Between-limb kinematic asymmetry during gait in unilateral and bilateral mild-to-moderate knee osteoarthritis

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Running Title: Between limb asymmetry in knee osteoarthritis

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We certify that no party having a direct interest in the result of the research supporting this article has or will confer a benefit on us or on any organization with which we are associated and, we certify that all financial and material support for this research and work are clearly identified in the title page of the manuscript.

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Title: Between-limb kinematic asymmetry during gait in unilateral and bilateral mild-to-
moderate knee osteoarthritis

Abstract

Objective: To compare between lower-limb kinematic asymmetries during gait in individuals
with unilateral and bilateral symptomatic osteoarthritis and controls.

Design: Cross-sectional

Setting: Laboratory

Participants: Participants had symptomatic unilateral (n=18) or bilateral (n=18) knee
osteoarthritis. Healthy controls were gender- and age-matched and similar in height and weight
to osteoarthritis groups (n=18).

Intervention: 3-dimensional motion analysis was conducted while participants walked on a
treadmill at 1.1m/sec.

Main Outcome Measures: Maximum joint angles and velocities of the knee and hip during
stance, knee flexion, knee adduction and hip adduction at initial contact, pelvic drop, stride
length and average toe-out.

Results: There was a significant “limb” effect for knee flexion at initial contact (p=0.01). The
bilateral osteoarthritis group demonstrated the largest between-limb asymmetry (2.83° (95% CI
0.88 to 4.78) ES 0.67). The bilateral osteoarthritis group also displayed tendencies towards
between-limb asymmetry in hip adduction at initial contact and peak knee adduction during
stance, effect sizes were small (ES 0.33 and 0.48). Lower limb kinematics were symmetrical in
the control and unilateral knee osteoarthritis groups.
Conclusion: Between-limb asymmetries are present even at mild-to-moderate stages of knee osteoarthritis. During this stage, between-limb asymmetry appears to be more prevalent in patients with bilateral symptomatic disease suggesting that patients with unilateral disease maintain kinematic symmetry for longer into the knee OA process. Further, early treatment strategies should target the restoration of gait symmetry and involve kinematics changes in both lower limbs. Future research is needed to determine the efficacy of such strategies with respect to kinematic asymmetry, pain and disease progression.

Keywords
Osteoarthritis, Biomechanics, Knee, Walking

Abbreviations
Osteoarthritis (OA), Three-dimensional (3D), Effect size (ES) Knee Osteoarthritis Outcome Survey (KOOS), Activities of Daily Living (ADL), Quality of Life (QoL), Visual analogue scale (VAS), Initial contact (IC)
Osteoarthritis (OA) is a non-random progressive joint disease occurring when damaged joint
tissues are unable to repair themselves normally resulting in a breakdown of bone and
cartilage.\textsuperscript{1,2} OA is a major source of disability in the adult population and the knee is the most
commonly affected weight bearing joint.\textsuperscript{3} It is widely accepted that knee OA is associated with
altered frontal and sagittal plane kinematics and kinetics during gait.\textsuperscript{4-7} Over the past decade,
particular interest has been paid to the external knee adduction moment due to its correlation
with medial knee load and knee OA progression.\textsuperscript{8,9} However, numerous studies have reported no
increase in the external knee adduction in their knee OA cohorts, regardless of the severity of
diagnosis.\textsuperscript{7,10,11} Authors postulate that the external knee adduction moment, and consequently
medial knee load, may be attenuated by a range of kinematic adaptations – such as increased toe-
out, stride length, hip abduction and hip internal rotation and altered knee flexion angle at initial
contact. In contrast, other kinematic gait adaptations (such as pelvic drop, increased knee
adduction and decreased knee flexion during stance) have been reported to be more prevalent in
individuals with severe knee OA and may contribute to knee OA progression.\textsuperscript{11-13} Moreover,
these kinematic adaptations have been hypothesized to place greater loads on the contralateral
limb due to unequal load distribution, which may increase the risk of developing OA in other
weight bearing joints.\textsuperscript{4} Therefore, due to their potential influence on knee OA progression,
further research into kinematic adaptations during gait is warranted.

