Published in final edited form as:

Gait Posture. 2012 January ; 35(1): 6–10. doi:10.1016/j.gaitpost.2011.07.012.

STRATEGIES USED DURING A CHALLENGING WEIGHTED WALKING TASK IN HEALTHY ADULTS AND INDIVIDUALS WITH KNEE OSTEOARTHRITIS

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Abstract

Knee osteoarthritis (OA) is a disease that affects millions of people. While numerous gait differences have been identified between healthy adults and adults with knee OA under normal and challenging conditions, adults with knee OA have not been studied during a challenging weighted walking task. Investigation of the effect of weighted walking on the initial contact and loading response phases of gait was undertaken in 20 healthy and 20 knee OA subjects ages 40–85 years old walking at 1.0 m/s while unweighted and weighted with 1/6th of their body weight in a weight vest. Subjects were grouped according to their Kellgren and Lawrence radiographic score and healthy subjects were age-matched to those with knee OA. ANOVA revealed significant effects for hip flexion angle at initial contact, step length, initial double support percent, and load rate. Post-hoc t-tests revealed subjects with knee OA had a larger initial double support percent and hip flexion angle at initial contact and a decreased load rate compared to unweighted, healthy adults. Also, both groups increased their initial double support percent in response to the challenging weighted walking task, but only the healthy adults increased their hip flexion angle at initial contact and decreased their load rate. During the weighted condition, the knee OA group had a shorter step length compared to the healthy group. Because the knee OA group only made minor compensations to their gait strategy, it appears that they may be unable or prefer not to adjust their gait mechanics due to underlying issues.

Keywords

Weight Vest; Osteoarthritis; Knee; Challenge; Gait

INTRODUCTION

Knee osteoarthritis (OA) affects approximately 27 million adults in the United States and 25% of the population aged 25–74 [1]. The effects of knee OA can impact economic [2], social [3], psychological [4], physical [5], and functional [6] aspects of life. Biomechanical changes that occur in a person's gait pattern may lead to further progression of the disease [7,8]. The knee adduction moment during gait has been the focus of much scrutiny because of its relation specifically to medial joint loading [9,10]. Joint loading has been hypothesized to be the driving factor in the incidence and progression of knee OA [7].

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Using challenging conditions to impose increased demand on the neuromusculoskeletal system can be beneficial to understanding movement strategies especially in an impaired population. Individuals with knee OA have been studied while walking quickly [11,12], negotiating stairs [13], and crossing an obstacle [14]. Challenging these individuals to a task that is more strenuous than their normal activities of daily living can uncover underlying movement impairments which otherwise would not be seen and may help researchers discover underlying impairments to target with therapeutic intervention. For example, when subjects with knee OA are challenged to walk up stairs, severe knee OA subjects exhibit significant forward trunk lean, that would not be present during level walking, and requires adjustments to their hip and knee flexion moments to compensate for weak quadriceps [13] which may be addressed with strength training.

When healthy, young adults are subjected to load carrying, they respond with decreased single support, increased initial double support, and decreased swing with little other effects on sagittal plane motion during stance [15,16]. There is also an increased metabolic demand and load rate as the percent of body weight carried is increased [17]. In other studies, older adults have used a weighted vest for exercise purposes [for example, 18]. Salem and colleagues [18] found that the kinetic effects of various weight vest loads were joint specific and load dependent. In their study, when the load was increased from 0% body weight to 3% body weight, there was only an increase in the peak external knee flexion moment, but comparing 0% body weight to 5% body weight, there was a significant increase in the peak external ankle dorsiflexion moment and knee flexion moment during the stance phase of gait [18].

The relationship between joint loading and knee OA [19,20] and the change in knee kinematics during weight acceptance in normal walking [21,22,23] leads us to believe there may be important strategies employed during loading which can influence the disease process. However, biomechanics during a challenging weighted walking condition have not been compared in healthy adults and adults with knee OA. The added load during a weighted condition will increase the forces on the lower extremity and may decrease the weight-bearing stability, possibly leading to compensatory biomechanical strategies. Therefore the objective of this study was to compare these strategies in individuals with knee OA and age-matched, healthy adults during the initial contact and loading response phases of gait.

