RESEARCH PROTOCOL

Anglia Ruskin University

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Section 1: Summary of protocol details

Title of project:

The effect of retro walking on pain, gait biomechanics and gait stability using non-linear analysis in people with knee osteoarthritis

1.2 Anglia Ruskin project reference number: NB1

1.3 Protocol version number and data: 4.0, 6 July 2026

Section 2: Research question(s)

1. Does retro walking exercise reduce pain, improve gait biomechanics and stability in people with knee osteoarthritis?

Section 3: Abstract

Knee osteoarthritis, a chronic musculoskeletal disease, is the most prevalent type of osteoarthritis and the leading cause of disability and major healthcare costs worldwide. The pathogenesis of the disease is not fully understood and there are few non-invasive disease-modifying therapies available to patients. Therefore, there is a critical need to enhance therapeutic interventions, which requires improvement of our understanding of knee osteoarthritis pathogenesis.

Increasing evidence suggests that physical activity and exercise training are cost-effective and widely available interventions for the treatment of knee osteoarthritis, however, consideration of type of physical activity and optimal exercise modality are needed to reduce pain, improve gait, knee joint function, stiffness, and muscle weakness in individuals with knee osteoarthritis.

The aim of this pilot clinical trial is to compare individuals with knee osteoarthritis who have not exercised with individuals that have performed retro walking exercise chosen from the systematic review and survey we have conducted previously to reduce pain and improve gait.

Biomechanical and non-linear analyses will be performed to determine the effects of exercise intervention - retro walking - on gait biomechanics and stability of movement in these patients.

These findings may form a basis for recommendations of exercise/physical activity interventions for the benefits of patients with knee osteoarthritis including pain reduction, mobility improvement and gait modification.

Section 4: Aims and objectives of the study

The overall aim of the study is to determine whether retro walking exercise reduces pain, improves gait biomechanical parameters and walking stability in people with knee osteoarthritis.

The primary outcome measures include changes in pain assessed through validated questionnaire (knee injury and osteoarthritis outcome score (KOOS).

Secondary outcomes include changes in pain intensity pain intensity measured using numeric pain rating scale (NPRS), gait parameters such as spatiotemporal, kinetic and kinematic and gait stability assessed through biomechanical and non-linear analyses respectively as a result of the changes/variations from the non-linear analysis as recorded from the gait analysis and confirmed with the standard and accepted definitions in the existing literature.

Objectives

1. To assess the effect of retro walking on pain in adults with knee osteoarthritis
2. To determine the effect of retro walking on gait biomechanics in adults with knee osteoarthritis
3. To examine gait stability of walking in the intervention group compared to the control group using non-linear analysis

Section 5: Background and rationale

5.1 Scientific background and relevance

Knee osteoarthritis, a chronic musculoskeletal disease, is the most prevalent type of osteoarthritis and the leading cause of disability and major healthcare costs worldwide. Globally, approximately 13% of women and 10% of men aged over 60 years have symptomatic knee osteoarthritis. The prevalence of knee osteoarthritis is expected to continue to increase globally due to ageing population and increasing rates of obesity and injury (Long *et al.*, 2022). Despite this significant healthcare and economic burden, the pathogenesis of the disease is not fully understood and there are few non-invasive disease-modifying therapies available to patients. Therefore, there is a critical need to enhance therapeutic interventions.

Knee osteoarthritis is a whole joint disease involving multifaceted interactions between structural, biological, and biomechanical factors. It is characterised by a progressive deterioration of the articular cartilage, formation of osteophytes, subchondral bone sclerosis, synovial proliferation, inflammation, and lax tendons (Samvelyan *et al.,* 2021; Samvelyan *et al.,* 2022). These ultimately lead to a loss of knee joint function, chronic pain, impaired mobility and proprioception, and disability.

Management of symptoms and pain are primary treatments for knee osteoarthritis (Hunter and Bierma-Zeinstra, 2019), with knee replacement surgery typically considered later in the disease. While medications such as non-steroidal anti-inflammatory drugs (NSAIDs) may be prescribed to relieve pain, physical activity and exercise are non-pharmacological recommendations for a long-term management of knee osteoarthritis (Moseng *et al.*, 2024).

