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Retention of kinematic patterns during a 6-minute walk test in people with knee osteoarthritis

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ABSTRACT

Background: Knee osteoarthritis (OA) is a chronic condition affecting the entire joint and surrounding tissue, resulting in pain, stiffness and impaired movement. Recent studies have suggested the use of physical performance tests, such as the six-minute walk test (6MWT) to assess joint function for those with knee OA. This study assessed lower limb sagittal plane joint angles during a 6MWT for people with mild-moderate knee OA.
Methods: Thirty-one participants (18 male, 13 female; 62.9 ± 8.4 years) with knee OA were recruited. Gait data were collected in a single session during which participants completed a 6MWT around a 20 m course. Sagittal plane joint angles for the hip, knee and ankle were calculated during the first and last minute of the 6MWT. Statistical parametric mapping (SPM) was used to investigate changes in kinematic traces over the gait cycle.
Results: Mean joint angles for the hip and knee showed no significant differences between the first and last minute of the 6MWT. Ankle joint kinematic traces indicated there to be a decrease in plantarflexion approaching toe-off in the last minute of the test – a 1.5° reduction from the first minute. No significant differences were calculated for walking speed or joint range of motion.
Discussion: The lack of significant change in joint kinematic parameters and walking speed suggests the relative fatigue and pain burden to the participant over the duration of the 6-minute period is insufficient to elicit any mechanical changes to walking gait.

1. Introduction

Knee osteoarthritis (OA) is a whole joint disease involving several joint tissues and is mainly characterized by the inhibition of natural cartilage repair processes brought about by biochemical and biomechanical changes in the joint [1]. Recent estimates indicate that approximately 4% of the worldwide population have symptomatic and radiographic disease, with the prevalence increasing with age and plateauing beyond 50 years [2]. Critically, there is currently no cure for knee OA with Osteoarthritis Research Society International (OARSI) guidelines for non-surgical management recommending exercise, weight management and non-steroidal anti-inflammatory drugs [3,4]. While such treatment protocols may serve to slow the progression of the disease, and allow for better pain management for sufferers, there are instances where surgical intervention is unavoidable. However, when considering surgical intervention, it is important to consider the osteoarthritic burden on the patient in terms of pain and symptoms but also functional status [5].

While total knee replacement surgery is clinically effective, with symptomatic improvement exceeding 85% [6,7], it is considered a fallback option for patients under 50 due to its finite lifespan and higher risk of revision [8,9], and is not employed for patients with mild-moderate knee OA [10]. Given the reluctance to intervene surgically upon first signs of osteoarthritic disability it is important to track disease progression from a radiological, symptomatic and functional standpoint. Previous studies have shown gait analysis to provide a valuable objective measure of knee function for OA sufferers, assessing both temporospatial [11] and kinematic parameters [12,13]. However, such motion capture systems are expensive and not readily available, thus it is necessary to consider alternative solutions for assessing joint function in people with knee OA.

Previous studies have identified a range of performance-based tests

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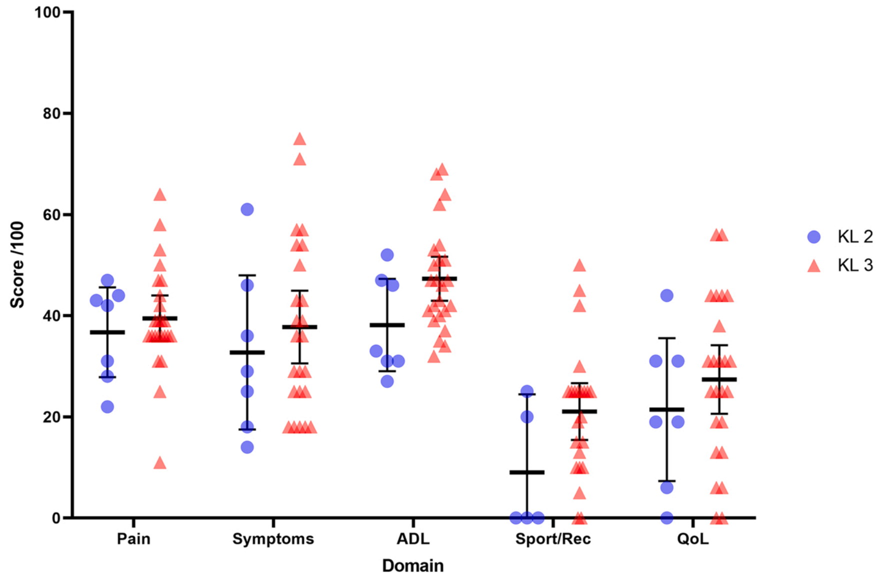

Fig. 1. Individual scores for each KOOS domain with mean and 95% confidence interval, participants separated based on KL grading. Circles represent KL Grade 2 and triangles KL Grade 3.