METHODS

Subjects between the ages of 40 and 85 years old were recruited and if they met our inclusion and exclusion criteria (Table 1) had a radiograph taken while standing with their toes pointed forward, knees flexed to 30 degrees, and weight equally distributed between the feet. The tibiofemoral joint in all radiographs was evaluated using the Kellgren and Lawrence scale [K/L; 24] by a board certified radiologist and the knee OA group consisted of those subjects who had a K/L score of 2, while the healthy group consisted of those subjects who were age-matched to the knee OA group and had a K/L score of 1. Twenty subjects were used for each group based on an a priori power analysis of dependent variables (found in Table 3).

Each subject received a full explanation of the study including the risks of participation and provided written informed consent. This study was approved by the University of Delaware Human Subjects Review Board.

Subjects completed the Knee Injury and Osteoarthritis Outcome Survey (KOOS) which is a subjective questionnaire that has 5 subsections asking about symptoms, pain, activities of

daily living, sports and recreation, and quality of life [25]. An isometric strength test was used to estimate knee flexor and extensor strength for each subject. Measurements were taken on a Biodex Systems 3 (Biodex Medical Systems, Shirley, NY, USA) dynamometer using a 60 degree isometric knee flexion and extension protocol. Each subject sat with the thigh and hips secured in the Biodex chair and performed three 3 second bouts of isometric muscle contractions for each muscle group with 20 seconds of rest in between. During the active muscle contraction, verbal encouragement was provided in order to maximize the force output.

Self-selected walking speed was measured over the middle 10m of a 30m segment of a hallway. Two walking passes were made and timed by a stopwatch. The average time was then used to determine the subject's self-selected walking speed in meters per second.

Gait data were collected with an 8 camera Motion Analysis system (Santa Rosa, CA) and an instrumented split-belt treadmill (Bertec Corporation, Worthington, OH). The kinematic data were collected at 60 Hz and the kinetics at 1080 Hz (EvaRT 5.0.4 and Cortex 1.0.0.198; Motion Analysis Corp., Santa Rosa, CA). A static standing trial was collected using 27 markers. Before any walking trials were completed, we removed the markers bilaterally from the medial knees and ankles and allowed the subjects 6 minutes of accommodation time [26] at their self-selected speed only for the unweighted condition. After accommodation, two 30 second walking trials at 1.0 m/s unweighted and while wearing a weighted vest were collected.

For the weighted condition, a front and back loaded weight vest (MiR Vest, Inc., San Jose, CA, USA) was used. The vest was placed over the head of each subject and an elastic strap was used to secure it. The weight was added to the trunk so as to allow unimpeded motion of the lower extremity during gait. One static trial on a single forceplate imbedded into the split-belt treadmill (Bertec Corporation, Worthington, OH) was used to get the most accurate weight of each subject while unweighted. The weight for the challenging condition was added in 2lbs increments until closest to 1/6th body weight and verified on the forceplate. This weight was moderately heavy for most subjects and was selected to pose a challenge but not completely disrupt gait. Subjects had no acclimatization time in the vest and walked with the weighted vest until two 30 second walking trials at 1.0 m/s had been completed.

Inverse dynamics were computed in Orthotrak 6.3.5 (Motion Analysis Corp., Santa Rosa, CA). From sequential gait cycles for each subject's 30 second walking trial, the final five full gait cycles on each leg were extracted and averaged into one representative gait cycle for each subject normalized to 100% of the gait cycle. The peak kinematic and kinetic values were taken from the averaged trial but the spatiotemporal parameters were calculated from the last 5 gait cycles and averaged. For the knee OA group, only data from the more severely affected limb is reported and random legs were chosen for the healthy group.