Mechanical knee instability constitutes a multitude of clinical symptoms whereby the knee joint feels unreliable, weak and gives way during normal activities. Several techniques are utilised clinically to assess the knee joint instability including (i) core physical examination tests such as Lachmann Test, Pivot Shift Test, Anterior and Posterior Draw Tests, Valgus/Varus Test and Dial test - each of these tests identifies a specific pathology for example anterior cruciate, medial collateral ligament or posterior-lateral instability (ii) instrumentation such as KT-1000 for measurement of anterior translation of tibia (iii) imaging such as MRI or (iv) biomechanical gait analysis.

Patients with knee osteoarthritis exhibit altered gait biomechanics when compared to age-matched healthy individuals (Astephen *et al.*, 2008; Favre and Jolles, 2016). Common gait changes include spatiotemporal parameters such as reduced walking speed and stance duration as well as increased step length. Three-dimensional patterns of the knee joint such as kinematic changes include reduced range of motion

in knee flexion, extension and rotation, and increased knee adduction, whereas kinetic changes include reduced peak knee extension moment, increased knee valgus moment and loading on the contralateral limb. Furthermore, alterations in gait biomechanics can impact other joints increasing likelihood of joint tissue damage, muscular injury and chronic pain.

The human gait is an example of a non-linear system where the gait cycle is a repeated action where no two cycles are the same (Harbourne and Stergiou, 2009; Stergiou and Decker, 2011). Human movement variability lies between too much and too little variabilities and if the gait is disturbed the next cycles of the gait will be disturbed (Harbourne and Stergiou, 2009). Gait characteristics are mainly measured linearly where averages are taken to observe the magnitude of change over time, however, previous research in our laboratory indicated that gait stability of walking should be measured using non-linear analysis (Strongman and Morrison, 2020). Non-linear measures are of a temporal nature and require a range of measurements taken over an uninterrupted time, for instance, range of motion of a knee joint, step length and stance time. Non-linear tools such as the Lyapunov component can be used to analyse time series data to show sensitivity to initial conditions, and entropy to show rigidity of a dynamical system (Harbourne and Stergiou, 2009; Stergiou and Decker, 2011; Strongman and Morrison, 2020). As individuals with knee osteoarthritis have deteriorated balance and gait, non-linear measures of entropy and rigidity are valuable in determining the effectiveness of an intervention.

Increasing evidence suggests that physical activity and exercise training are cost-effective and widely available interventions for the treatment of knee osteoarthritis, however, consideration of type of physical activity and optimal exercise modality are needed if the aim is to reduce pain, improve gait, knee joint function, stiffness, and muscle weakness in individuals with knee osteoarthritis.

For example, low-impact physical activities including walking, swimming, and cycling have been shown to be beneficial for individuals with severe knee osteoarthritis (Raposo, Ramos and Lúcia Cruz, 2021). Regular aquatic exercises can help to relieve pain and improve daily function in people with both knee and hip osteoarthritis(Bartels *et al.*, 2016; Arthritis Foundation, 2025), whereas high-impact activities such as running and jumping can potentially worsen symptoms of knee osteoarthritis by increasing stress and inflammation in affected joints (Sandmeier, 2000; Messier et al., 2021).

The aim of this two-arm parallel randomised controlled clinical trial (pilot) is to investigate the effect of retro walking exercise on pain, gait biomechanics and walking stability in adults with knee osteoarthritis.

5.2 Study rationale

Physical activity and exercise training have shown to be beneficial for reducing pain and improving gait biomechanics particularly the spatiotemporal parameters in osteoarthritic patients (Azizi et al., 2020; Vincent and Vincent, 2020; Chen et al., 2021; Sedaghatnezhad et al., 2021; Bhore and Shinde, 2023).

Despite this, a limited number of studies assessed the therapeutic effects of physical activity/exercise interventions on gait biomechanic parameters specifically kinetic and kinematic changes and joint mobility improvements. Our recent systematic review with meta-analysis revealed that previous studies mainly used strength-based exercises or resistance training for improvement of quadriceps muscle groups (Paul *et al.*, 2016; Kean *et al.*, 2017; Vincent and Vincent, 2020) with significant gap in assessing the clinical relevance of low-impact physical activity/exercise such as walking or retro walking (also known as walking backwards) in people with knee osteoarthritis.