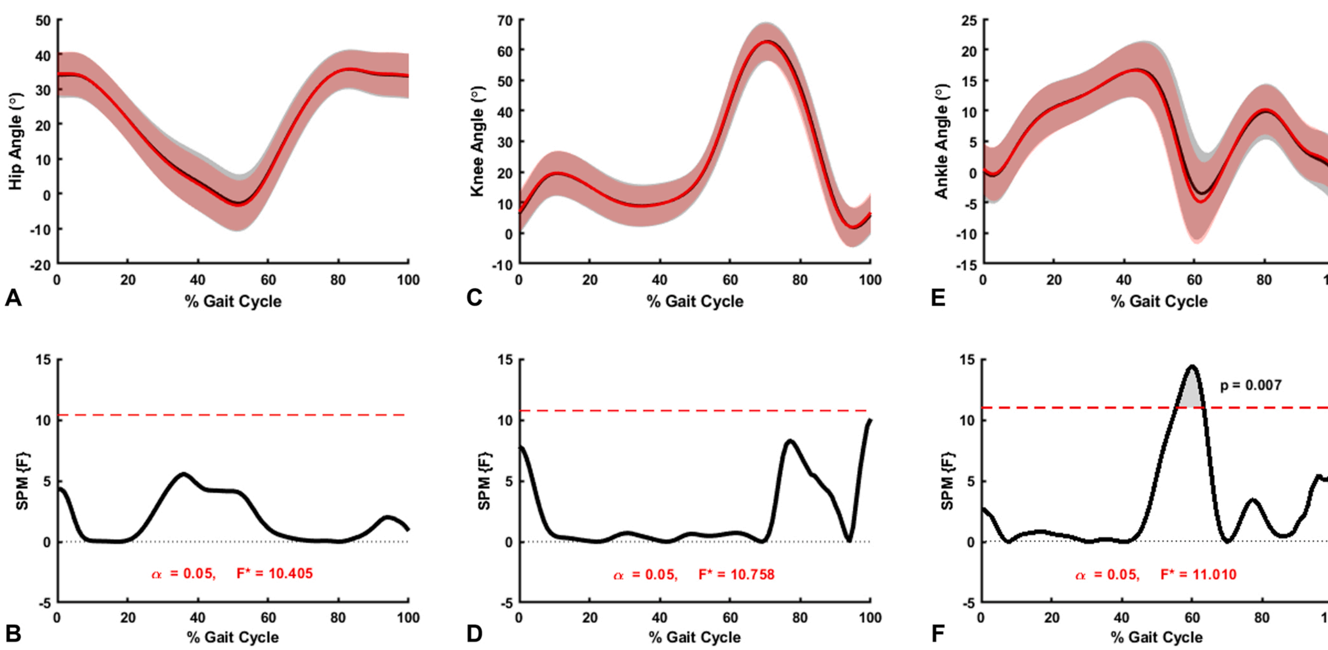

Fig. 2. A, C, E – Mean and standard deviation for hip (A), knee (C) and ankle (E) angles during the first (red) and last (black) minute of the 6MWT. B, D, F – The repeated measures ANOVA test statistic SPM{F} for the within-subjects analysis. At the ankle, the critical threshold F* = 11.010 was exceeded at the supra-threshold cluster between 57% and 64% with p = 0.007, indicating more plantarflexion within stance phase during the first minute of the 6MWT.

of physical function that can evaluate what individuals are truly capable of as opposed to what their perceived capabilities are [14]. OARSI recommendations have identified the 6-minute walk test (6MWT) to be a strong measure for assessing physical function in people with knee OA [14,15]. However, when considering the implementation of such a test it is important to consider the metabolic cost to the participant associated with performance. Gait adaptations associated with knee OA often generate less mechanically efficient movement patterns [16,17], which in turn increases the metabolic cost associated with walking, thereby exacerbating fatigue [18]. As a time-limited test, the 6-minute walk enables the participant to adopt a comfortable walking speed ensuring they can sustain their effort and complete the test without fatiguing metabolically [19]. Previous research assessing those with moderate knee OA found that during a 6-minute treadmill familiarization task there were minimal changes to knee biomechanics [20]. Similarly, research assessing multiple sclerosis sufferers has suggested the 6MWT is of insufficient length to elicit biomechanical changes, although was suitable to discern reduction in overall walking distance against a healthy cohort [21]. While research within an osteoarthritic population has assessed knee function over the course of six minutes [20], such work has only evaluated performance for treadmill walking, this does not allow for a formal assessment of walking distance as a metric to measure physical function due to the designation of belt speed prior to testing. Furthermore, given the inherent differences between treadmill and overground walking [22] it would seem necessary that if aiming to implement an overground 6-minute walk assessment it is necessary to

Table 1
Walking speed and kinematic parameters for the first and last minute of the six-minute walk test.

