -4.3 to 24.8; $p=0.228$) were not significant. The

KOOS SR mean change data passed the Shapiro-Wilk test of normality but upon visual inspection these data did not appear to be normally distributed. Analysis of co-variance is considered quite robust to non-normality when group sample sizes are equal, and was still performed (Field, 2009). The TE group reported greater improvements in KOOS SR scores compared to NE (mean difference, 30.8; 95% CI, 3.0 to 58.7; p=0.027). The differences between YE and TE (mean difference, -6.2; 95% CI, -34.1 to 21.8; p=0.925); and YE and NE (mean difference, 24.7; 95% CI, -3.2 to 52.5; p=0.094) were not significant.

To achieve normally distributed data, equal variance between groups, and homogeneity of regression slopes, one participant in the TE group was removed from analyses of mobility performance measures (SMW, 40mW, 30sCS, TUG, SA tests) due to this individual's data existing beyond three standard deviations from the group mean. This participant verbally expressed that performance on the day of follow-up was impaired due to a symptomatic flare-up of a pre-existing condition (fibromyalgia). There were no significant between-group differences (p>0.05) in mean changes for any of the mobility performance measures.

There was a greater increase in knee flexor strength in the TE group relative to the YE group (mean difference, 0.1; 95% CI, 0.01 to 0.21; p=0.028). There were no significant differences (p>0.05) between groups in mean changes of KOOS QoL scores, CESD scores, or knee extensor strength.

Table 2. Pairwise between-group differences in outcome measures using analysis of covariance adjusting for baseline values. A Sidak adjustment for multiple comparisons was used. Significant differences are denoted with an asterisk*.

	YE vs. NE		YE vs. TE		TE vs. NE	
	Mean difference (YE minus NE) [95% CI]	P value	Mean difference (YE minus TE) [95% CI]	P value	Mean difference (TE minus NE) [95% CI]	P value
Primary Outcome						
KOOS Pain (/100)	22.9* [6.9, 38.8]	0.003	11.3 [-5.1, 27.6]	0.247	11.6 [-4.5, 27.7]	0.212
Intermittent Pain (/100)	-19.6* [-34.8, -4.38]	0.009	-8.3 [-23.6, 7.0]	0.448	-11.3 [-26.6, 4.0]	0.448
Constant Pain (/100)	-16.0 [-39.0, 7.0]	0.240	-11.8 [-34.8, 11.2]	0.492	-4.2 [-27.2, 18.8]	0.955
Secondary Outcomes						
KOOS Function in ADL (/100)	17.9* [3.8, 32.0]	0.010	7.6 [-7.0, 22.2]	0.477	10.3 [-4.3, 24.8]	0.228
KOOS Function in SR (/100)	24.7 [-3.2, 52.5]	0.094	-6.2 [-34.1, 21.8]	0.925	30.8* [3.0, 58.7]	0.027
Six Minute Walk (m)	24.4 [-21.6, 70.4]	0.463	-0.52 [-45.7, 44.7]	1.000	24.9 [-21.0, 70.8]	0.444
40 Meter Walk (s)	-1.2 [-4.4, 2.0]	0.710	0.3 [-2.9, 3.4]	0.995	-1.5 [-4.7, 1.7]	0.573
30 Second Chair Stand (reps)	1.3 [-1.1, 3.7]	0.453	0.8 [1.6, 3.2]	0.776	0.5 [-1.9, 2.9]	0.937
Timed Up and Go (s)	-1.0 [-2.1, 0.1]	0.074	-0.4 [-1.6, -0.7]	0.756	-0.6 [-1.8, 0.6]	0.487
Stair Ascent (s)	-1.4 [-3.0, 0.3]	0.131	-0.4 [-2.1, 1.2]	0.891	-1.0 [-2.6, 0.7]	0.399
Tertiary Outcomes						
KOOS QoL (/100)	15.2 [-2.0, 32.3]	0.095	4.8 [-12.8, 21.6]	0.891	10.8 [-6.5, 28.1]	0.327
CESD (/60)	0.2 [-5.9, 6.4]	1.000	-1.6 [7.6, 4.4]	0.882	1.8 [-4.1, 7.7]	0.829
Knee extensor strength (Nm/kg)	0.1 [-0.1, 0.3]	0.250	0.0 [-0.1, 0.2]	0.910	0.1 [-0.1, 0.2]	0.603

Knee flexor strength (Nm/kg)	-0.3 [-0.1, 0.1]	0.791	-0.1* [-0.2, -0.1]	0.028	0.1 [-0.0, 0.2]	0.190

* YE = Yoga Exercise; TE = Traditional Exercise; NE = No Exercise; KOOS = Knee Osteoarthritis Outcome Score; ADL = activities of daily living; SR = sport and recreation; QoL = quality of life

Within-group comparisons

Within-group comparisons and mean differences for all outcomes are presented in Table 3. There were no significant differences at follow-up compared to baseline for any of the outcomes in the NE group. There was a 21.5 point improvement in YE group KOOS pain scores (follow-up minus baseline mean difference, 21.5; 95% CI, 15.1 to 27.9; $p<0.001$) and a non-significant 8.3 point improvement in the TE group (mean difference, 8.3; 95% CI, -32.1 to 6.9; $p=0.164$). For intermittent pain, the YE group reported a 23.7 point decrease (mean difference, -23.7; 95% CI, -16.5 to -30.9; $p<0.001$) and TE a 14.3 point reduction (mean difference, -14.3; 95% CI, -5.2 to -23.4; $p=0.006$). The YE group reported a 24.5 point reduction in constant pain (mean difference, -24.5; 95% CI, -9.0 to -40.0; $p=0.006$). Constant pain scores in the TE group decreased by 15.0 points (mean difference, -15.0; 95% CI, 0.50 to 29.5; $p=0.044$) but was not significant with the adjusted alpha value of 0.017.

The YE group reported a 17.9 point improvement in KOOS ADL scores (mean difference, 17.9; 95% CI, 8.7 to 27.2; $p=0.002$) and 21.3 point improvement KOOS SR (mean difference, 21.3; 95% CI, 9.7 to 32.9; $p=0.002$). The TE group reported a 17.9 point increase in KOOS ADL scores (mean difference, 8.7; 95% CI, 0.2 to 17.2; $p=0.047$) and 29.2 point improvement KOOS SR (mean difference, 29.2; 95% CI, 2.9 to 55.5;

$p=0.033$), however these differences were not significant with the adjusted alpha value. The YE group demonstrated improvements in the SMW, 30sCS, TUG, and SA tests ($p<0.017$). The TE group improved on the SMW, 40mW, 30sCS, and SA tests ($P<0.017$).

The YE reported a 23.7 point increase in KOOS QoL scores (mean difference, 23.7; 95% CI, 16.5 to 30.9; $p<0.001$); the only group to demonstrate a significant improvement in quality of life. There were no differences in CESD scores between baseline and follow-up ($p<0.017$). There were also no significant changes knee extensor or flexor muscle group strength ($p<0.017$)

Table 3. Within-group differences in outcome measures. Baseline and follow-up group means ± standard deviations are presented with mean differences (follow-up minus baseline) and 95% confidence intervals (CI). Significant differences compared using 2-tailed paired t-tests are denoted with an asterisk*. A Bonferroni corrected alpha value of 0.017 was used to adjust for multiple comparisons.