Retro walking is already a fitness trend among adults that offers unique benefits including improving muscle engagement, balance and calorie burning (Aysha *et al.*, 2024). This type of exercise is shown to enhance both physical and mental health such as muscle strength and cognitive function. Therefore, this cost-effective and accessible low-impact physical activity/exercise intervention may be beneficial for osteoarthritic patients and further supports the study rationale that the chosen retro walking exercise may provide long lasting benefits in terms of gait stability and pain reduction in patients with knee osteoarthritis.

Further, the effectiveness of retro walking intervention on stability of walking in these patients can be assessed using non-linear analysis (Strongman and Morrison, 2020).

5.3 Clinical relevance

Osteoarthritis is a major contributor to disability and health care costs around the world. People that have been diagnosed with knee osteoarthritis gradually lose their mobility, independence and ultimately become disabled due to disease progression. As there are very few therapeutic options available, and primary symptoms are largely managed through NSAIDs there is a significant need for non-invasive therapeutic interventions. Since most of the knee osteoarthritis cases progress to moderate and severe severity, individuals' ability to perform exercise or physical activities are significantly impacted. Therefore, there is a pressing need for a low-impact physical activity/exercise interventions to help alleviate symptoms and use as therapeutic strategies to prevent progression of the disease.

This study will allow to determine the benefits of retro walking physical activity/exercise intervention in patients with knee osteoarthritis. If we can identify reduction in pain assessed using standardised and validated questionnaire such as KOOS and NPRS, improvement in gait biomechanic parameters and stability of walking before and after the retro walking intervention then we would be able to make recommendations to patients with knee osteoarthritis with respect to retro walking as therapeutic intervention to obtain maximal benefits from this low-impact accessible physical activity/exercise.

Section 6: Plan of investigation

6.1 Study design

In this pilot study, adults over the age of 20 with knee osteoarthritis will be recruited that are able to perform low-impact physical activity/exercise.

This will be a randomised clinical trial; participants will be randomly assigned to retro walking or control groups. Participants in the intervention group will perform treadmill retro walking exercise 3 days/week for 6 weeks adapted from previous studies (Alghadir et al., 2019; Joshi et al., 2019). Participants in the control group will maintain their existing level of activity.

Prior to the intervention participants will be made familiar with retro walking on the treadmill. The exercise will consist of a forward walking for 5min on the treadmill for warm-up followed by retro walking for 10 min and a cool-down for 5 min. Participants will be instructed to increase their retro walking time up to 30min if the pain sensation continuously was reduced (pain scores < 3 on numerical rating scale).

The comfortable speed of the retro walking will be determined by the participant under supervision of the researchers. No slopes or inclination will be used in this study for participant safety. In the warm-up and cool-down sessions prior to treadmill retro walking participants will be asked to perform muscle stretch, ankle toe movements and heel raise exercises.

All participants will undergo a baseline assessment for health history (PAR-Q). Baseline measurements of age, weight, height, BMI and anthropometric data for biomechanical parameters will be performed to characterise the study sample.

6.2 Power calculation

The pre- and post-intervention assessment will be performed for all the outcomes at two time points (at 0 weeks and 6 weeks) between the intervention and control groups.

The sample size is calculated according to Osteoarthritis Research Society International (OARSI) Clinical Trials recommendations (McAlindon et al., 2015). Previous studies evaluating therapeutic exercises for knee osteoarthritis reported a post-treatment mean difference of 2.12 points between the intervention and control groups on the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain subscale (Dantas et al., 2020).

Sample size estimation was performed using G*Power for a repeated-measures ANOVA assessing the within-between interaction (group × time). Assuming a moderate-to-large effect size ($f = 0.33$), $\alpha = 0.05$, statistical power of 80%, two groups, two measurement time points, and a correlation among repeated measures of 0.5, the estimated required sample size was 40 participants (20 participants per group).

Allowing for an anticipated dropout rate of approximately 10%, recruitment will aim to enrol up to 44 participants. As this is a pilot randomised controlled trial, the study will also provide preliminary estimates of treatment effects and feasibility outcomes to inform future larger-scale trials.

This sample size is in line with other studies in this area and as a pilot study, the sample size is based on feasibility and estimation of effect sizes.