	First Minute Mean (SD)	Last Minute Mean (SD)	Effect Size (Cohen's *d*)	P-value
Walking Speed (m/s)	1.24 (0.24)	1.21 (0.25)	0.34	0.071
Hip ROM (°)	41 (6)	40 (6)	0.43	0.024
Knee ROM (°)	62 (8)	63 (8)	-0.23	0.211
Ankle ROM (°)	25 (4)	24 (4)	0.26	0.161
Max Knee Flexion (°)	63 (6)	63 (6)	-0.16	0.374
Min Knee Flexion (°)	1 (6)	1 (6)	0.15	0.409

ROM – Range of motion.

initially assess participant performance in such an environment. Therefore, the aim of this study was to investigate if lower limb sagittal plane kinematics changed during a 6MWT in patients with mild-moderate knee OA. We hypothesized that lower limb joint kinematics would remain stable over the course of the 6MWT. Furthermore, given the commonality with which patient self-reported outcomes are utilized both clinically and within the literature as a measure of disease progression, as a secondary aim we assessed correlations between patient self-reported outcomes and objective measures of physical function (joint range of motion and walking distance).

2. Methods

2.1. Participants and protocol

Participants with knee OA were recruited prospectively as part of a multicentre clinical research trial (trial registration: NCT04124042) investigating a new treatment for knee osteoarthritis. The data for this study is taken from the baseline (pre-intervention) assessments. The multicentre trial had a target sample size of 270 participants with our site being the only one to collect functional outcomes incorporating gait analysis. No formal sample size calculation was performed for our analysis.

At our site, participants were recruited between May 2020 and March 2021 and were eligible if they (1) were between 45 and 85 years old; (2) had radiographic tibiofemoral OA defined as Kellgren-Lawrence (KL) grade 2–3; and (3) had a BMI < 40 kg/m^2. In participants where both knees were eligible, measurements were taken only on the most symptomatic knee, as designated by the participant. Prior to completing the gait assessment each participant completed the Knee injury Osteoarthritis Outcome Score (KOOS) [23] which is a patient reported outcome measure specifically designed to assess knee pathologies. Ethics approval was granted by the Central Adelaide Local Health Network (CALHN) Human Research Ethics Committee (CALHN reference: R20191105). All participants provided informed written consent.

2.2. Gait analysis

Gait data were collected in a single testing session during which participants were required to complete a 6-minute walk test [14]. Participants completed the 6MWT around a marked course of dimensions 9 × 1 m, requiring four turns to complete a full 20 m lap (Supplementary Figure 1). Over this course a total capture volume of 5 m in length was utilised to record walking gait using a 10-camera Vicon Vantage system (Vicon, Oxford, UK) and two AMTI force platforms (Advanced Medical Technology Inc., Watertown, MA) sampling at 100 Hz and 2000 Hz, respectively. Thirty-eight retro-reflective markers were placed on anatomical landmarks of the pelvis and lower limbs to define the joints along with four rigid clusters attached to the thighs and shanks [24]. Marker trajectories were reconstructed using Vicon Nexus (V2.12, Vicon, Oxford, UK).

Kinematic analysis of the data was undertaken in Visual3D (V6, C-Motion Inc., Germantown, MD, USA). The kinematic model consisted of seven segments (pelvis, thighs, lower legs and feet) with three rotational degrees-of-freedom (DoF) at the hip, one rotational DoF at the knee and three rotational DoF at the ankle. Marker trajectories and ground reaction forces were low-pass filtered using a zero-lag 2nd order Butterworth filter with cut-off frequencies of 6 Hz and 50 Hz, respectively. Force platforms were used for initial heel strike event detection with a kinematic-based approach [25] using pattern recognition applied thereafter to identify those strikes outside of the platform range. Inverse kinematics were used to reconstruct model motion from the gait data and joint angles were calculated as Euler angles using ISB recommendations [26]. Joint angles for the hip, knee and ankle along with walking speed were determined for the first and last minute of the 6MWT. Joint angles were resampled to 101 data points for each gait cycle for the affected limb. In measuring performance of the affected limb within the first and last minute, three consecutive gait cycles for each of the first, and final, two laps of the course were reconstructed, thereby accounting for a total of twelve gait cycles for each participant to be used for the statistical analysis.