	Yoga exercise (n=10)			**Traditional exercise (n=10)**			**No exercise (n=10)**		
	Baseline	Follow-up	Mean difference [95% CI]	Baseline	Follow-up	Mean difference [95% CI]	Baseline	Follow-up	Mean difference [95% CI]
Primary Outcomes									
KOOS Pain (/100)	48.8±12.4	70.3±12.8	21.5* [15.1, 27.9]	57.3±14.3	65.6±13.7	8.3 [-4.1, 20.7]	52.0±17.9	49.9±24.7	- 2.1 [-12.6, 8.4]
Intermittent Pain (/100)	52.2±14.9	28.5±16.9	- 23.7* [-30.9, -16.5]	46.4±22.2	32.1±20.6	- 14.3* [-23.4, -5.2]	52.6±27.1	48.4±27.2	- 4.2 [-16.7, 8.3]
Constant Pain (/100)	36.5±27.7	12.0±14.9	- 24.5* [-40.0, -9.0]	40.5±21.1	25.5±23.5	- 15.0 [-29.5, -0.5]	40.0±34.3	29.5±28.7	- 10.5 [-34.1, 13.1]
Secondary Outcomes									
KOOS Function in ADL (/100)	56.2±16.7	74.1±15.1	17.9* [8.7, 27.2]	66.0±17.6	74.7.7±16.0	8.7 [0.2, 17.2]	56.3±15.2	56.3±23.1	0.0 [-8.6, 8.6]
KOOS Function in SR (/100)	33.0.7±17.0	54.3±20.2	21.3* [9.7, 32.9]	28.5±14.7	57.7±31.1	29.2 [2.9, 55.5]	31.3±24.8	28.6±27.8	-2.7 [-14.5, 9.1]
Six Minute Walk (m)	426.9±91.9	486.19±67.0	59.3* [22.5, 96.0]	456.0±61.6	510.0±77.0	54.0* [28.5, 79.5]	428.2±78.9	447.3±108.7	19.1 [-16.8, 54.9]
40 Meter Walk (s)	33.4±7.3	29.5±3.8	-3.9 [-7.4, -0.3]	30.8±3.5	27.9±3.7	-2.9* [-5.0, -0.8]	33.5±6.3	37.5±23.6	4.01 [-9.9, 17.9]
30 Second Chair Stand (reps)	9.4±2.7	12.8±2.5	3.4* [2.0, 4.8]	10.0±3.3	12.5±4.4	2.5* [0.9, 4.1]	9.6±2.0	11.4±2.2	1.8 [0.3, 3.3]

Timed Up and Go (s)	9.0±1.4	7.7±0.7	-1.3 [-2.3, -0.3]	7.9±0.9	7.6±1.2	-0.3 [-1.0, 0.4]	9.5±1.7	9.7±3.3	0.2 [-1.2, 1.6]
Stair Ascent (s)	7.1±2.1	5.4±1.2	-1.7* [-2.8, -0.7]	6.1±1.3	5.3±1.2	-0.7* [-1.3, -0.2]	7.2±2.9	9.0±8.3	1.9 [-2.8, 6.5]
Tertiary Outcomes									
KOOS QoL (/100)	33.8±16.5	47.7±17.0	13.9* [5.7, 22.1]	29.7±16.7	40.4±17.8	10.7 [-4.9, 26.3]	35.6±20.6	33.8±23.2	-1.8 [-9.8, 6.2]
CESD (/60)	7.6±5.1	6.6±5.6	1.0 [-4.6, 2.6]	11.3±6.9	10.3±8.2	1.0 [-3.5, 1.5]	13.2±9.8	9.6±5.7	-3.6 [-9.5, 2.3]
Knee extensor strength (Nm/kg)	0.9±0.3	1.0±0.3	0.1 [0.0, 0.2]	1.0±0.2	1.0±0.2	0.0 [-0.0, 0.1]	0.9±0.2	0.9±0.3	0.0 [-0.1, 0.1]
Knee flexor strength (Nm/kg)	0.4±0.1	0.4±0.1	0.0 [-0.1, 0.1]	0.4±0.1	0.5±0.1	0.1* [0.0, 0.2]	0.4±0.1	0.4±0.1	0.0 [-1.0, 0.1]

* KOOS = Knee Osteoarthritis Outcome Score; ADL = activities of daily living; SR = sport and recreation; QoL = quality of life; greater values on KOOS represent less troublesome scores (including Pain subscale)

Discussion

This was a direct comparison of a biomechanically-designed yoga program with the current gold standard of physical therapy, and a no-exercise attention equivalent control involving meditative relaxation in women with clinical knee OA. Relative to the NE control group, the YE group experienced greater improvements in pain and patient-reported physical function. Improvements in such outcomes were similar between the YE and TE groups. These findings are consistent with the study hypothesis. This yoga program appears to be an efficacious exercise option that is comparable, and in some aspects, potentially superior to traditional exercise for alleviating the physically debilitating symptoms of knee OA in women.

Strengths and limitations

An important feature of this study was the randomized control trial design including an experimental group, an active treatment comparison group, and an attention-equivalent control group. These findings are also subject to limitations. Firstly, based on a-priori power calculations the sample was statistically underpowered to detect all potential differences between and within groups. Post-hoc analyses (using SPSS v.23, IBM) of the ANCOVA models used to detect between group differences in patient-reported pain and physical function reveal observed power values of 0.81, 0.80, 0.32, 0.79, 0.72 for the outcomes: KOOS pain, intermittent pain (ICOAP), constant pain (ICOAP), and KOOS function in ADL, and SR, respectively. Secondly, this study involved women only thus limiting the generalizability. Third, the presence of medial knee OA was not confirmed via radiographs; however radiographic disease severity does not appear to influence the effectiveness of exercise (Kean, Birmingham, Garland, Bryant, & Giffin, 2010). The intent of exercise is to address symptoms and all participants met the American College of Rheumatology criteria for symptomatic knee OA (Altman et al., 1986).

Clinical relevance of findings

The results of this trial are presented relative to the minimal clinically important differences (MCID) and patient acceptable symptoms states (PASS) for clinical interpretation. The MCID represents the smallest increment of change that a patient would identify as important. The PASS values are those in which scores equal or above are deemed “unacceptable” to live with by individuals with OA. The MCID of KOOS scores is considered to be a change of 8 to 10 points (Roos & Lohmander, 2003). Specifically for the pain subscale of the KOOS, a change of 15 points is indicative of “moderate improvement” (Singh, Luo, Landon, & Suarez-Almazor, 2014). In this sample, clinically important improvements in KOOS pain scores of 21.5 and 8.3 were observed in the YE and TE groups respectively. A non-clinically relevant decrease of 2.1 was observed in the NE group. These findings are illustrated in Figure 2.

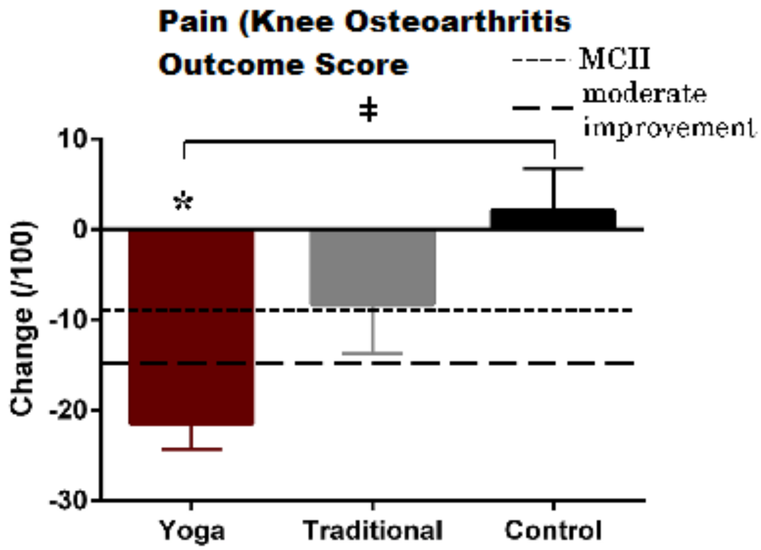

Figure 2: Mean ± standard error change (baseline minus follow-up values) in KOOS pain scores relative to the minimal clinically important improvement (MCII) and moderate improvement values. Significant between-group differences are denoted with ǂ and with-in group change with *.

Established MCID values for the ICOAP in persons with knee OA are 18.4 for the intermittent pain subscale, and 18.7 for the constant subscale. Values associated with moderate improvement are 24.3 and 29.6 for the intermittent and constant subscales respectively. A clinically relevant improvement of 23.7 in intermittent pain was reported by the YE group. The TE and NE mean improvements did meet or surpass the MCID. Similarly for constant pain, the YE group experienced a clinically notable improvement of 24.5 while TE and NE groups did not demonstrate clinically relevant changes.