A two-way repeated measures analysis of variance (ANOVA) was performed in SPSS 17.0 (SPSS Inc., Chicago, IL) to determine the effect of knee OA and the weighted condition on walking patterns. The independent variables were group (Healthy or Knee OA) and condition (Unweighted or Weighted). The dependent variables were ankle, knee and hip flexion angles at initial contact, knee flexion excursion, step length, load rate, peak braking force, peak hip and knee flexion moments and initial double limb support. We also tested for an interaction effect to analyze the differences between the changes of each group due to the additional weight (Group*Condition). Significance was set at $p < 0.05$. If significance was found with the two-way repeated measures ANOVA, then two-tailed, paired t-tests were done within groups and two-tailed, student's t-tests were done between groups to find

exactly where the difference was occurring. Significance for the t-tests was also set at $p < 0.05$.

RESULTS

The subjects in our study were grouped according to their K/L score from a flexed knee radiograph and the healthy group was age-matched to the knee OA group (Table 2). The knee OA group had a higher weight ($p = 0.001$), increased BMI ($p < 0.001$), decreased isometric knee flexor ($p = 0.003$) and extensor strength ($p = 0.001$), decreased self-selected walking speed ($p = 0.006$), and poorer reported KOOS scores regarding their pain ($p < 0.001$) and symptoms ($p < 0.001$). There was no significant difference between the age ($p = 0.713$) and height ($p = 0.976$) of the two groups. Specific to our study, the percent which each subject was weighted was significantly different ($p = 0.002$), but the overall weight put on each subject was not ($p = 0.087$).

The hip flexion angle at initial contact (Table 3, Figure 1A) showed a significant effect for condition ($p = 0.001$), and post-hoc tests revealed that only the healthy group ($p < 0.001$) increased their hip flexion angle at initial contact in response to the load while the knee OA group did not ($p = 0.225$). The effect of group ($p = 0.051$) was not significant nor was there a significant interaction effect for group*condition ($p = 0.138$).

The step length data (Table 3, Figure 1B) showed no significant differences for condition ($p = 0.525$) or for the group*condition effect ($p = 0.530$). There was a significant difference for the group effect ($p = 0.025$). Post-hoc analysis revealed that there was no significant difference between the healthy and knee OA groups in the unweighted condition ($p = 0.272$), but the knee OA group had a shorter step length compared to healthy in the weighted condition ($p = 0.027$).

The ANOVA yielded a main effect of condition ($p < 0.001$) with both the healthy ($p < 0.001$) and knee OA ($p = 0.018$) groups showing a larger percent of gait in initial double support during the weighted condition compared to themselves during the unweighted condition (Table 3, Figure 1C). There was also a main effect of group ($p = 0.002$), and post-hoc t-tests also showed a significant difference between the groups in both conditions (unweighted $p = 0.002$; weighted $p = 0.027$) with the knee OA group having a significantly longer initial double support percent in both conditions. No group*condition effect ($p = 0.216$) was observed.

Load rate (Table 3, Figure 1D) showed no significant difference in the ANOVA model for condition ($p = 0.057$), but there was a significant difference for the group ($p = 0.038$) and group*condition interaction effects ($p = 0.043$). Between group differences existed during the unweighted condition ($p = 0.009$) with the knee OA group having a lower load rate than their healthy, age-matched counterparts, but there was no statistical difference between groups during the weighted condition ($p = 0.211$).

DISCUSSION

The knee OA subjects were heavier, with higher BMI, increased pain and symptoms, and decreased isometric knee flexor and extensor strength on their more affected limb which is consistent with previous studies [22, 27]. Also, consistent with reports that knee OA subjects compensate for pain and loading by decreasing walking speed [for example, 28], our knee OA group had a slower self-selected walking speed. However, when walking unweighted at a control speed of 1.0 m/s, their load rate was less than healthy, age-matched adults.

The current results also reveal an increased hip flexion angle at initial contact, due to both an increase in the pelvic tilt and an increase in the thigh flexion calculated post-hoc, and increased initial double support percent with the more affected limb forward in the unweighted knee OA group and the weighted healthy group compared to the unweighted healthy group. A recent study of young healthy soldiers has shown an increase in hip range of motion under a load that is roughly 20% of their body weight [29]. We did not report range of motion in our study, but the healthy group did increase their hip flexion angle at initial contact in response to roughly 15% of their body weight while the knee OA subjects did not. The increase in motion at the hip seen in soldiers [29] could be the best available and preferred response to walking under a loaded condition. This strategy may have been implemented by the healthy group but was not selected by the knee OA group possibly because they already use this compensation due to their increased body weight compared to healthy adults.