2.3. Statistical analysis

Statistical analyses were performed in MATLAB (R2020a, The Mathworks Inc, USA) and SPSS (V27, IBM, New York, USA). Normality was assessed using Q-Q plots. To compare joint kinematics between the first and last minute, a repeated measures ANOVA was implemented in MATLAB using SPM1D [27] to determine if there was a difference in sagittal plane joint angles for the hip, knee and ankle across the entire gait cycle. This was completed by analysing twelve, time-normalised gait cycles for each participant (six from each of the first and last minute), where individual changes are determined before calculating group statistics for the first and last minute of the 6MWT. Significance was set at $\alpha = 0.05$. Sphericity corrections were not applied, and equal variance was assumed. The SPM repeated measures ANOVA calculates the traditional F statistic for the within-subjects analysis, subsequently referred to as SPM{F} over the entire normalized time series. The SPM analysis comprised the following steps. (1) Computation of the test statistic, SPM{F}, for the complete time series. (2) Estimation of the temporal smoothness of the data based on the average temporal gradient. (3) Calculation of the critical threshold F^* using random field theory, this is the threshold above which only 5% of the data would be expected to reach had the test statistic trajectory resulted from an equally smooth random process. (4) Computation of probability values for each "supra-threshold cluster". For instances where there were multiple consecutive points crossing the critical threshold, a "supra-threshold cluster" was identified and a cluster-specific p-value was calculated using random field theory [28].

To determine if walking speed and lower limb joint range of motion (ROM) changed between the first and last minute of the 6MWT, a paired samples t-test was performed using SPSS. Statistical significance was set at $\alpha = 0.05$. The level of significance for pairwise comparisons was adjusted with a Bonferroni correction accounting for multiple comparisons (α adjusted to 0.008). Data are presented as the mean and standard deviation for the first and last minute along with the effect size (Cohen's *d*). Joint ROM was calculated for each participant across the entire gait cycle and a group mean taken for the first and last minute of the 6MWT.

Finally, a two-tailed bivariate Pearson correlation was used to compare scores from KOOS domains with walking distances achieved and total knee ROM, along with the change in walking speed and knee ROM during the first and last minute of the 6MWT.