The PASS values for the ICOAP according to an abstract that was published by the American College of Rheumatology Annual Scientific Meeting in 2012 are 40 for intermittent pain and 20 for constant pain (Anna Liu et al., 2012). These values are comparable to those published from a large prospective, multi-national study investigating several rheumatic conditions (Tubach et al., 2012). At baseline, all three groups reported intermittent and constant pain scores greater than PASS values; indicating unacceptable levels of pain. At follow-up, intermittent pain scores were less than the PASS value in the YE and TE groups. For constant pain, only the YE group attained a mean score less than the PASS value at follow-up. These findings are displayed in Figure 3.

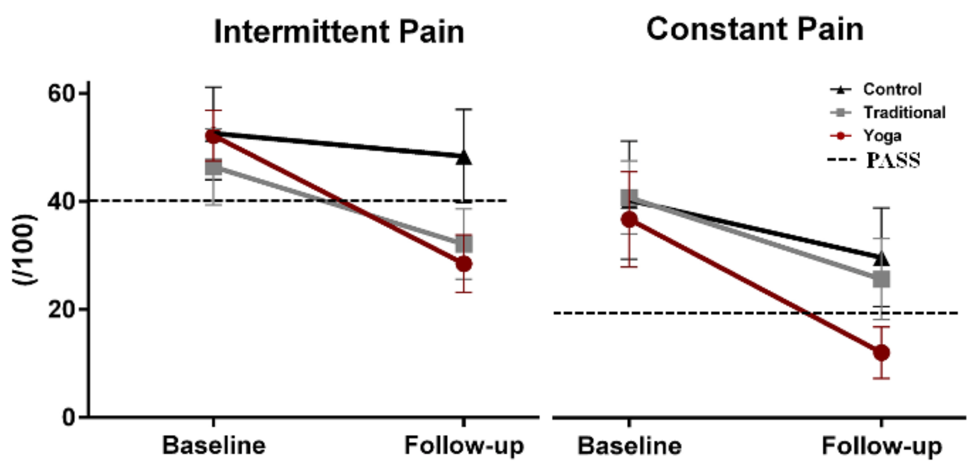

Figure 3: Baseline and follow-up values from the Measure of Intermittent and Constant Osteoarthritis Pain. Data are presented as group means ± standard error presented relative to the patient acceptable symptom state (PASS) values.

As previously mentioned, the MCID values for the KOOS are 8 to 10 (Roos & Lohmander, 2003). In this study, clinically relevant improvements of 17.9 and 8.7 in KOOS ADL scores were observed in the YE and TE groups, respectively. For KOSS SR scores, clinically important improvements of 21.3 and 29.2 were observed in the YE and TE groups, respectively. A non-clinically relevant decrease of 2.7 was observed in the NE group. These results are shown in Figure 4.

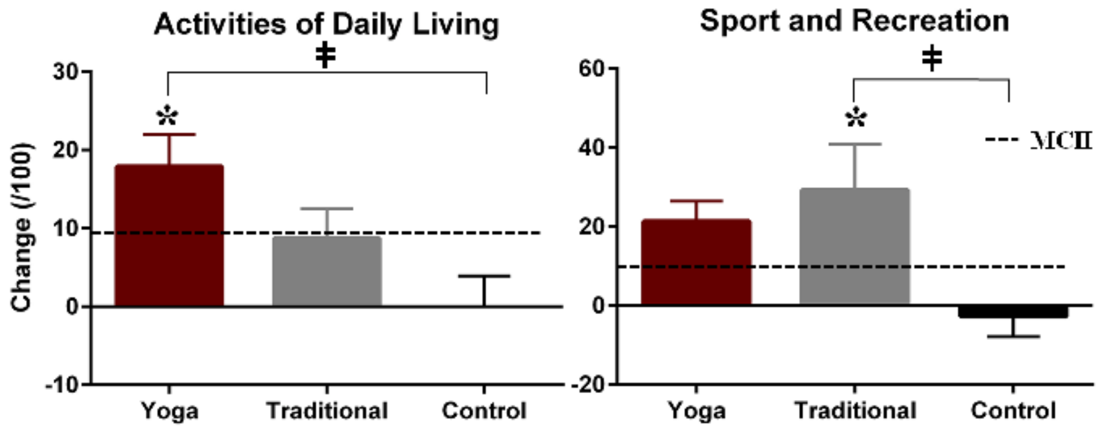

Figure 4: Patient reported physical function measured using the Knee Osteoarthritis Outcome Score. Data are presented as mean ± standard error change (follow-up minus baseline values) in scores relative to the minimal clinically important improvement (MCII) values. Significant between-group differences are denoted with ǂ and with-in group change with *.

Regarding the mobility performance measures, there are no established MCID values for exercise interventions in OA of the knee. In OA of the hip, 2 to 3 additional repetitions in the 30sCS test and a decrease of 0.8 to 1.4 seconds in the TUG test have been considered clinically important (Dobson et al., 2012). In the current study at follow-up relative to baseline, the YE and TE groups performed an additional 3.4 and 2.5 repetitions in the 30sCS test, respectively; and decreased TUG times by 1.4 and 0.3 seconds, respectively.

Conceptually, the MCID represents improvement associated with "feeling better;" whereas the PASS is designed to reflect partial symptomatic remission, relating to "feeling good" (Tubach et al., 2005). From a clinical standpoint, the YE group appeared to achieve more meaningful improvements in pain and physical function compared to the TE and NE groups.

Congruence with previous studies

The effectiveness of land-based exercise for improving pain, physical function, and quality of life is well-established. A large-scale review of randomized and controlled exercise intervention trials for knee OA concluded the absolute (follow-up minus baseline values divided by 100) and relative (follow-up minus baseline divided by baseline values) improvements, expressed as percentages, that can be anticipated in such domains from exercise (Fransen et al., 2015). The authors examined 44 studies yielding high quality evidence (future studies are unlikely to change confidence of the estimate or the effect) that land-based exercise yields a 12% (95% CI: 10-15) absolute and 27% (95% CI: 21-32) relative improvement in pain for individuals with knee OA. This meta-analysis also included 44 studies providing moderate quality evidence (future work will likely increase confidence of estimate and may change effect) suggesting a 10% (95% CI: 8-13) absolute and 26% (95% CI: 20-32) relative improvement in physical function for those who engage in an exercise intervention. Lastly, there was high quality evidence that a 4% (95% CI: 2-5) absolute and 9% (95% CI: 5-13) relative improvement could be expected in quality of life following an exercise program.

In the current study, for pain according to the ICOAP total score (a measure of pain independent of physical function), a 24% absolute and 53% relative improvement was observed in the YE group. There was a 15% absolute and 34% relative improvement in the TE group; and a 4% absolute and 8% relative improvement in the NE group. For physical function according to the KOOS ADL subscale, there was an 18% absolute and 32% relative improvement in the YE group; a 9% absolute and 13% relative improvement in TE; and a 0% change in the NE group. The KOOS SR data did not appear normally distributed upon visual inspection despite passing the Shapiro-Wilk normality test; this issue is likely a reflection of the small sample. The KOOS ADL subscale and mobility performance measures provide corroborating evidence of improved physical functioning as a result of exercise. For quality of life assessed using the KOOS subscale, a 14% absolute and 41% relative improvement was observed in the YE group; a 10.7% absolute and 36% relative improvement in the TE group; and 2% absolute and 1% relative improvement in the NE group. The TE intervention was designed to reflect the current exercise prescription for knee OA, which was very similar to the majority of the studies reviewed in the meta-analysis (Fransen et al., 2015). As would be expected, the magnitude of change in pain, function, and quality of life in the TE group was similar to those values presented in the review, in some cases slightly larger. The magnitude of change observed in the YE group was substantially larger.

Our initial investigation of the YE intervention in the previously mentioned study (Brenneman et al., 2015) yielded similar results. Both studies demonstrated improvements in pain, patient-reported physical function, mobility performance, and quality of life; the magnitude of change in the current study was slightly larger across outcomes. Given this discrepancy in effect sizes, it is possible that the magnitude of change in the current study is an overestimation due to the small sample (Thorlund et al., 2011). Nonetheless, these findings are consistent with our previous work and other studies investigating yoga for OA (Brenneman et al., 2015; Haaz & Bartlett, 2011; Sharma, 2014).