The majority of gait studies involving individuals with knee OA have only investigated the
involved limb, or the most symptomatic limb in the case of bilateral knee OA. Therefore, while
the effect of OA on the ‘affected’ knee is well substantiated, there is a dearth of information
regarding the effect of symptomatic OA on the contralateral knee, specifically, in the context of
asymmetry. Between-limb asymmetry, defined as the lower limbs exhibiting different biomechanical patterns,\textsuperscript{14} is a conceivable consequence of the gait alteration associated with knee OA and numerous asymmetries have been observed in several knee OA cohorts.\textsuperscript{4,15,16} Briem et al\textsuperscript{4} hypothesized such asymmetries could have important consequences in the development of multi-articular lower limb OA. Recently, Creaby et al\textsuperscript{16} reported between-limb asymmetry to be limited to individuals with unilateral knee OA, as those with bilateral disease displayed altered lower limb biomechanics in both limbs. However, to date, all studies investigating lower limb asymmetry have included more severe stages of knee OA (i.e., Kellgren-Lawrence grades $\geq 3$). Thus the treatment strategies they suggest are largely palliative and have not addressed early-stage OA patients. Hunter\textsuperscript{17} has recently called for a paradigm shift in OA management towards early intervention. As gait alterations have been observed even at mild stages of the disease,\textsuperscript{7} examining the presence and magnitude of between-limb asymmetries in mild-to-moderate unilateral and bilateral OA may provide further insight into how to structure early rehabilitation protocols to slow the progression of the disease process.

Symmetrical movement between homologous body segments is controversial, even in healthy individuals. Sadeghi et al\textsuperscript{14} argued that asymmetry reflects a normal functional difference relating to the contribution of each limb to propulsion and control. In an early study of asymmetry between individuals with knee OA and healthy age- and gender-matched control participants, Messier et al\textsuperscript{6} reported significant between-limb differences in knee range of motion occurring in both groups and concluded that asymmetries during gait are present to some extent among older persons in general. This observation was supported by Karamandis et al\textsuperscript{18} who found knee angular velocity to be significantly asymmetrical between limbs of healthy
runners. However, recent studies reporting on healthy individuals, over a range of ages, exhibit predominantly symmetrical gait patterns.\textsuperscript{16,19} 

The purpose of this study, therefore, was to compare between-limb kinematic asymmetries of the pelvis, hip and knee as well as temporospatial variables between healthy controls and individuals with mild-to-moderate symptomatic unilateral and bilateral knee OA. We expected both healthy controls and bilateral knee OA individuals would exhibit symmetrical gait patterns, but hypothesised that bilateral knee OA would have compromised lower limb kinematics bilaterally compared with healthy controls. Subsequently our second hypothesis was that gait asymmetries would be more prevalent in the unilateral OA group as compared with the bilateral group.

Methods

Participants

Fifty-four participants were recruited from the local Calgary community between 2009 and 2011. Eighteen participants were diagnosed with unilateral symptomatic knee OA, 18 were diagnosed with bilateral symptomatic knee OA and 18 were healthy controls. There was gender matching amongst groups (n=18, males=5, females=13). All participants were >40 years of age, had a BMI of <33kg/m\textsuperscript{2}, were able to walk without assistive devices and did not have any physical or medical condition for which the testing protocol would be contra-indicated.

Participants were included in the OA groups if they met the American College of Rheumatology clinical criteria for mild-to-moderate knee OA.\textsuperscript{20} In addition, OA participants were required to have recent posterioanterior or skyline radiographs confirming the presence of knee OA, a
Kellgren-Lawrence score <3 and knee pain >20 mm on a 100 mm visual analog scale (VAS) on most days of the previous week. For participants to be included in the bilateral group these criteria had to be met for both knees, although their most symptomatic limb was the designated ‘affected limb’. Knee OA participants were excluded if they (1) were diagnosed with severe knee OA (K-L grade >3), (2) were currently undertaking physiotherapy or other conservative management practices, including corticosteroid injections, (3) had taken oral corticosteroids or anti-inflammatory drugs in the 24 hours prior to testing, (4) had undergone, or were scheduled to undergo, joint preservation surgery or total joint arthroplasty, (5) had evidence of OA in any other weight bearing joint or (6) had systemic arthritic conditions.