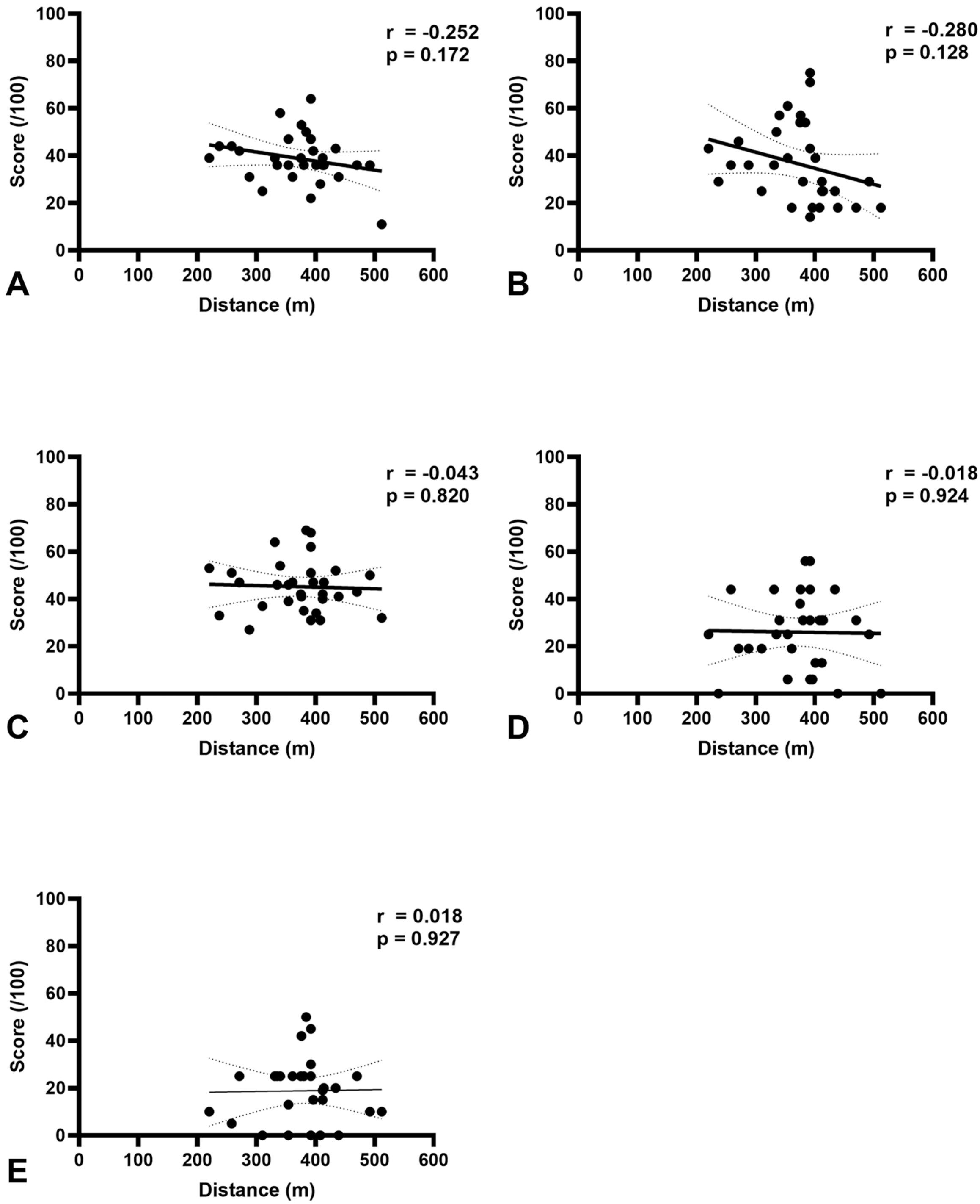

Fig. 3. Pearson correlation between KOOS domains (Pain, Symptoms, ADL, QoL and Sport/Rec) and distance walked during 6MWT. A – Pain. B – Symptoms. C – ADL. D – QoL. E – Sport/Rec. The line of best fit and 95% confidence interval are presented for each dataset.

3. Results

Thirty-one participants (18 M/13 F) were included in this analysis with a mean age 62.9 ± 8.4 years, height 1.71 ± 0.10 m, body mass 90 ± 18.5 kg and body mass index 30.7 ± 4.42 kg/m^2. Radiographic severity of knee OA was graded using the KL scale (Grade 2 = 7, Grade 3 = 24). The mean walking distance during the 6MWT was 372 ± 69 m. Mean KOOS domains, separated based on KL grading, are presented within Fig. 1. Participants categorized as KL grade 3 had a greater mean score for each KOOS domain relative to participants graded as KL 2 (Fig. 1).

3.1. Joint kinematics and patient self-reported outcomes

Joint angles averaged across participants, for the first and last minute of the 6MWT, are presented in Fig. 2. Mean joint angles at the hip and knee were similar for the entirety of the first and last minute of the 6MWT, not exceeding the critical threshold in either case (Fig. 2A-D). A single supra-threshold cluster was identified for the ankle (57–64%), exceeding the critical threshold of F = 11.010 (p = 0.007) and indicating there to be more plantarflexion at the ankle in the first minute of the 6 MW (Fig. 2F). However, these angles measured less than 1.5° in each instance and were therefore considered to be within the potential