Despite the significant difference in knee flexor muscle group strength between the TE and YE group, there were no significant within-group improvements in knee extensor or flexor muscle strength relative to body mass in any of the groups. This result is not consistent with previous work. With respect to the YE intervention, our initial proof-of-principle study demonstrated significant strength improvements in both muscle groups (Brenneman et al., 2015). Though these increases were statistically significant, the clinical relevance of such improvements are debatable (K. L. Bennell, Wrigley, Hunt, Lim, & Hinman, 2013; Kean et al., 2010). Besides the current and our previous study, strength as an outcome has not been extensively explored in yoga for arthritis. There is ample evidence that strength increases are achievable in knee OA (Zacharias, Green, Semciw, Kingsley, & Pizzari, 2014); thus it was surprising there were no significant improvements in the TE group. Lower extremity muscle strength, especially that of the knee extensor muscle group, is an important topic in knee OA rehabilitation (K. L. Bennell et al., 2013) and is of great interest to researchers. It is not however what individuals living with knee OA find most troubling; the pain and disability associated with the disease is of greater concern (Maly & Krupa, 2007; Rosemann et al., 2006). These data provide evidence that increases in muscle strength are not necessary to elicit improvements in symptoms of knee OA.

In the current study, none of the groups demonstrated significant improvements in depressive symptoms. Depression is a common co-morbidity associated with knee OA (Badley & Glazier, 2004; Ferreira et al., 2015). Exercise is an effective treatment for depression (Cooney et al., 2013); however in a meta-analysis of exercise for depressive symptoms in rheumatic conditions, zero trials investigating the effects of exercise for depression in OA met the inclusion criteria (Kelley & Kelley, 2014). It should be noted that neither of group means at baseline satisfied the criteria for clinical depression (Radloff, 1977). Thus, depression was not overtly prevalent in the study sample, which may explain the lack of improvement in depressive symptoms as a response to exercise.

Contribution to the literature

In the aforementioned large-scale systematic review and meta-analysis of exercise for knee OA by Fransen and colleagues in 2015, high quality evidence was presented supporting the effectiveness of exercise in addressing the major symptoms of knee OA. In this study, "high quality evidence" was defined as that in which further research is very unlikely to influence the magnitude, direction, or confidence of the effect (Fransen et al., 2015). Large scale reviews like this are very effective for synthesizing enormous amounts of data to provide succinct conclusions. However, in this process the effects of important attributes pertaining to individual studies can be washed out or missed entirely. Considering the breadth of research on exercise in knee OA, perhaps it is possible that the overall effect size of this treatment option is minimally or not at all indicative of potentially enhanced effects found in one or few studies with unique methodological features (e.g. a novel exercise types or approaches). Data from the current study beg the question of whether it is possible to augment the effectiveness of exercise by addressing the mechanical joint loading aspect of such exercise.

The current trial and the previous proof-of-principle study (Brenneman et al., 2015) are the first exercise interventions designed and tested specifically to minimize potentially harmful biomechanical loads incurred by the OA affected knee joint. Previous exercise prescriptions have not been based upon measures of mechanical loading known to influence knee OA progression. We now have concrete evidence that, in those with established OA of the knee, exposure to large KAMs is linked with increased degradation of joint tissues (K. L. Bennell et al., 2011; Chang et al., 2015; Chehab et al., 2014; Miyazaki et al., 2002). This is a concern because exercise is effective in ameliorating symptoms with regular, chronic engagement, not on an acute basis. To ensure individuals with knee OA are not compromising their joint health every time they exercise, the mechanical loading aspect of such physical activity cannot be disregarded. Though small, this is the first RCT to conduct a head-to-head comparison of traditional exercise to a program designed to minimize KAM exposure.

Conclusion

This biomechanically-based yoga intervention appears to be well tolerated and shows promise as an efficacious approach to alleviate the major burdening symptoms of the disease in women with clinical knee OA. At this point, yoga does not appear to be inferior to traditional exercise for improving pain, physical function, and quality of life; and there is reason to believe it may be superior in some aspects. Future trials of yoga for knee OA with larger samples are warranted to establish effectiveness; as well as possibly investigate superiority and less harm relative to traditional modes of exercise.

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CHAPTER 3: Elaborated discussion

This thesis features a randomized controlled trial that compares, head-to-head, the efficacy of a biomechanically-defined yoga program versus traditional exercise and no exercise in women with clinical knee OA. The findings contribute a novel approach to refining exercise treatment of this chronic and debilitating disease.

Comparison of the exercise interventions

To improve pain and physical function in knee OA, the authors of a review and meta-analysis on exercise type and dose in knee OA concluded optimal exercise programs should target aerobic fitness, quadriceps strength, or lower extremity function in a supervised exercise format carried out at least three times per week (Juhl et al., 2014). Factors that do not appear to influence the effectiveness of an exercise intervention include intensity of the exercise, the duration of individual sessions, radiographic disease severity, and baseline pain (Juhl et al., 2014).

Not all exercise is equal, especially for individuals with compromised joints as a result of OA. It is important to pay careful attention to exercise dose and to distinguish various forms of exercise. Exercise dose can be defined as a function of frequency (sessions per week), duration (time commitment per session), and intensity (which can be defined in multiple ways) (K. Bennell et al., 2011). We standardized frequency and duration between study arms; however standardizing intensity was considerably more challenging. Intensity can be defined by a proportion of one-repetition maximum or percent of maximal voluntary muscle activation (American Geriatrics Society Panel on

Exercise and Osteoarthritis, 2001). Comparing YE and TE in these terms of intensity is difficult. Defining a one-repetition maximum in yoga is a challenge given the resistance of the exercises cannot easily be adjusted in small increments like traditional resistance exercise. Also, given the isometric nature (actively engaged muscles that do not change in length with relatively static corresponding joint angles) of the physical postures in yoga, there little emphasis on "repetitions" and thus intensity cannot easily be defined by percentages of one-repetition maximum. Regardless, intensity defined by percent of one repetition maximum does not appear to influence the effectiveness of exercise as a means of improving symptoms in knee OA (Juhl et al., 2014; Regnaux et al., 2015). One potential solution is utilizing electromyography to define intensity. Electromyography can be used to measure muscle activation; but still a direct comparison of the two programs is complicated because of the isometric nature of yoga and the concentric/eccentric muscle actions of resistance exercise. Electromyography is most accurate when assessing isometric muscle actions, lending itself nicely to the study of static yoga postures but to a lesser extent in the dynamic movements of resistance exercise. It should be noted however that the YE intervention in the current study employed a variety of postures that achieve quadriceps muscle activation levels comparable to those recommended for traditional isometric resistance exercise in knee OA (American Geriatrics Society Panel on Exercise and Osteoarthritis, 2001; K. L. Bennell et al., 2013; Longpré et al., 2015). In this study protocol, exercise intensity was defined as rating of perceived exertion to allow for direct comparison and consistency between the two interventions. In accordance with this definition, the YE and TE programs were similar; participants were asked to exercise at an intensity that yielded a rating of perceived exertion of approximately seven on a visual analog scale ranging from zero to ten (Borg, 1982). Exercise frequency, duration, and intensity were equivalent between YE and TE; thus overall exercise dose was consistent. The nature of these exercises (i.e. type of form) however were not the same.

From a mechanical standpoint, traditional resistance exercise involves brief, intense, and repetitive muscular contractions that are often performed using exercise machines to move mass against the force of gravity from pulley-assisted weight stacks or weighted plates mounted on mechanical levers (Vincent & Vincent, 2012). Alternatively, in yoga the physical postures are largely static, emphasizing postural control and slow movement in and out of the poses; and the mechanical loads resisted by the engaged musculature are derived from the force of gravity acting on body mass as opposed to objects outside of the body. Weight bearing (sometimes referred to as closed kinetic chain) yoga poses, in comparison to resistance exercise machines (that are often performed in sitting or supported open kinetic chain positions), may resemble the postures and movements associated with those used to ambulate and perform activities in daily life more closely. In the current study, there were four participants that verbally reported an aggravation of knee pain that they attributed to the knee extension exercise in the TE intervention. Their programs were then modified such that the knee extension exercise was removed and substituted with additional work volume on the other quadriceps dominant exercise (leg press machine which involves concentric and eccentric action of the knee and hip extensor muscle groups). Following this modification, all four participants articulated an improvement in pain with the replacement of open kinetic chain knee extension with a closed kinetic chain knee extensor muscle group dominant exercise. There were no reported cases of aggravated symptoms in YE group. In the YE intervention, all of the exercises were scaled to the individual and there was no use of unfamiliar apparatuses as a means of providing mechanical resistance. The quadriceps-dominant exercises in the YE program were squat and lunge based postures that, out of all exercises in the TE regimen, were most similar to the leg press machine given the closed kinetic chain, weight bearing nature. I hypothesize that because resistance exercises on machines do not reflect the typical, regular demands on the knee, and because of the inability to appropriately fit some participants to universal exercise machines, some participants in TE reported an aggravation of symptoms. Yoga may offer a "gentler" form of exercise that could serve as an alternative or adjunct modality to traditional resistance exercise. This may be intriguing for individuals with knee OA who are possibly intimidated by resistance exercise, or simply not interested.