Control participants were healthy individuals with no signs or symptoms of knee OA. These controls did not undergo radiographic examination but did not meet any of the American College of Rheumatology criteria. The affected limbs for the control group were matched to corresponding limbs of the unilateral group. Ethics approval was obtained from the University of Calgary Conjoint Health Research Ethics Board and all participants provided written informed consent. Prior to gait analysis, all OA participants indicated their average pain over the past week on a 100 mm VAS and completed the Knee Osteoarthritis Outcome Survey (KOOS). The KOOS consists of 5 subscales measuring symptoms, pain, activities of daily living (ADL), sport and recreation and quality of life (QoL). Scores for each subscale are from 0 to 100 with higher scores indicating fewer problems.
Three-dimensional (3D) lower limb kinematics were collected while participants walked on a treadmill at 1.1 m/s wearing standard laboratory shoes (Pegasus). All participants were experienced treadmill users and were permitted as much time as they required to familiarize themselves with treadmill walking. Kinematic data were collected at 120 Hz using an 8-camera VICON motion capture system and 9 mm retro-reflective markers as described by Pohl et al. Three markers, glued to a rigid plastic shell, were attached to the pelvis over the sacrum with self-adhering straps. Similarly, four rigid plastic shells with four retro-reflective markers each were attached to the posterior aspect of thighs and shanks bilaterally. Three markers were taped to the heel counter of each of the test shoes. These twenty-five markers represented seven rigid segments. Two markers individually placed on the anterior aspect of each shoe were used for used for detecting toe-off events. An additional 14 markers were temporarily attached to anatomical landmarks during a neutral standing trial to identify joint centre locations and to calculate the segment coordinate systems. These landmarks included the greater trochanters, medial and lateral knee joint lines, medial and lateral malleoli, 1st metatarsal heads, and 5th metatarsal heads bilaterally. This marker set has been reported to produce highly reliable kinematic waveforms. Data were analyzed in MATLAB. After marker trajectories were filtered with a 10 Hz low-pass 2nd order recursive Butterworth filter, 3D rigid body kinematics were calculated using a single value decomposition approach outlined by Söderkvist and Wedin and the Joint Coordinate System suggested by Cole et al.

Data Management

The average values of kinematic and temporospatial variables over 10 consecutive strides (from initial contact to ipsilateral heel contact) were analysed for each limb. Temporospatial variables
were stride length and average toe out from early to mid stance. Maximum joint angles and
velocities of the knee (flexion, adduction and internal rotation, flexion velocity, abduction
velocity and internal rotation velocity) and hip (extension, adduction, internal rotation, abduction
velocity and internal rotation velocity) during stance were extracted from kinematic data as were
peak pelvic drop, knee adduction at IC, knee flexion at IC and hip adduction at IC. These
variables were chosen based on previous studies of between limb asymmetry.\textsuperscript{4,6,16,24}

Additionally, anatomical joint marker data from the neutral standing trial were used to determine
frontal plane knee alignment (varus/valgus alignment). Marker based lower limb alignment has
been reported to have high correlation with mechanical axis alignment.\textsuperscript{25}

Data Analysis

Statistical analysis was conducted in SPSS (version 19).\textsuperscript{5} Between-limb asymmetry was
examined using a mixed model analysis of variance (ANOVA) with group (unilateral, bilateral
and control) and limb (affected, non-affected) as main effects. ANOVA results are presented as
the test statistic (Wilk’s Lambda $\Lambda$), F-statistic and significance level (p-value). Significant
(p<0.05) and near significant (p<0.1) main effects and interactions were followed with univariate
tests with Bonferroni corrections. Univariate tests are presented as mean differences, 95%
confidence intervals and effect sizes (ES = mean difference/pooled standard deviation). ES was
referenced to Hopkins’ system as trivial (<0.2), small (0.2 to 0.6), moderate (0.61 to 1.2) and
large (>1.2).\textsuperscript{26} Confidence intervals that did not include zero on univariate interaction tests were
considered indicative of asymmetry.\textsuperscript{16}