6.3 Study measurements

Pain will be assessed over the study duration via validated questionnaire KOOS and NPRS. The KOOS incorporates all of the original 24 WOMAC questions but expands

on them to provide a more comprehensive assessment for wide range of patients including younger patients.

The gait biomechanical parameters including spatiotemporal such as walking speed (velocity, meters/sec), cadence (steps/min), stride/step length (meters or cm), swing/stance phases and double support time (both % of gait cycle), kinetic such as knee adduction moment (KAM) (Newton meters Nm), knee flexion/extension moment (Newton meters Nm), vertical ground reaction (vGRF) and joint contact forces (JCF) (both Newtons N) and kinematic such as knee flexion angle, Range of Motion (ROM) and knee adduction/abduction (Degrees (°)) will be assessed using VICON motion analysis system at two timepoints pre- and after the intervention. The stability of walking will also be measured using non-linear analysis including Lyapunov (1/s or s^(-1)) and Hurst Exponents before and after the intervention.

6.4 Methods

6.4.1 Familiarisation

The participants in the intervention group will be familiarised with operation of a treadmill; they will determine their own self-selected retro walking speed for all visits. The participants will select their pace using the treadmill setting and once comfortable they will retro walk at that selected speed. If the pace they have selected is too high, it will be adjusted to a more comfortable speed for the safety of the participant.

6.4.2 Retro walking protocol

The participants in the retro walking group will perform 10 min of supervised retro walking training with 5min warm-up and cool-down sessions prior to retro walking 3 days a week for 6 weeks at their comfortable walking speed. The participants will be instructed to gradually increase their walking time up to 30 min over the 6-week period if they consistently experience less pain (e.g. pain scores < 3 on numerical rating scale). In the warm-up and cool-down sessions, the subjects will be instructed to perform heel raise exercises, ankle toe movements, and gastrocnemius-soleus and hamstring stretches (Alghadir *et al.*, 2019).

6.4.3 Biomechanical data assessment

All participants will have reflective markers placed on their body at anatomical relevant locations such as toe, tibia, outer or lateral knee, femur, and pelvic bones so motion capture system can build body segments in real time and allow for motion to be captured over time to generate spatiotemporal, kinematic and kinetic data for analysis.

The Helen Hayes marker set consisting of 16 lower limb reflective markers will be used (Thomas et al, 2009). Participants will also be instructed to walk along a 20-meter walkway at a self-selected speed while wearing shoes with two Kistler force plates placed at the midpoint of the walkway to observe ground reaction forces. This will be repeated three times to ensure sufficient data is captured for biomechanical parameter analysis. Participants speed will be recorded during this stage for non-linear analysis set up. Data will be taken before intervention starts and after intervention concludes.

6.4.4 Gait stability assessment

Non-linear analyses will be performed to determine the effect of retro walking exercise intervention on gait normalisation and stability of movement changes in both intervention and control groups. The human gait is an example of a nonlinear system, gait stability can be assessed by gathering time series dependant data.

Overall stability can be evaluated using Lyapunov and Hurst exponents along with sample entropy, which are useful for analysing human gait signals under different conditions (e.g., walking). These measures help quantify local dynamic stability, long-range correlations and self-similarity and determine regularity and predictability indicators if gait stability has improved following an intervention (Goshvarpour and Goshvarpour, 2012).

To determine overall stability an inertial measurement unit (IMU) will be used and placed on the pelvis to track acceleration. All participants will walk on a treadmill for 5 minutes with IMU's at the speed they selected from the overground trial they feel comfortable with in footwear. Data will be taken at the beginning and end of trial for both groups (weeks 0 and 6).

6.4.5 Pain severity, function and mobility assessment

Pain severity, function and mobility will be assessed using the validated questionnaire KOOS and NPRS (Alghadir *et al.*, 2018; Roos, 2024). This self-administered questionnaire KOOS will be used to assess pain, activities of daily living, knee related quality of life and symptoms in participants with knee osteoarthritis. NPRS will be used in this study due to its ease of use and quickness in its application versus VAS (visual analogue scale) where scales will have to be measured manually and may be more difficult to implement over time (Johnson, Roosevelt and Lombard, 2005; Karcioglu *et al.*, 2018).

6.5 Setting for the project

The study will be conducted at the Biomechanics laboratory at Compass House (Anglia Ruskin University, Cambridge). The study will conform to all standards of Good Clinical Practice and will be overseen by an experienced academic.