Traditional resistance exercise effectively reduces pain and disability associated with knee OA (Fransen et al., 2015). Although the underlying causes are not well understood, potential mechanisms include restoration in muscle function, through increased strength and voluntary activation which can affect joint mechanics; as well as improved self-efficacy which may in turn alleviate fear of movement and symptoms of anxiety and depression (Vincent & Vincent, 2012). In theory, these same principles apply in hatha-based yoga. Distinct from traditional resistance exercise however, it is possible yoga may offer additional benefits through the integration of biomechanically-sound physical posture (Longpré et al., 2015), breathing techniques to elicit relaxation (Jerath, Edry, Barnes, & Jerath, 2006; Telles, Singh, & Balkrishna, 2014), and somatic awareness through mindfulness-based meditation (Tang, Hölzel, & Posner, 2015). These three processes, commonly practiced in isolation, are used coincidently in yoga to harness the therapeutic potential of mind-body integration that take form through a variety of hypothesized neurobiological and psychosocial mechanisms (Esch & Stefano, 2010; Riley & Park, 2015). It should also be noted that the YE (and the NE) intervention was instructor led (by teachers of the same sex) in a group-based format; whereas the TE intervention was not instructor led in the same fashion but rather supervised by multiple staff (of both sexes) as participants individually rotated exercise machines/stations.

Traditional resistance exercise and yoga are very different practices; it is reasonable to assume the effects of these differing stimuli may also vary across outcome domains. This study focused on the major clinical detriments of OA but did not investigate outcomes such as body composition, systemic inflammation, hormone status and other variables that can be altered by resistance exercise. These data do not point to yoga as a direct substitute for resistance training but rather an alternative mode of exercise for individuals with knee OA in search of a more holistic approach to address the physical and psychological symptoms of the disease.

The no-exercise control group

The NE group was used as an attention-control in the current study; this intervention however was not benign, and was different from traditional controls (e.g. waitlist). There is ample data supporting the effectiveness of physical therapy from comparisons of exercise to waitlist control in knee OA (Fransen et al., 2015). Waitlist control groups can be considered unethical, because waiting for treatment of a chronic pain condition often leads to a worsening condition (Kinser & Robins, 2013; Lynch et al., 2008). The control group in the current study was designed to be active and provide similar non-physically active exercises to the YE intervention.

The NE intervention involved guided practice of mindfulness-based meditation techniques. This practice includes development of somatic awareness using physical sensations in the body as focal points for attention. Specific exercises included breath and body-scan meditations (John Kabat-Zinn, 1990). Though the core concepts and practices of mindfulness based intervention are heavily rooted in Buddhist traditions dating back 2500 years; modern practice techniques have been adapted for use in Western medicine in the last 25 years (John Kabat-Zinn, 1990). The rationale guiding mindfulness based intervention for pain is the uncoupling of the somatosensory component of pain from the cognitive and emotional components thereby reducing the inflicted suffering (J. Kabat-Zinn, 1982). The fundamental principle is that the presence of pain is not the problem, but rather it is the cognitive and emotional interpretation of which and subsequent aversion to nociception that gives rise to suffering. The essence of this concept is elegantly described by the Buddhist proverb "pain is inevitable, suffering is optional." The overarching aim of mindfulness practice is the development of deliberate, non-judgmental contact with events of subjective experience in the present moment. In contrast to some conventional medical interventions for pain where the explicit goal is to control or reduce intensity; mindfulness offers an alternative strategy where the non-evaluative awareness of such phenomenon without the necessity to immediately change it can be therapeutic in and of itself (Reiner, Tibi, & Lipsitz, 2013). Given this framework, mindfulness practice can increase perceived well-being and decrease the psychological distress associated with pain (Nyklícek & Kuijpers, 2008).

In addition to alleviating psychological distress despite the presence of pain, mindfulness based intervention also appears to be capable of reducing the actual intensity of the pain itself (Reiner et al., 2013). It was surprising the NE group did not report significant improvements in pain. One potential explanation for this is the apparent dose-response relationship between mindfulness practice and subsequent decreases in pain and improvements in perceived well-being (Rosenzweig et al., 2010). These clinical improvements appear to be mediated by the development mindfulness itself, or specific self-reported mindful attributes (Carmody & Baer, 2008; Rosenzweig et al., 2010). In the original eight or twelve week mindfulness based stress reduction program developed by Jon Kabat-Zinn and colleagues from the University of Massachusetts Medical School, there is about three hours per week of didactic instruction that is delivered in a logical progression throughout the course. Participants are also required to practice individually for approximately one hour per day. The NE intervention in the current study consisted of three, one hour practical sessions per week with no theoretical content. Participants were also not required to engage in home-based practice. It would appear as though this "dose" of mindfulness training and mode of delivery is not sufficient to yield improvements in pain status.

Intervention adherence

Like any medical treatment, intervention adherence is paramount to effectiveness; physical therapy is no exception. Exercise appears to be most effective for treating knee OA when performed at least three times per week (Juhl et al., 2014) and better adherence is generally associated with more favorable outcomes (K. Bennell et al., 2011). In the current study, participants were asked to attend the interventions three times weekly. The mean ± standard deviation attendance rates were 3.0±0.75 sessions per week for YE, 2.7±0.52 for TE, and 2.7±0.62 for NE. Though statistically non-significant in this sample ($p>0.05$), the YE group attended an additional 0.3 sessions per week compared to the TE and YE groups. However, larger sample would be required to determine true differences in adherence. Nonetheless, this trend is consistent with a review that covered yoga for arthritis studies between the years 1980 to 2010; the authors concluded attrition in yoga interventions was comparable or better than that of traditional exercise (Haaz & Bartlett, 2011). Long-term adherence to traditional forms of exercise in knee OA is also a substantial concern. It is clear that physical therapy-mediated improvements in symptoms decline and eventually disappear upon discontinuation from exercise (van Baar et al., 2001). Therefore, it is imperative that individuals with knee OA find a mode of exercise that they are not only capable of performing acutely, but also one that they can maintain regular engagement in over time.

Future directions

This study provides evidence that yoga may be viable alternative mode of exercise for addressing the major clinical burdens of knee OA. Future studies of similar design with larger samples are warranted to validate the efficacy of yoga as a conservative treatment for clinical knee OA. Based on these data, yoga does not appear to be inferior to traditional exercise. In theory, this biomechanically suitable yoga program may be less traumatic to compromised knee joints compared to traditional aerobic and resistance exercise due to the minimized KAM (K. L. Bennell et al., 2011; Chang et al., 2015; Chehab, Favre, Erhart-Hledik, & Andriacchi, 2014; Longpré et al., 2015; Miyazaki et al., 2002). Future researchers may consider investigating the superiority of yoga for addressing the major symptoms of knee OA compared to traditional physical therapy. Future studies could feature longer interventions, multiple post-intervention follow-up points, and include imaging techniques (e.g. magnetic resonance) to study the in-vivo response of tissues relevant to disease progression (e.g. articular cartilage and skeletal muscle).

Closing remarks

Ultimately, exercise is of great use in knee OA for alleviating debilitating symptoms, improving overall well-being, and preserving independence. This study identifies yoga, as an exercise intervention, may be effective in the treatment of knee OA. Offering patients a variety of exercise options may increase the number of individuals who actually engage in regular exercise and capitalize on the numerous benefits. Individuals with knee

OA are encouraged to engage in a form of exercise that they personally enjoy and tolerate well; and most importantly, one that enables them to live a meaningful and fulfilling life.