Results
Demographic characteristics of participants, stratified by group, are shown in table 1. All groups were similar in age, height and weight (p >0.05). The unilateral and bilateral OA knee groups were also similar in pain and all KOOS domains (p>0.05). All groups exhibited similar alignment. Although OA participants had medial compartment involvement, the majority of OA participants had multiple compartments involved (Table 2).

There were no significant main effects for group, indicating that there were no differences in magnitude of variables between unilateral OA, bilateral OA and controls. A significant main effect for limb was found for knee flexion at IC (Λ = 0.912, F= 4.84, p=0.032), and near significant limb effects for peak hip abduction velocity and peak knee internal rotation (Table 3). At IC, the affected limb exhibited 1.51° (95% CI 0.1 to 2.2) greater flexion than the non-affected limb regardless of group allocation, which corresponded to a small effect (ES 0.43). Significant interactions were also present for knee flexion at IC (Λ = 0.831, F= 5.069, p=0.01) and peak hip internal rotation velocity (Λ = 0.848, F= 4.109, p=0.023). In both instance, the bilateral OA group exhibited significant asymmetry, with the more symptomatic limb exhibiting moderately more (2.83° (0.88 to 4.78) ES 0.67) knee flexion at IC and moderately slower internal rotation velocity (-19.52°/sec (-35.45 to -3.59) ES 0.63) than the less-symptomatic limb. For the unilateral OA group, there was a trend for the affected knee to be more flexed than the non-affected limb (1.76° (-0.05 to 3.57) ES 0.45) (Figure 1).

Investigation of group*limb interactions revealed the bilateral OA group exhibited greater prevalence of asymmetry and tendencies towards asymmetry than the control and unilateral OA groups. At IC, the more symptomatic limb of bilateral group exhibited a tendency to be less
adducted at the hip (-1.09° (-2.39 to 0.22)) as well as exhibiting a tendency towards greater peak knee adduction during stance (1.7° (-0.1 to 3.5)) compared with their less symptomatic limb (Figure 1). However, the effect sizes of these findings were small (ES 0.33 and 0.48 respectively). The 95% confidence intervals of control and unilateral group data included zero for all interactions, indicating no between-limb asymmetries evident during gait (Figure 1).

Discussion

Several studies have examined between-limb asymmetries of individuals with knee OA, indicating that numerous kinematic asymmetries occur between the affected and non-affected limbs. However, all of the aforementioned investigations have included individuals with moderate and severe knee OA with varus malalignment. Therefore our data provides novel evidence that gait asymmetries are evident even at milder stages of the disease and in individuals with similar mechanical alignment to healthy controls.

Interestingly, our data illustrate that between-limb kinematic asymmetries during walking were more prevalent in individuals with bilateral mild-to-moderate knee OA. Further, the less symptomatic limb in the bilateral OA group exhibited kinematic variables of the same magnitude as those observed by healthy controls. These findings are in direct contrast to the findings of Creaby et al, who included more progressed stages of OA, and our hypothesis that individuals with bilateral OA would exhibit compromised gait kinematics in both limbs. This may be due to attempts of individuals with early knee OA to unload their more painful limb. It has been suggested that increased hip abduction and knee flexion at IC reflect attempts to stabilize the knee and shift the centre of mass laterally in order to unload the knee joint and decrease
pain. However, altered load distribution in one lower extremity has been hypothesized to have significant effects on joint loading in the contralateral limb and increase the risk of multi-articular OA progression. We do, however, advise caution in interpreting this finding as, despite being a systematic change, the magnitude of asymmetry observed for hip adduction did not exceed published mean differences in joint angles and could potentially reflect measurement error.