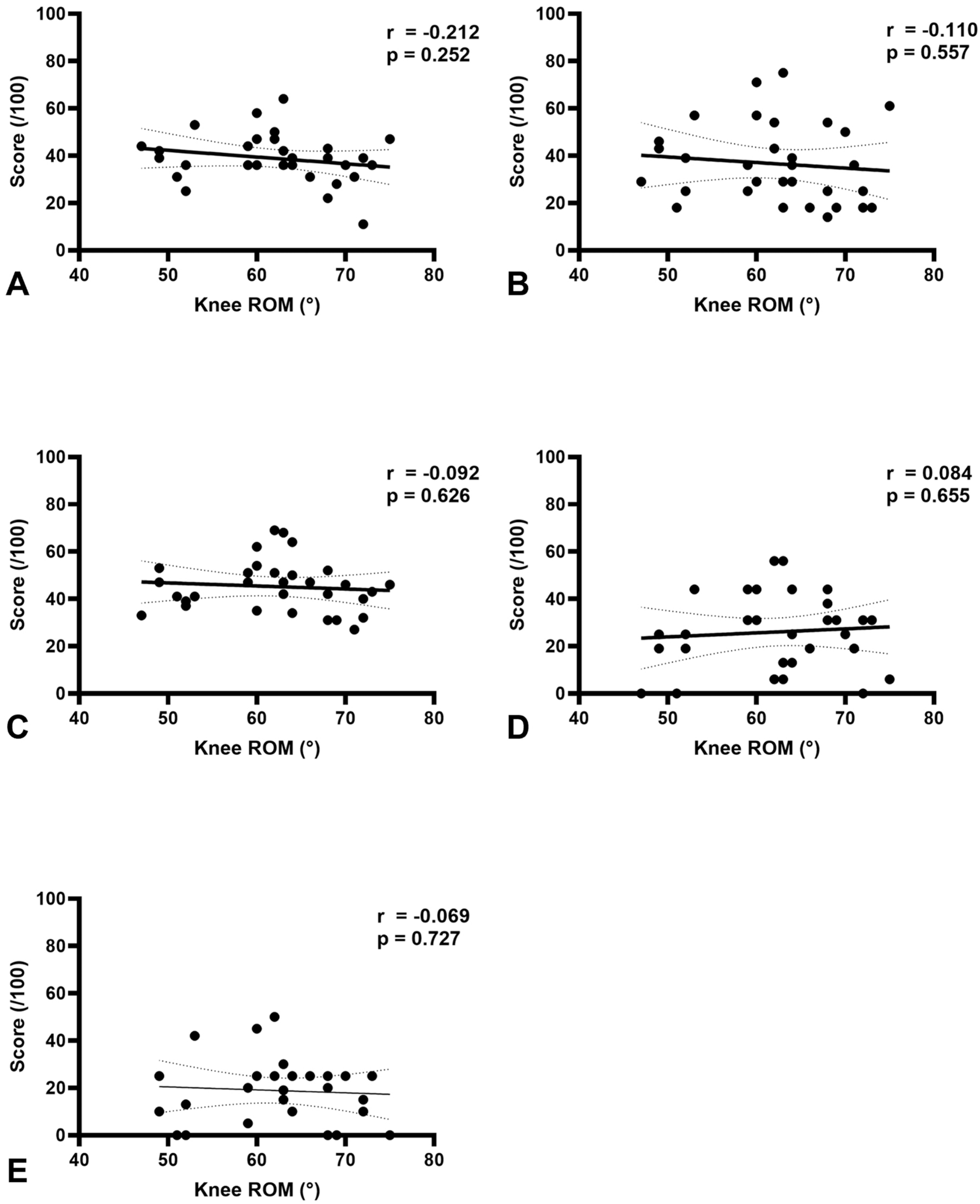

Fig. 4. Pearson correlation between KOOS domains (Pain, Symptoms, ADL, QoL and Sport/Rec) and knee range of motion (first minute) during 6MWT. A – Pain. B – Symptoms. C – ADL. D – QoL. E – Sport/Rec. The line of best fit and 95% confidence interval are presented for each dataset.

measurement error (Fig. 2E).

Walking speed showed no significant difference ($p = 0.071$) between the first and last minute of the 6MWT (Table 1). Similarly, there were no significant differences in joint ROM at the hip, knee or ankle at the start and end of the 6MWT (Table 1). Additionally, ROM changes grouped by KL grading showed consistency between groups (Supplementary Figure 2). However, this was not considered a formal outcome measure due to the limitations associated with sample size in the KL 2 group ($n = 7$).

There were no correlations between KOOS domains and distance walked during the 6MWT (Fig. 3) or total knee ROM (Fig. 4). However, when considering the change in knee ROM between the first and last minute there was a statistically significant ($p < 0.05$) association for domains; Pain, Symptoms, ADL and Sport/Rec (Fig. 5). Specifically, those participants indicating a lower score across KOOS domains displayed an increase in joint ROM between the first and last minute of the test (Fig. 5). Conversely, those with a higher score across domains showed a decrease in joint ROM over the course of the 6MWT (Fig. 5).