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APPENDIX A: Yoga Exercise Program

Warm-up

The warm-up includes large body movements against the resistance of gravity only. Postural cues are emphasized.

Strengthening Series

When performed properly, each of the exercises produces a small knee adduction moment, suggesting each yields a minimal load on the medial knee. Below are descriptions of the required exercises and suggestions for modification and progression. Progression is an important component of the program. The specific modifications and progressions will be prescribed by the physiotherapist, with knowledge of each participant's biomechanical assessment of the exercises. The exercise instructor will be consulted regarding the modifications to ensure the participants are cued to their modification. The physiotherapist will attend the classes to support modifications. A general rule will be to encourage progression every 2-3 weeks.

Participants will be encouraged to work at a rating of perceived exertion between 5 and 7 and a pain rating at 5 or below.

The following outlines the core strengthening exercises to be included in every class.

Exercise	Modification	Progression	Duration, Repetition
1. Squat  Level 4	*Minor*: Change exercise to wall squats (removes balance challenge).	*Level 1*: Hands on hips, bend knees to 30°.	Hold 5 s. Repeat 2 times.
		Level 2: Hands on hips, bend knees to 60°.	Hold 10 s. Repeat 2 times.
	Major: Provide a chair and request participant to hover above the chair.	*Level 3*: Shoulders flexed to 90° with elbows straight, bend knees to 60°.	Hold 10 s. Repeat 5 times.
		Level 4: Shoulders flexed to 180° (or as close as possible), bend knees to 80°. Look to the ceiling for an added balance challenge.	Hold 10 s. Repeat 5 times.

1. Squat – Wide-Legged

Level 3

Minor: Reduce the width of stance. Change to wall squats.	*Level 1*: Hands on hips, bend knees to 30°.	Hold 5 s. Repeat 2 times.
	Level 2: Hands on hips, bend knees to 60°.	Hold 10 s. Repeat 2 times.
Major: Provide a chair and request participant to hover above the chair.	*Level 3*: Shoulders abducted to 90° with elbows at 90°, bend knees to 60°.	Hold 10 s. Repeat 5 times.
	Level 4: Shoulders flexed to 180° (or as close as possible), bend knees to 80°. Look to the ceiling for an added balance challenge.	Hold 10 s. Repeat 5 times.

2. Supported Lunge

Minor: Provide a pillow beneath the trail leg (hip in extension). Reduce hip range of motion for the lead and trail legs.	*Level 1*: Hands on hips, the hip of the trail leg is in neutral position (no flexion, no extension).	Hold 5 s. Repeat 2 times.
	Level 2: Hands on hips, the hip of the trail leg is in extension.	Hold 10 s. Repeat 2 times.
Major: Kneeling position.	*Level 3*: Shoulders flexed to 90° with elbows straight, the hip of the trail leg is in extension.	Hold 10 s. Repeat 3 times.

1. Lunge – Lateral Trunk

Level 2

Minor: Provide support with a chair or block.	*Level 1*: Place elbow on the knee of the lead leg. Place the other hand on the hip.	Hold 5 s. Repeat 2 times.
Major: Sitting on a chair, work towards the upper body position	*Level 2*: Place elbow on the knee of the lead leg. Stretch the other shoulder such that it is flexed to 180° (or as close as possible).	Hold 10 s. Repeat 2 times.
	Level 3: Place hand beside the foot instep of the lead leg. Stretch the other shoulder such that it is flexed to 180° (or as close as possible).	Hold 10 s. Repeat 3 times.
	Level 4: Place hand beside the lateral side of foot, of the lead leg. Stretch the other shoulder such that it is flexed to 180° (or as close as possible).	Hold 10 s. Repeat 3 times.

2. Lunge – Upright Trunk 1

Level 4

Minor: Reduce length of stride.	*Level 1*: Hands on hips.	Hold 5 s. Repeat 2 times.
Major: Supported lunge.	*Level 2*: Shoulders flexed to 90° with elbows straight.	Hold 10 s. Repeat 2 times.
	Level 3: Shoulders flexed to 180° (or as close as possible.)	Hold 10 s. Repeat 3 times.
	Level 4: Shoulders flexed to 180° (or as close as possible.) Look to the ceiling for an added balance challenge.	Hold 10 s. Repeat 3 times.

1. Lunge – Upright Trunk 2  Level 2-4	*Minor*: Reduce length of stride. *Major*: Supported lunge.	*Level 1*: Hands on hips. *Levels 2-4*: Arms abducted to 90° with elbows straight.	Hold 5 s. Repeat 2 times. Hold 10 s. Repeat 2-3 times.
2. Bridge  Level 2-4	*Minor*: Reduce height of bridge. *Major*: Place a support (e.g., 4 inch foam block) under the sacrum for a passive stretch).	*Level 1*: Arms by side. *Levels 2-4*: Clasp hands together. Increase height of bridge as appropriate.	Hold 5 s. Repeat 2 times. Hold 10 s. Repeat 5 times.

Cool-Down

Sitting or lying position for stretches of major muscle groups of the lower extremity:

- Trunk flexors, extensors and rotators,
- Hip flexors, extensors, adductors,
- Knee flexors and extensors, and
- Ankle plantarflexors.

Each class focuses on stretching the knee flexors and extensors.

APPENDIX B: Traditional Exercise Intervention

General Overview

This exercise program is targeted toward clinical management of symptoms for knee osteoarthritis. The compulsory components of the program involve cardiovascular endurance, lower-limb strengthening, and balance training. Included also are target sets and repetitions. Following the progressions properly are an important element of the program. As a general guide, participants should look to progress exercises after 3-4 weeks as long as form and pain level are appropriate. Additionally, on a scale of 0 (no pain) to 10 (worst pain imaginable) pain in the knee joint should never exceed a 2. If an exercise is aggravating pain, or if a participant is unsure of how to perform an exercise properly, please see a Kinesiologist on staff at the PACE or a researcher from the study for exercise modifications.

The first section of this program introduces the equipment used in the program (HUR resistance equipment) and how to set up the equipment for use. Next, the exercises are introduced with targeted repetitions (number of times the exercise is completed) and sets (number of times you repeat that exercise for the given amount of repetitions).

In this program, walking intensity will be based on a percentage of age-predicted maximum heart rate. Please do these calculations before starting the program. Please seek assistance if needed.

Age-predicted HRMax: 220 - ________ = ________ beats/minute

(Your age)

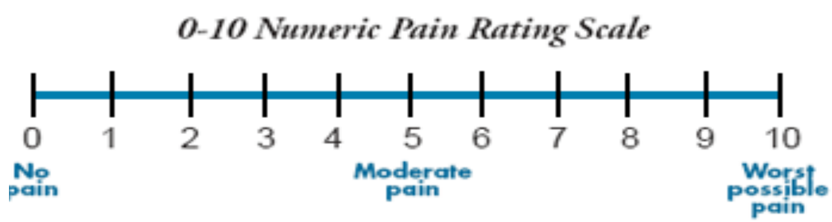
50-60% HRMax = _______ - ________ beats/minute

60-70% HRMax = _______ - ________ beats/minutes

rating	description
0	NOTHING AT ALL
0.5	VERY, VERY LIGHT
1	VERY LIGHT
2	FAIRLY LIGHT
3	MODERATE
4	SOMEWHAT HARD
5	HARD
6	
7	VERY HARD
8	
9	
10	VERY VERY HARD (MAXIMAL)

We will ask that all exercise be monitored personally using the Borg Exertion Scale (left). Exercise should reach up to a 5 on the scale ('Hard'). If the exercise above this, reduce the resistance. If the exercise is below this, then the resistance can be increased.

We will also ask that all pain during the exercise session be monitored using the 0-10 Numeric Pain Rating Scale (bottom). Pain in the knee should NOT exceed an increase in pain more than 2 points. For example, if knee pain is rated 3 to start the exercise session, it should not exceed a 5 at the end. If the exercises are causing pain, please see a research staff member for exercise modification.



Introduction to Equipment

On the first day in the gym, each participant will be provided a folder containing this booklet and a chip card. The chip card is to be used with the resistance equipment to record resistance and repetitions of an exercise.