In contrast, the trend towards between-limb asymmetry in peak knee adduction during stance might indicate focal areas of load in the medial tibiofemoral compartment of the more painful limb. This asymmetry has been observed in individuals with more severe knee OA and could reflect an increased risk of OA progression in the more symptomatic limb. As such, between-limb asymmetries exhibited by individuals with mild-to-moderate bilateral knee OA may have adverse longer-term consequences for both the symptomatic and contralateral knee in terms of increased pain and disease progression. This may explain why individuals with more severe bilateral disease than the current study exhibit symmetrically altered kinematics. It also suggests that individuals with mild-to-moderate knee OA may benefit from early rehabilitation strategies targeted towards restoring or sustaining between-limb symmetry. This may be accomplished by encouraging bilateral adoption of gait strategies that unload the medial compartment (e.g., increased hip abduction, lateral trunk lean or medial thrust gait) or decreasing the magnitude of knee adduction during stance in the more symptomatic limb. Further research is needed to determine the efficacy of treatment strategies, which involve both limbs, on the presence of asymmetry, pain and bilateral disease progression.
An additional between-limb asymmetry observed in this study was a moderate reduction of hip internal rotation velocity in the more symptomatic limb of the individuals with bilateral diagnosis. Velocity of motion is seldom examined in knee OA cohorts, however, transverse plane variables have been identified as important differentiators between individuals with knee OA and controls. Increased hip internal rotation has been advocated as a component of a successful gait strategy to reduce medial knee joint load. Changes in transverse plane moments have been postulated to alter toe-out angle. It may be that decreased hip internal rotation velocity also alters the timing or duration of toe-out during stance – which were not measured in this study. Therefore further investigation into the implications of decreased hip internal rotation velocity is warranted.

Our second hypothesis, that gait kinematic asymmetries would be more prevalent in the unilateral OA group, was not supported by our findings. The 95% confidence intervals from the unilateral group included zero for all of the kinematic interactions examined in this study. This would indicate that individuals with mild-to-moderate unilateral knee OA walked with relatively symmetrical gait patterns that were similar to our healthy controls with respect to the variables examined. Previous studies that include individuals with more severe knee OA diagnosis demonstrate that significant between-limb asymmetry is present in those with unilateral disease. The prevalence and magnitude of kinematic adaptations in individuals with knee OA, including variables examined in this study, increases with increasing severity of the disease. Due to the non-random progression of knee OA, this would suggest that the occurrence of asymmetry in unilateral knee OA cohorts is inevitable. However, the findings from our study indicate that those with unilateral disease maintain symmetry for longer into the OA
process than those with bilateral disease. Further, the incidence of between-limb asymmetries in individuals with unilateral knee OA may be an important clinical marker of disease progression.

In addition to disease progression, this study builds on current evidence, which highlight that other factors also influence the presence and magnitude of between-limb asymmetries. Previous studies investigating between-limb asymmetry in knee OA have only included participants with medial compartment involvement and varus lower-limb malalignment. In the current study, the majority of OA participants had multiple compartments involved and exhibited alignment similar to healthy controls. The magnitude and direction of lower kinematic changes associated with knee OA, particularly in the frontal plane, greatly differ depending on the compartment involved. As forces across the knee are transmitted more through the medial compartment while walking, and to an even greater extent in the presence of genu varus, individuals with medial compartment OA and varus malalignment may be more susceptible to between-limb asymmetries than other knee OA profiles. Further research is needed to compare this subpopulation with a more generalized knee OA cohort as was included in this study.

Study limitations

Due to the lack of radiographic data for control subjects, we are unable to rule out articular degeneration in this group. However, the control subjects did not meet any of the American College of Rheumatology criteria for knee OA and exhibited symmetry between limbs for all variables examined. A further limitation of this study is that posterioranterior radiographs were not available for all OA participants, consequently frontal plane knee alignment was calculated from anatomical joint marker data during the neutral standing trial. Hunt et al demonstrated...
that marker-based alignment and mechanical axis alignment were highly correlated but not identical and this needs to be considered when interpreting our data. Regardless, our OA participants exhibited the same alignment as our healthy controls compared with former studies (e.g. 15,16) where OA participants and controls significantly differed. Finally, the cross-sectional nature of this study means that we are unable to comment on the relationship between between-limb asymmetries and the progression of knee OA. Future longitudinal studies are required to further examine this relationship.