4. Discussion

Our study aimed to evaluate the use of a six-minute walk test as an

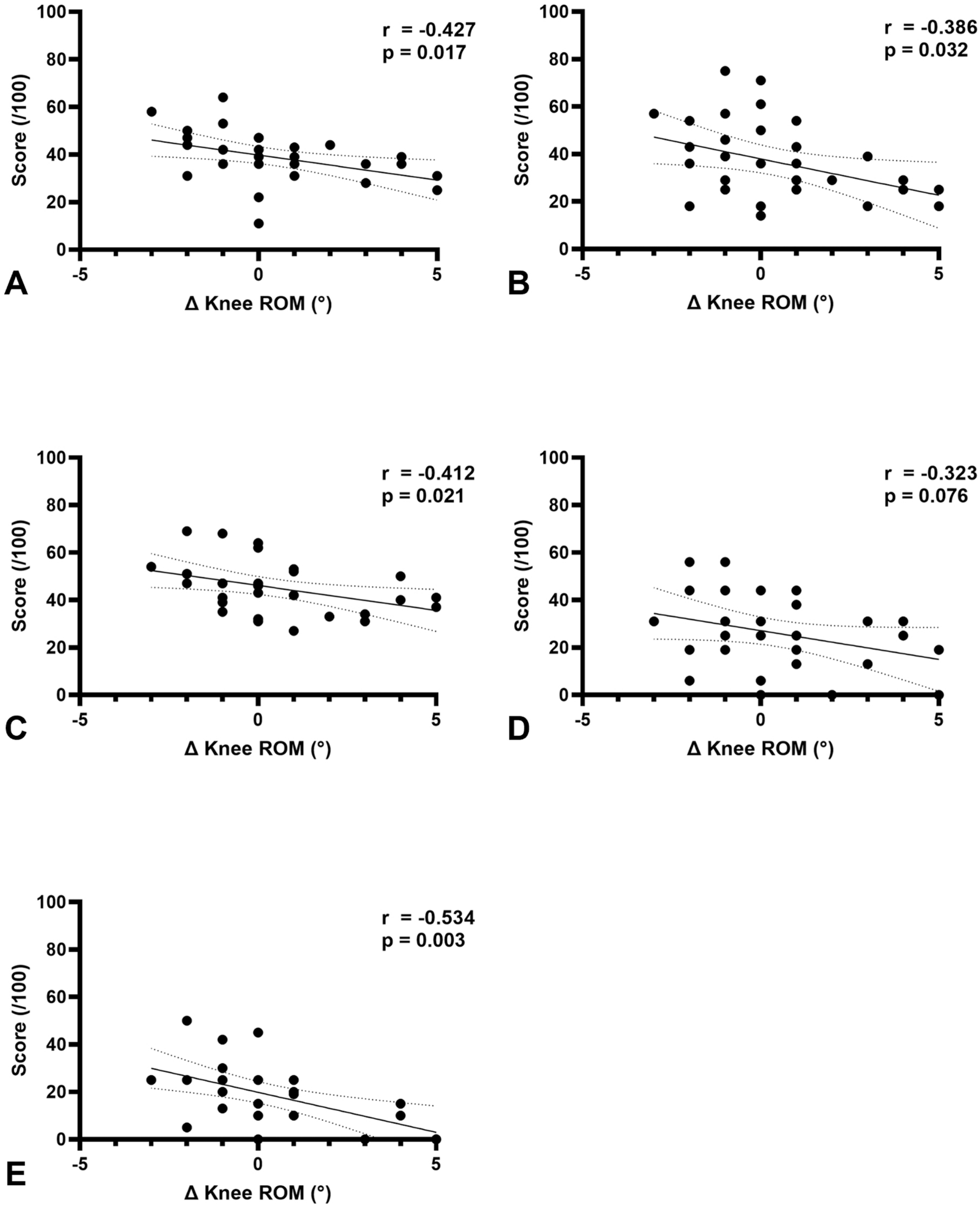

Fig. 5. Pearson correlation between KOOS domains (Pain, Symptoms, ADL, QoL and Sport/Rec) and change in knee range of motion during 6MWT. A – Pain. B – Symptoms. C – ADL. D – QoL. E – Sport/Rec. The line of best fit and 95% confidence interval are presented for each dataset.

indicator of physical function for knee OA sufferers through evaluating changes in lower limb joint kinematics over the course of the test. In doing this, we assessed sagittal plane joint angles for the hip, knee and ankle within the first and last minute of the 6MWT to evaluate consistency. There were no differences measured for hip and knee kinematics across the gait cycle. A statistically significant difference was measured between 57% and 64% of the gait cycle for ankle kinematics, although such measures equated to less than 1.5° and were deemed to be within the potential measurement error of the system [29]. Given the similarities in joint angles for the hip, knee and ankle it was shown that the participants retained consistency in their walking gait across the six-minute period. Similarly, walking speed showed minimal difference (0.03 m/s) within the first and last minute of the test, indicating participants retained consistency in walking speed over the course of the test.