The principal investigator is Dr Jasmine Samvelyan (Senior Lecturer in Biomedical Science, Anglia Ruskin University School of Medicine, Chelmsford) and co-investigators for the study are Mr Nathan Bytheway (PhD student, Anglia Ruskin University School of Medicine), Dr Andrew Morrison (Senior Lecturer in Psychology, Sport and Sensory Sciences, Anglia Ruskin University School of Medicine, Cambridge) and Professor Kevin Cheah (Consultant Orthopaedic Surgeon, Nuffield Health and Honorary Doctor of Health Sciences, Anglia Ruskin University School of Medicine, Chelmsford) and Mr Wasim Khan (Consultant Orthopaedic Surgeon, Nuffield Health Cambridge Hospital).

Mr Vikas Khanduja (Consultant Orthopaedic Surgeon, Nuffield Health Cambridge Hospital, Addenbrooke's Cambridge University Hospitals NHS Foundation Trust) is collaborator and will provide clinical academic advice for the study concept and design.

Data collection (with appropriate training) will be the responsibility of Mr Nathan Bytheway under the supervision of Drs Jasmine Samvelyan and Andrew Morrison.

6.6 Participants

Participants will be adults aged over 18 years with knee osteoarthritis.

6.7 Recruitment

Participants will be invited to take part in the study by invitation email and by poster. Posters will be distributed around Anglia Ruskin University Campus Buildings at all sites. Invitation emails will be sent via researcher networks and Hospitals' R&D offices.

Potential participants will be followed up by telephone or email for screening to make sure that they meet the eligibility criteria for the study. Participants that are eligible for the study will be sent an appointment letter to confirm their study visit.

6.7.1 Informed consent

All participants must give informed consent before enrolment on this study. All participants will receive a participant information sheet (PIS) giving details of the study and will have at least 24 hours to consider their participation in this study before attending their first study visit to give consent for participation. All participants will be given the opportunity to ask any questions about the study before giving informed consent. Informed consent will be collected from each potential participant by the principal investigator or co-investigator. Participants will also have opportunity to ask any questions that they have during any of their study visit.

6.7.2 Inclusion/Exclusion Criteria

Inclusion criteria:

- Male and female
- Any ethnicity
- Adults over 18 years old
- Meet the UK guidelines for physical activity supported by NICE (National Institute for Health and Care Excellence) and NHS (able to exercise if it is safe with regular breaks)
- Otherwise, adults with clinically diagnosed knee osteoarthritis according to NICE criteria or confirmed by a healthcare professional able and willing to participate and provide written informed consent

Exclusion criteria:

- Any musculoskeletal injury
- Any conditions known to affects gait (e.g. Parkinson’s disease or stroke)
- Any surgical intervention in the previous 12 months on lower limbs
- Surgical replacement of hip or knee joints
- BMI (body mass index) over 35
- Athletes or take part in significant recreational activity
- Takes any medication known to affect the gait and ability to walk

- Received an intra-articular injection in the last 3 months
- Have been told by medical professionals that they should not take part in any intensity exercise/physical activity

6.8 Outcome measures and participant involvement in each visit

All participants will be required to attend the Biomechanics Laboratory at Compass House, ARU Cambridge. Participants in the intervention group will attend approximately 20 study visits over 6 weeks, including baseline, familiarisation, supervised exercise sessions, and final assessments.

At the **first visit** each participant will give informed consent and confirm eligibility. Consenting participants will have their baseline anthropometric measures including age, weight, height and BMI taken. Along with baseline measurements, KOOS questionnaire and NPRS will be completed by all participants to obtain the baseline of pain, function and mobility, symptoms and activity of daily living and measure baseline pain severity.

Full biomechanical analysis of gait will be performed using motion capture systems for linear analysis of gait. The IMUs will be used to gather time series dependant data for non-linear analysis of gait to assess stability over time.

Computer-generated randomisation with allocation concealment will be used to assign participants to either intervention (retro walking) or control groups.

Participants in the control group will be encouraged to maintain their existing level of physical activity. Participants in all groups will be advised to maintain any pre-existing treatment of their knee osteoarthritis such as pharmacologic therapy.