The pieces of equipment to be used in the current program are a **walking treadmill, a leg press machine, and a leg curl/extension machine**. A total of 6 **treadmills** are available for use for the walking portion of the program. In addition, a small track outlined with coloured lines on the gym floor surround the perimeter of the gym and can be used for the walking portion. With warmer weather on the way, walking outside for the walking portion is also encouraged!

There are 3 **leg press machines** available for use: 1 red machine (machine #8) with a single platform for the feet, and 2 grey machines (machine #1 and #18) with platforms for each foot. Each leg press machine is equipped with a small monitor (Figure 1). To set up the machine, simply touch the monitor to come to the start screen. Before starting, make sure to reset the monitor (circled in purple on Figure 1) so that Load (kg) and Reps are set to 0. The yellow circle on the top of Figure 1 is where the chip card will be inserted into the monitor. To increase the resistance (make it feel heavier) on the machine, use the button circled in green on Figure 1. Similarly, to decrease the resistance (make it feel lighter), use the button circled in red on Figure 1. As repetitions of an exercise are performed, the counter in the Reps box will increase. The chip will record the numbers in the Load (kg) and Reps boxes upon completion of the exercise.

Figure 1. Monitor for the leg press machine. Machine numbers 1, 8, and 18 will have this screen.

There are 3 **leg curl/extension machines** (machine #4, #14, and #15). Each machine is built to complete both exercises, with a 'switch' button that toggles between the 2 exercise types (circled in blue on Figure 2A and 2B). Similar to the monitor for the leg press machine, the monitor for the **leg curl/extension machine** has a spot to insert the chipcard (**yellow** circle), a button to clear previous results (purple circle), a button to increase the resistance of the machine (green circle), and a button to decrease the resistance (red circle). Figure 2C shows the screen displayed when the 'switch' button is pressed (blue circle). Before switching the exercise, make sure to get off of the equipment for safety reasons. Once the screen has switched to the opposite exercise, exercise may commence. Figure 3 (next page) shows the three pieces of resistance machines used in this program.

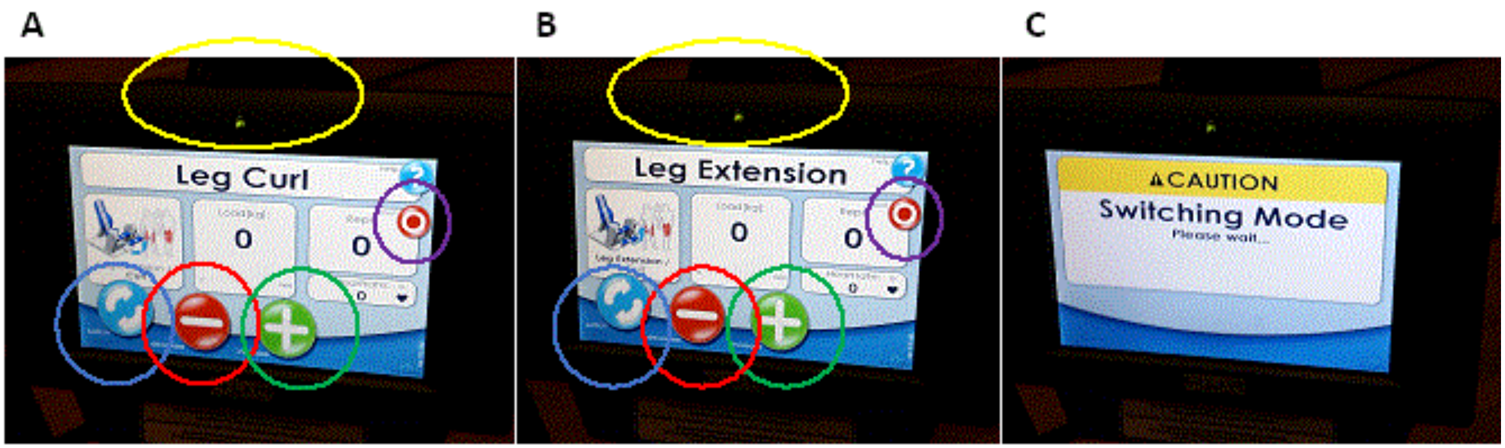


Figure 2. A) Monitor for the leg curl exercise; B) monitor for the leg extension exercise; and C) monitor shown when the machine is 'switching between the 2 exercise modes.

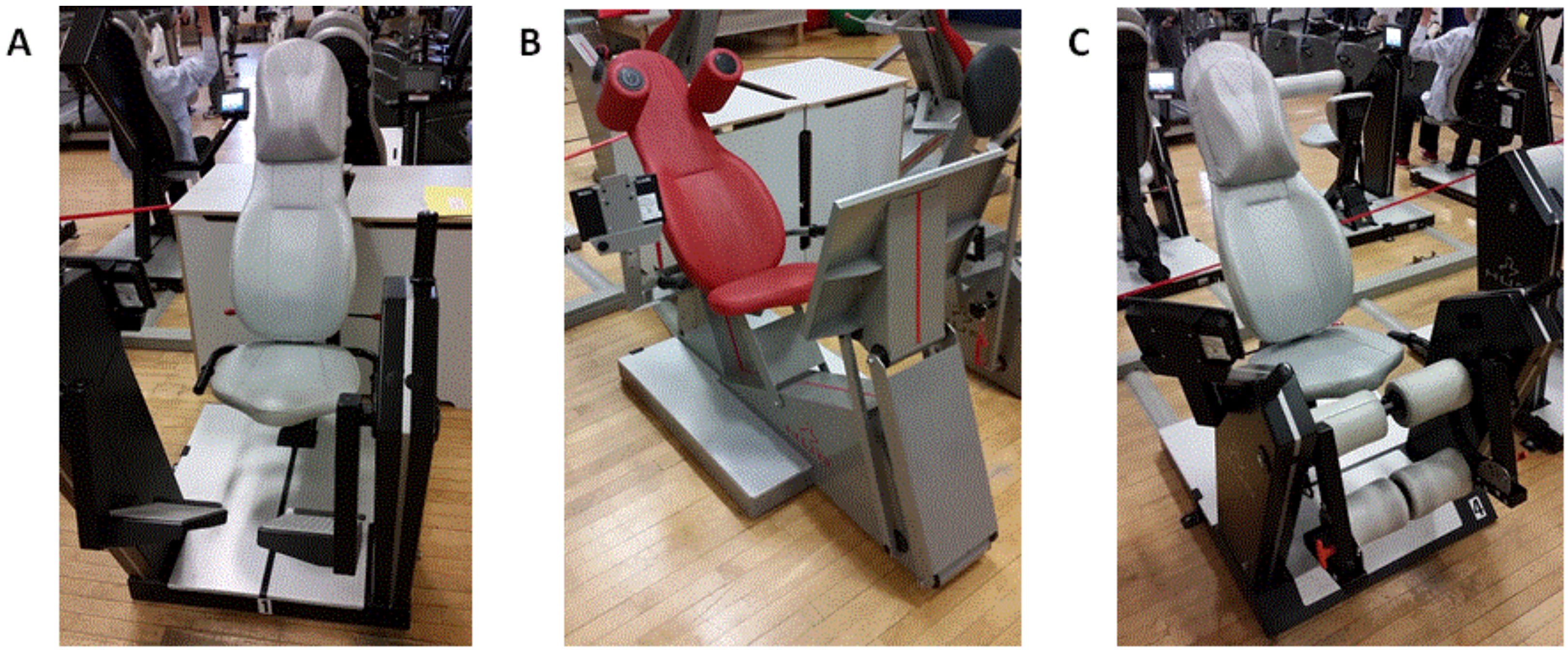
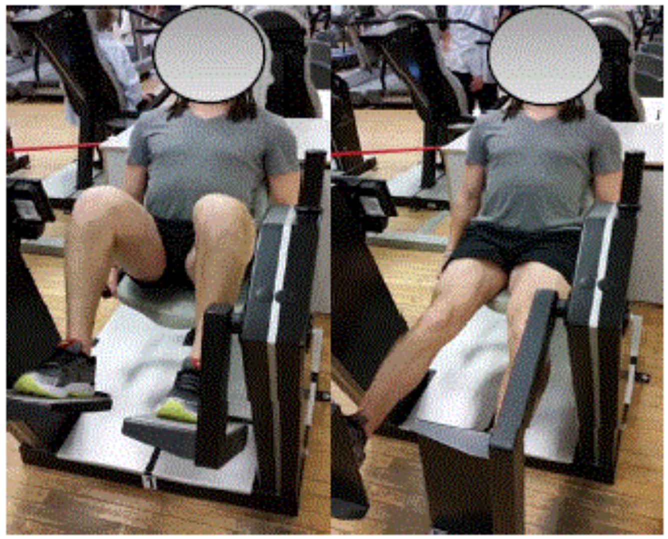


Figure 3. A) The leg press machine with a platform for each foot. This is the preferred machine for the leg press exercise. The two leg press machines are #1 and #18. B) The leg press machine with a platform for both feet. This is the preferred machine for the calf exercise. This is machine #8. C) The leg curl/extension machine. The monitor for this machine will switch between the two exercise modes. The leg curl/extension machines are #4, #14, and #15.