Previous research has identified alterations in walking speed [30,31] and knee joint kinematics [32,33] to be indicative of osteoarthritic severity across individuals. Therefore, when considering the implementation of a physical performance test to assess function, it is important for such a test to limit fatigue related mechanical changes and acute pain which would likely inhibit peak performance. The consistencies in walking speed and kinematics identified in this study suggest the timing and execution of the 6MWT to be suitable to restrict the impact of fatigue and exercise induced pain on physical performance, supporting the findings of previous studies indicating the relative fatigue burden of a 6MWT to be insufficient to provoke kinematic changes to walking gait [21]. Thus, the implementation of such a test can provide clinicians a means to objectively assess patient disability along with the ability to monitor changes in physical function over time. The findings from this study align well with similar work assessing function for those with mild-moderate knee OA in terms of walking speed [34,35], although the total knee joint ROM measured in our study is greater than that previously reported [20,36]. However, when evaluating patient disability, it is important to consider aspects of health relating to both the physical functioning of the patient along with more subjective measures of function – assessing pain, symptomatic burden, and quality of life.

Within this study, patient self-reported outcome measures were assessed using the KOOS questionnaire. When looking at associations between 6MWT distance and knee ROM with scores across KOOS domains for Pain, Symptoms, Activities of Daily Living and Quality of Life there were no significant correlations identified. This is potentially influenced by relatively minor differences in pain and symptomatic burden between mild-moderate stage OA [37], making it difficult to truly discern any functional or mechanical discrepancies between the two stages. Given the significant range in pain and symptoms between mild and severe knee OA [34,37–39], it is plausible to consider that the inclusion of more severe cases may in fact show more degenerative functional changes in walking distance and knee ROM. However, KOOS metrics measured within this study align more closely with those considered to have severe knee OA based on KL grading [20,34], suggesting that radiographic severity and subjective measures of function may not align perfectly and may be subject to inherent day-to-day variability in pain and symptoms for the sufferer.

While previous research has identified significant differences across patient self-reported outcome measures along with functional gait characteristics, such differences have been most identifiable when comparing asymptomatic or moderately symptomatic knees to more severe cases [30–32], which were not assessed in this study. However, when considering knee joint ROM over the course of the 6MWT the data presented here suggests there to be a significant association between change in knee ROM and KOOS domain. The results here indicate a negative correlation between KOOS domain and change in knee joint ROM, however, the majority of these changes fall within $\pm 3^{\circ}$ and should therefore be interpreted with caution. Given the disparity in KOOS scores and KL grading presented within this study, along with the associations identified between change in joint ROM and KOOS domains, it is plausible to suggest that the inclusion of functional metrics such as 6MWT performance may allow for greater agreement as to the stage of disease burden experienced by the individual through truly assessing their physical capability in a normal activity of daily living.

The results presented here have identified the 6MWT to be a suitable performance test to assess functionality in knee OA sufferers, however, there are some limitations. Firstly, this study focused only on those with mild or moderate knee OA (KL grade 2 or 3), identifying no differences in locomotion across the duration of the six minutes. However, there is potential that more severe cases (KL grade 4) may exhibit alterations in the gait cycle across the 6MWT due to the likelihood that the knee has degenerated to a greater extent. Secondly, due to the timed nature of the 6MWT, there is a learning effect for participants to ensure they pace themselves to retain walking speed for the duration of the test and maximize the distance walked. Given the importance of ensuring maximal effort to attain an appropriate measure of disability, it seems pertinent that such an assessment be performed on more than a single occasion when aiming to establish a baseline measure of function. Finally, in testing the proposed hypothesis, the authors application of the Bonferroni correction makes it more challenging to prove that there were no significant differences between time points. However, when coupling the measurement error of the system with the joint angles for the hip, knee and ankle having an absolute difference of 1° is it unlikely that any measurable difference was calculated between the first and last minute of the 6MWT.

5. Conclusion

Due to the progressive nature of OA, identification of a performance test capable of limiting sessional fatigue or pain related mechanical changes could be invaluable in assessing functional regression associated with knee OA and supplement patient self-reported outcome measures. Study results show no significant difference in lower limb range of motion and walking speed between the first and last minute of the 6MWT. Similarly, joint angles for the hip and knee remained consistent across the entirety of the gait cycle indicating retention of kinematics throughout the full six-minute period. Future work should be focused longitudinally to investigate if any relationships exist between patient self-reported outcome measures and gait performance to determine if long-term functional deficits are also indicative of increased pain or symptomatic burden.

Author contributions statement

SCM, KB, MR and DT were involved in the conception and implementation of the research, collection of data, analysis of results and writing of the final manuscript. All authors have read and approved the final submitted manuscript.

Declarations of interest

none.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2023.02.004.

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