At the **second visit,** participants in the intervention group will be familiarised with the use of a treadmill and its operation. Participants will be supervised and retro walking will be explained including the rotation of warm up, walking and then retro walking. Each participant will self-select and choose their pace for retro walking.

In the **following visits**, the participants in the intervention group will complete the retro walking exercise for maximum 6 weeks at their chosen pace. They will be instructed to gradually increase their walking time if they experienced less pain measured by NPRS.

In the **final visit,** the last set of exercises will be completed by the participants in the intervention group. The final biomechanical data set will be taken for comparison between baseline and end of study. All outcomes will be assessed pre- and post-intervention.

Full biomechanical analysis and non-linear analysis of gait will be performed, KOOS questionnaire and NPRS will be completed by all participants of the study.

6.8.1 Summary of participant involvement by study time point

Study time point	**Familiarisation visit**	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	**Study end visit**
Activity								
Informed consent	X							
Demographic data	X							
Anthropometric data	X							
KOOS questionnaire	X							X
NPRS	X	X	X	X	X	X	X	X
Treadmill familiarisation		X						
Retro walking (intervention group)		X	X	X	X	X	X	
Gait assessment	X							X
Gait stability assessment	X							X
Participant expenses given (£20 gift voucher)								X

6.9 Statistical analysis

All statistical analyses will be performed using appropriate statistical software (e.g., SPSS, R, or GraphPad Prism), with statistical significance set at $p < 0.05$ (two-tailed). As this is a pilot randomised controlled trial, analyses will primarily focus on estimation of effect sizes, variability, and feasibility outcomes to inform future larger-scale studies.

Prior to analysis, data will be screened for completeness, outliers, and distributional assumptions. Normality of continuous variables will be assessed using the Shapiro–Wilk test, supported by visual inspection of histograms and Q–Q plots. Normally distributed data will be presented as mean ± standard deviation (SD), whereas non-normally distributed data will be summarised using median and interquartile range (IQR).

Baseline demographic and clinical characteristics will be compared descriptively between the retro walking and control groups to assess comparability following randomisation. Continuous variables will be analysed using independent-samples *t*-tests or Mann–Whitney *U* tests, depending on data distribution. Categorical variables will be summarised as frequencies and percentages.

The primary analysis will evaluate changes in pain outcomes (using KOOS and NPRS scores) over time between groups. Secondary analyses will examine changes in gait biomechanics (spatiotemporal, kinetic, and kinematic parameters) and gait stability measures derived from non-linear analyses, including entropy and Lyapunov-based metrics.

For repeated outcome measures collected at baseline and post-intervention (week 6), a two-way repeated-measures analysis of variance (ANOVA) will be used to assess the effects of group (retro walking vs control), time (baseline vs post-intervention), and the group × time interaction. Where assumptions for repeated-measures ANOVA are not met, linear mixed-effects modelling will be employed as a robust alternative, allowing for inclusion of missing observations and participant-level random effects.

Where significant interaction or main effects are identified, post hoc pairwise comparisons with appropriate adjustment for multiple testing (e.g., Bonferroni correction) will be performed. Effect sizes will also be reported using partial eta squared (η^2p) for ANOVA models and Cohen's *d* for pairwise comparisons to aid interpretation of clinical relevance.

For non-parametric repeated measures data, equivalent non-parametric tests will be used, including the Wilcoxon signed-rank test for within-group comparisons and Mann–Whitney *U* tests for between-group comparisons.

Missing data will be reported and explored descriptively. Given the pilot nature of the study, analyses will primarily follow a complete-case approach; however, linear mixed-effects models inherently accommodate missing repeated measures under the assumption of missing at random.

Results will be reported in accordance with CONSORT recommendations for pilot and feasibility randomised controlled trials.

6.9.1 Data collection

Consent forms, questionnaires and measurements will be stored electronically and will be managed by members of the research team.

Electronic source data forms will be used to collate all the collected data for each subject. Members of the research team will complete data entry into an electronic case report form from participant questioning and measurements.

All data from the electronic case report forms and the measurement reports will be entered onto the study database and the data will be stored according to the regulations of the Data Protection Act 2018.

Data entry will be checked by a second operator at a different time point. Participant consent forms will be signed as a paper copy, scanned, and stored electronically. The paper copy will be destroyed. The electronic case report forms, other study documents (e.g. study log) and study database and will be protected by the standard University windows and network login passwords as well as a database login unique to the study.