Conclusions

This is the first study to compare between-limb kinematic asymmetries during walking between individuals with unilateral and bilateral mild-to-moderate knee OA. Our data demonstrated that asymmetries were more prevalent in those with bilateral disease, occurring at the hip and the knee. The magnitudes of between-limb asymmetries observed were small to moderate. Individuals with unilateral disease were not only symmetrical between-limbs, the magnitude of joint angles were similar to that of healthy controls. These findings suggest that individuals with unilateral disease maintain kinematic symmetry further into the knee OA process than those with bilateral disease. They also suggest that in mild-to-moderate stages of knee OA, individuals may benefit from treatments targeted at restoring or maintaining kinematic asymmetry during gait, which in the case of those with bilateral disease, may include treating both the more and less symptomatic limb.
References


11. Hunt MA, Wrigley TV, Hinman RS, Bennell KL. Individuals with severe knee osteoarthritis (OA) exhibit altered proximal walking mechanics compared with individuals with less severe OA and those without knee pain. Arthritis Care Res. 2010;62:1426–32.


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<table>
<thead>
<tr>
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<th></th>
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</thead>
<tbody>
<tr>
<td>27.</td>
<td>Hunt MA, Birmingham TB, Giffin JR, Jenkyn TR. Associations among knee adduction moment, frontal plane ground reaction force, and lever arm during walking in patients</td>
</tr>
</tbody>
</table>


Figure caption

Mean differences (solid shapes) between symptomatic and non/less symptomatic limb and 95% confidence intervals (error bars) for significant and near significant kinematic variables. Positive values indicate greater values in the more symptomatic limb. Abbreviations: Degrees (deg), Degrees per second (deg/sec)

Suppliers

a Bertec Corporation, 6171 Huntley Road, Suite J, Columbus, OH 43229, USA
b Nike, 1 Bowerman Drive, Beaverton OR, 97005, USA
c Vicon, Oxford Metrics, 14 Minns Business Park, West Way, Oxford OX2 0HB, UK
d MathWorks, 3 Apple Hill Drive, Natick, MA, 01760-2098, USA
e IBM Corp, 1 New Orchard Road, Armonk, NY, 10504-1722, USA
Table 1: Participant demographics and clinical measures (mean and SD)

<table>
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<tr>
<th>Characteristic</th>
<th>Unilateral</th>
<th>Bilateral</th>
<th>Control</th>
<th>Sig*</th>
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<tr>
<td>Females/males</td>
<td>13/5</td>
<td>13/5</td>
<td>13/5</td>
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<tr>
<td>Age (years)</td>
<td>53.11 (7.23)</td>
<td>54.61 (7.84)</td>
<td>52.53 (10.81)</td>
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<tr>
<td>Height (m)</td>
<td>1.69 (0.98)</td>
<td>1.67 (0.10)</td>
<td>1.67 (0.85)</td>
<td>0.794</td>
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<td>Weight (kg)</td>
<td>72.28 (10.71)</td>
<td>72.35 (11.39)</td>
<td>67.89 (9.56)</td>
<td>0.373</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>25.7 (1.88)</td>
<td>25.17 (2.84)</td>
<td>24.34 (2.66)</td>
<td>0.195</td>
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<tr>
<td>Pain†</td>
<td>4.33 (2.05)</td>
<td>4.18 (1.9)</td>
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<td>0.816</td>
</tr>
<tr>
<td>KOOS</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Symptoms</td>
<td>69.75 (17.17)</td>
<td>70.91 (14.3)</td>
<td>n/a</td>
<td>0.83</td>
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<td>Pain</td>
<td>65.12 (18.31)</td>
<td>60.78 (14.59)</td>
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<td>0.445</td>
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<td>ADL</td>
<td>76.71 (20.71)</td>
<td>72.31 (17.42)</td>
<td>n/a</td>
<td>0.503</td>
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<tr>
<td>Sport and Rec</td>
<td>49.69 (26.04)</td>
<td>41.43 (23.07)</td>
<td>n/a</td>
<td>0.369</td>
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<tr>
<td>QoL</td>
<td>36.18 (18.43)</td>
<td>34.19 (19.53)</td>
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<td>0.686</td>
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<tr>
<td>Alignment‡</td>
<td>181.03° (4.91)</td>
<td>180.76° (3.44)</td>
<td>180.44° (3.87)</td>
<td></td>
</tr>
</tbody>
</table>