Exercises

Demonstration		Repetitions
Exercise 1. Walking		
Walk on a treadmill, on the track around the perimeter of the gym, or outside if weather permits.		Treadmill should be set to 0 degrees of inclination (flat). **5 minutes** at a comfortable pace. Aim for levels around 50-60% of your heart rate maximum (HRMax). Take 60 seconds to rest if required. **10 minutes** at a moderate- to- vigourous pace. The heart rate should be elevated and you should be experience increased breathing rate. Aim to work at approximately 60-70% of your HRMax. **NOTE: This should NOT be a jog or run.**

	Demonstration	Repetitions
Exercise 2. Leg Press		
Place feet on the feet platform with the knees and his flexed as shown on the left of the demonstration figure. Push the feet platform away by extending at the knees and hips. Slowly return back to the starting position and repeat.		Weeks 1-4: Complete **2 sets of 12-15 repetitions** of this exercise. Resistance should be increased when 15 repetitions can be completed with ease. Weeks 5-8: Complete **3 sets of 12-15 repetitions** of this exercise. Resistance should be increased when 15 repetitions can be completed with ease. Weeks 9-12: Complete **4 sets of 12-15 repetitions** of this exercise. Resistance should be increased when 15 repetitions can be completed with ease.

	Demonstration	Repetitions
Exercise 3. Leg Curl		
*First make sure the monitor is set to the **Leg Curl** exercise.* Sit in the chair and strap the lower thigh to the chair with the clips and straps provided. Start with the legs straight and the foot pad just above the ankles. Contract the back thigh muscles (hamstrings) and flex the knees to bring the foot pad closer to the chair. Slowly release back to starting position and repeat for repetitions.		Weeks 1-4: Complete **2 sets of 12-15 repetitions** of this exercise. Resistance should be increased when 15 repetitions can be completed with ease. Weeks 5-8: Complete **3 sets of 12-15 repetitions** of this exercise. Resistance should be increased when 15 repetitions can be completed with ease. Weeks 9-12: Complete **4 sets of 12-15 repetitions** of this exercise. Resistance should be increased when 15 repetitions can be completed with ease.

	Demonstration	Repetitions
Exercise 4. **Leg Curl**		
*First make sure the monitor is set to the **Leg Extension** exercise.* Sit in the chair and strap the lower thigh to the chair with the clips and straps provided. Start with the legs in a regular sitting position with the foot pad placed just above the ankles on the **front** of the shin. Contract the front thigh muscles (quadriceps) and extend the knees to push the foot pad away from the chair. Slowly release back to starting position and repeat for repetitions.		Weeks 1-4: Complete **2 sets of 12-15 repetitions** of this exercise. Resistance should be increased when 15 repetitions can be completed with ease. Weeks 5-8: Complete **3 sets of 12-15 repetitions** of this exercise. Resistance should be increased when 15 repetitions can be completed with ease. Weeks 9-12: Complete **4 sets of 12-15 repetitions** of this exercise. Resistance should be increased when 15 repetitions can be completed with ease.

	Demonstration	Repetitions
Exercise 5. **Calf Press**		
Move the back rest to a comfortable position. Sit in the chair and place the toes and balls of the feet on the platform. Contract the back calf muscles and extend the ankles to push the platform away from the chair (it will only move slightly as the ankles extend). Slowly release back to starting position and repeat for repetitions.		Weeks 1-4: Complete **2 sets of 12-15 repetitions** of this exercise. Resistance should be increased when 15 repetitions can be completed with ease. Weeks 5-8: Complete **3 sets of 12-15 repetitions** of this exercise. Resistance should be increased when 15 repetitions can be completed with ease. Weeks 9-12: Complete **4 sets of 12-15 repetitions** of this exercise. Resistance should be increased when 15 repetitions can be completed with ease.

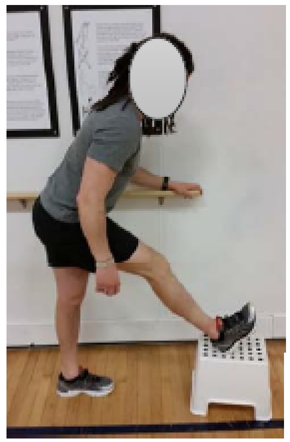
	Demonstration	Repetitions
Exercise 6. Tandem Stance		
Place the heel of one foot at the toe of the other (one foot in front of the other. Stand within arm's reach of the wall for balance if required. Let go of the wall and attempt to maintain balance. *If this exercise is too easy, try closing the eyes to challenge balance further.* *Make sure that to be in arm's reach of the wall at all times for safety.*		<u>Weeks 1-4:</u> Complete **2 sets of 30 second holds** of this exercise. Switch feet so that each foot is the front foot, twice. <u>Weeks 5-8:</u> Complete **3 sets of 30 second holds** of this exercise. Switch feet so that each foot is the front foot, twice. <u>Weeks 9-12:</u> Complete **4 sets of 30 second holds** of this exercise. Switch feet so that each foot is the front foot, twice.

	Demonstration	Repetitions
Exercise 7. Marching		
Stand close to the wall without touching it. One leg at a time, flex the hip and the knee in a marching position. Hold for **2-3 seconds** and switch legs. *If this exercise is too easy, try closing the eyes to challenge balance further.* *Make sure that to be in arm's reach of the wall at all times for safety.*		<u>Weeks 1-4:</u> Complete **2 sets of 30 seconds (march for 30 seconds)** of this exercise. <u>Weeks 5-8:</u> Complete **3 sets of 30 seconds (march for 30 seconds)** of this exercise. <u>Weeks 9-12:</u> Complete **4 sets of 30 seconds (march for 30 seconds)** of this exercise.

	Demonstration	Repetitions
Exercise 8. Heel-Toe Walk		
Place one foot in front of the other and walk heel-to-toe. Repeat for 20 steps.		<u>Weeks 1-4:</u> Complete **2 sets of 20 steps.** <u>Weeks 5-8:</u> Complete **3 sets of 20 steps.** <u>Weeks 9-12:</u> Complete **4 sets of 20 steps.**

Stretches

	Demonstration	Repetitions
Stretch 1. Quadriceps		
Pick one of the following quadriceps exercises. 1) Place one knee on the bed comfortably. Push the hips forward until a stretch is felt in the hip and front of the thigh. 2) Place one hand on the railing. Grab the ankle with the opposite hand and hold the stretch for the front of the thigh.	1) 2) 	Complete **2 repetitions of a 30 second hold** on each leg.

	Demonstration	Repetitions
Stretch 2. Hamstrings		
Prop the heel of one foot on a foot stool available in the stretch area. Keep the back in a neutral posture. Bend forward from the hips until a stretch is felt at the back of the thigh and calf.		Complete **2 repetitions of a 30 second hold** on each leg.

	Demonstration	Repetitions
Stretch 3. Calf		
Place both hands on the wall at about head height. Step one leg back and aim to push the back heel into the ground until a stretch is felt in the back of the calf.		Complete **2 repetitions of a 30 second hold** on each leg.

	Demonstration	Repetitions
Stretch 4. Hip		
Sit in a chair. Cross one ankle over the opposite knee and flex forward from the hips until a stretch is felt in the gluteal (butt) muscle.		Complete **2 repetitions of a 30 second hold** on each leg.