All samples and data will be linked anonymously before analysis. No publications will contain information that will be able to identify individual participants.

6.10 Project Plan

We aim to carry out data collection between June 2026 and August 2026. Analysis of all outcomes will be completed by November 2026.

We will consider the study complete when all participants have completed study data collection time points pre- and post- intervention, all laboratory analyses have been performed, the data entered into a database and checked, statistical analysis is completed and the final report is written.

Section 7: Project management

7.1 Study team

Principal Investigator: Dr Jasmine Samvelyan

Co-Investigators: Mr Nathan Bytheway, Dr Andrew Morrison, Mr Wasim Khan, Professor Kevin Cheah

Biomechanical supervision: Dr Andrew Morrison

Statistical Support: All investigators

All investigators will be responsible for study design and study oversight. Mr Nathan Bytheway will be responsible for day-to-day running of the study. This includes screening, consent and overseeing study visits. Mr Nathan Bytheway will be responsible for data collection and study visits.

The PI, co-investigators and collaborators will meet on a regular basis to review the progress of the study and to ensure that the project delivers its intended outcomes on time.

7.2 Amendments to the protocol

If it is necessary for the protocol to be amended, the amendment and/or a new version of the study protocol will be notified through the Haplo system for local approval. If necessary, revised Participant Information Sheets will be prepared and approved through Haplo before participants are provided with this new information and asked to re-consent.

Section 8: Expertise of the researcher and associated team

Jasmine Samvelyan, The School of Medicine, Faculty of Health, Education, Medicine and Science (FHEMS), Anglia Ruskin University (ARU) is a Senior Lecturer in Biomedical Science, and Lead of the Musculoskeletal and Developmental Biology research group at ARU. She has 10-year extensive research experience in utilising cellular, molecular, and *in vivo*, clinical trial approaches to study musculoskeletal ageing including bone wasting diseases such as osteopenia and osteoporosis, and osteoarthritis. Dr Samvelyan uses models of osteoarthritis to explore associations between chondrocyte phenotypes, growth plate dynamics and articular cartilage degradation in young adult and aged mice as well as genetically modified models. Dr

Samvelyan has conceived the original idea of this study. This project received a prestigious ARU Vice Chancellor's PhD Scholarship Award.

Nathan Bytheway is a PhD student at the School of Medicine of ARU and member of Musculoskeletal and Developmental Biology Research Group (first supervisor Dr Jasmine Samvelyan and co-supervisor Dr Andrew Morrison, PhD advisor Prof Kevon Cheah). Nathan completed his MEng in Biomedical Engineering at the University of Strathclyde.

Andrew Morrison is a Senior Lecturer at Faculty of Science and Engineering of ARU. He has a bachelor's degree from the University of Birmingham, an MSc in Sport and Exercise Biomechanics from the University of Roehampton and a PhD from the University of Ulster. Andy's PhD thesis focused on bridging the gap between golf coaching and biomechanics, developing novel biomechanical studies into the golf swing. This included investigating how golfers coordinate their limbs in the golf swing to achieve repeatable shot outcomes. Andy has applied this with some of the highest ranked golfers in the world. Drawing on his expertise in analysing the complex movement of the golf swing, Andy applies this to a variety of other areas such as running, falls and injury prevention.

Wasim Khan is an Associate Professor at the University of Cambridge, as well as Consultant Orthopaedic Surgeon specialising in trauma and knee surgery, based at Addenbrooke's Hospital. After graduating from Manchester University in 1999, he completed his orthopaedic training at the Royal National Orthopaedic Hospital, Stanmore where he was a Lecturer at University College London, from 2010-14. He completed national (Bristol and Cardiff) and international (Europe and Australia) clinical fellowships before starting work in Cambridge in 2016. Professor Khan has a particular interest in primary and complex knee replacements as well as revision knee replacements.

Kevin Cheah was appointed as a Consultant Orthopaedic Surgeon at the Mid-Essex NHS Trust in 1996 and subsequently into full-time Private Practice in 2002. He was involved in the establishment of the Medical Engineering Research Group of Anglia Ruskin University and was awarded the Master of Science (honorary) in 2002 and a visiting Professorship in 2006. He is a co-founder of the Post-Graduate Medical Institute which led to the establishment of the School of Medicine at Anglia Ruskin University in 2018.