* Comparisons between unilateral, bilateral and control groups for age, height and weight. All other comparisons between unilateral and bilateral groups
† Measured on a 100 visual analogue scale, 100= worse pain imaginable
‡ Measured using knee joint centre relative to the hip and ankle calculated from the neutral standing trial
Table 3: Mixed Model ANOVA tests for kinematic variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Limb</th>
<th>Group*Limb</th>
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<tbody>
<tr>
<td></td>
<td>F (df)</td>
<td>Sig</td>
<td>Wilk’s Λ</td>
</tr>
<tr>
<td>Knee flexion at IC</td>
<td>1.696 (2)</td>
<td>0.194</td>
<td>0.912</td>
</tr>
<tr>
<td>Knee adduction at IC</td>
<td>0.657 (2)</td>
<td>0.523</td>
<td>0.998</td>
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<tr>
<td>Hip adduction at IC</td>
<td>1.715 (2)</td>
<td>0.19</td>
<td>0.997</td>
</tr>
<tr>
<td>Peak knee flexion</td>
<td>0.967 (2)</td>
<td>0.387</td>
<td>0.968</td>
</tr>
<tr>
<td>Peak knee adduction</td>
<td>0.206 (2)</td>
<td>0.815</td>
<td>0.98</td>
</tr>
<tr>
<td>Peak knee internal rotation</td>
<td>0.421 (2)</td>
<td>0.659</td>
<td>0.936</td>
</tr>
<tr>
<td>Knee peak flexion velocity</td>
<td>0.422 (2)</td>
<td>0.658</td>
<td>0.97</td>
</tr>
<tr>
<td>Knee peak abduction velocity</td>
<td>1.344 (2)</td>
<td>0.27</td>
<td>0.999</td>
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<td>Knee peak internal rotation velocity</td>
<td>0.474 (2)</td>
<td>0.625</td>
<td>0.987</td>
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<tr>
<td>Peak hip extension</td>
<td>0.815 (2)</td>
<td>0.448</td>
<td>0.999</td>
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<td>Peak hip adduction</td>
<td>0.378 (2)</td>
<td>0.687</td>
<td>0.986</td>
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<tr>
<td>Peak hip internal rotation</td>
<td>1.46 (2)</td>
<td>0.242</td>
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<tr>
<td>Peak hip abduction velocity</td>
<td>0.073 (2)</td>
<td>0.930</td>
<td>0.927</td>
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<tr>
<td>Peak hip internal rotation velocity</td>
<td>1.459 (2)</td>
<td>0.243</td>
<td>0.969</td>
</tr>
<tr>
<td>Pelvic drop</td>
<td>0.811 (2)</td>
<td>0.421</td>
<td>0.989</td>
</tr>
<tr>
<td>Average toe out</td>
<td>0.126 (2)</td>
<td>0.882</td>
<td>0.954</td>
</tr>
<tr>
<td>Stride length</td>
<td>0.112 (2)</td>
<td>0.895</td>
<td>0.956</td>
</tr>
</tbody>
</table>

Velocity measured in degrees per second. Peak magnitudes are measured during stance.
Table 2: Distribution of knee OA participants affected compartments

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Unilateral knee OA (n=18)</th>
<th>Bilateral knee OA (n=18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Medial and patellofemoral</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Medial and lateral</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Tri-compartmental</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>