Vikas Khanduja is a research collaborator is a consultant orthopaedic surgeon specialising in both preservation and arthroplasty aspects of hip surgery and has a particular interest in arthroscopic surgery of the hip. Vikas Khanduja works in the Department of Orthopaedics and Trauma, Cambridge University Hospitals NHS Foundation Trust, UK. Vikas has been instrumental in setting up the tertiary referral service for Young Adult Hip Surgery in Cambridge and is the Lead of the Elective Clinical Trials for Orthopaedics. Vikas's research is focused on the management and outcomes of patients with femoroacetabular impingement (FAI) which is a pre-arthritic condition of the hip joint. In particular, his interest lies in disease stratification via novel imaging techniques, optimisation of arthroscopic management of FAI and precision surgery via navigation and robotics to improve outcomes.

Section 9: Ethical considerations

The study protocol will be implemented after favourable opinion has been received from the ARU research ethics panel and IRAS (Integrated research application system). The protocol will also be signed off by a licensed physiotherapist.

All study participants will receive an information sheet prior to attending the study visit and will give written informed consent at the study visit prior to undergoing the study procedures. Informed consent will be obtained in accordance with GCP (Good clinical practice) procedures to ensure confidentiality, and privacy. The security of the research data will be assured by acting in accordance with the 2018 Data Protection Act (General Data Protection regulation).

The study will be carried out in compliance with the protocol and GCP procedures as described in ICH GCP 1996 and the Declaration of Helsinki concerning medical research in humans (2008) are in place to ensure appropriate consent, confidentiality, and privacy.

Risk to participants is minimal. Participants will have to exercise on a treadmill at a self-selected walking pace. All participants will be shown how to use equipment safely and effectively. Treadmills are fitted with a safety tether to stop the machine in the event of a fall, all study visits will be supervised. Participants may feel tired and after rounds of retro walking, sufficient breaks will be advised, participants will have the option to take longer breaks if necessary. While exercising participants may become fatigued to the point of failure, to ensure this does not happen participants will be allowed to stop before this happens and take a break from exercise and may not continue with the session. If any complications occur from exercise a first aider will be on site to assist in any medical conditions occurring or in the event of a slip, trip or fall.

Participants will have to complete a medical screening questionnaire to determine if they are fit enough to complete sessions to minimise risk of injury. As the study recruits from a knee osteoarthritic population, pain when exercising before and after will also be a concern. Participants will also be advised if pain in the knee becomes intolerable, they will have to discontinue the session.

Any adverse events occurring during exercise sessions or assessments will be documented and reported to the Principal Investigator. Exercise sessions will be supervised by trained researchers familiar with treadmill safety procedures. Participants will be permitted to stop exercise immediately if they experience pain, dizziness, fatigue, instability, or discomfort.

A first aider and emergency procedures will be available on site in accordance with University safety policies.

Section 10: Methods for disseminating research results

It is intended that the results of this study will be published in a peer-reviewed journal as well as presented at national and/or international conferences.

Section 11: Strategy for taking the work forward

This study is a pilot study and data collected will be used to form part of a wider programme of the study investigating the effect of physical activity/exercise on gait and pain in people with knee osteoarthritis to contribute to new recommendations of exercise therapy for people with knee osteoarthritis.

Section 12: Funding

This project has received ARU VC Scholarship Award and funding through ARU Doctoral School.

Section 13: References

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Section 14: Additional information

Location of data collection:

The Cambridge Centre for Sport and Exercise Sciences (CCSES)

Anglia Ruskin University

East Road, Cambridge CB1 1PT

Laboratory details:

Biomechanics Laboratory Compass House

Anglia Ruskin University

Newmarket Rd, Cambridge, CB5 8DZ

Appendix A: Project Plan

Year	Year 1										
Project Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Date	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
Month relative to recruitment start	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
Activity											
Study methodology											
Recruitment strategy											
Study standard operating procedures (SOPs)											
Project management meetings											
Documentation for research ethics application											
Submission to IRAS											
Ethical approval expected											
Expected recruitment start date											
Study visits											
Biomechanical measurements pain assessment											
Data entry											
Data analysis											
Reports/abstract/manuscripts											