When the healthy group was weighted, they more closely resembled the unweighted knee OA group in terms of BMI and gait parameters including initial double support percent, hip flexion at initial contact and load rate. The increase in initial double support percent has been seen in older adult populations who have a fear of falling [30] and could be in response to decreased stability. The decreased load rate is contrary to previous studies involving young adults during weighted walking tasks [15], but may be due to our normalization of the kinetics to the weight of the person plus the vest during the weighted condition.

The knee OA group increased their initial double support percent when weighted, and they had a significantly smaller step length compared to the weighted healthy group. Similar to the weighted healthy group, the weighted knee OA group could be increasing their initial double support percent for stability reasons. The smaller step length could be a result of pain potentially induced during the challenging task which may have caused the knee OA subjects to modify their walking pattern.

While undergoing this challenging weighted walking task, the healthy adults responded with different biomechanics during the weight acceptance phase of gait. The results suggest that the control strategy responsible for reduced load rate (as employed by healthy adults) was either not available to or not preferred by individuals with knee OA and this limited compensatory strategy could potentially be a factor contributing to disease progression. Also, there may be some underlying limitations present in knee OA subjects, namely decreased relative strength, that prevented them from changing some of their gait mechanics when challenged. Knee OA subjects are forced to use a higher percent of their peak isometric force during normal and challenged walking which could limit the compensations they can make in these conditions. Altered neuromuscular control resulting in enhanced co-contraction and stiffness in knee OA subjects [31,32] may further explain the limited range of compensatory strategies observed.

Although using a controlled speed of 1.0 m/s allowed for a better statistical comparison, walking at a speed slower than normal could have influenced the results. In addition, because we wanted to explore global group differences in compensatory strategies for weighted walking, we chose not to match by gender or weight. Consequently, there was a higher percentage of women in the knee OA group than healthy group which could influence the results. Body weight was not matched but rather accounted for through normalization. Furthermore, we did not have an equivalent relative weighted condition due to the limitations of our weight vest (i.e., 2lbs increments). As a result, the changes seen may be related to absolute weight added which was slightly but not significantly higher for OA subjects. Future studies might also consider using varying levels of challenging weighted walking conditions as only one weight was added in this study and may not have provided

the optimal scenario for investigating compensations. It is possible that the knee OA subjects prefer to keep their gait pattern consistent even under a weighted condition because of an innate control preference underlying a desire to decrease pain and increase function. Subjective measures of pain were not recorded in this study and could suggest possible motives for selected compensatory strategies.

Overall, the knee OA group did not respond the same way as the healthy adults to the weighted condition. The healthy adults responded to the challenging weighted walking condition by reducing load rate, and increasing initial double support percent and hip flexion angle at initial contact while the knee OA group only prolonged their initial double support percent. These significant findings lead us to believe that individuals with knee OA are performing close to capacity during unweighted walking and that only subtle compensatory strategies are employed when challenged.

Acknowledgments

We gratefully acknowledge the input of Katherine Rudolph, Kurt Manal and Stephen Messier to the thesis on which this manuscript is based. Additionally, we would like to acknowledge Joe Zeni, Jr. for his assistance during data collections. Funding provided by NIH P20-RR16458.

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Figure 1.

(A) Hip flexion angle at initial contact. The y-axis represents the positive hip flexion angle in degrees ($^{\circ}$). The weighted, healthy group and the unweighted, knee OA group had a significantly larger hip flexion angle at initial contact compared to the unweighted, healthy group. (B) Step length with the more affected limb forward. The y-axis is the length of the step in centimeters (cm). The weighted, knee OA group had a significantly shorter step length compared to the weighted, healthy group. (C) Initial double limb support percent with the more affected limb forward. The y-axis is the percent (%) of the gait cycle (out of 100%) that the subject is in double limb support with their more affected limb forward. The weighted, healthy group and the unweighted, knee OA group had a significantly longer double support percent compared to the unweighted, healthy group. Also, the weighted, healthy group and the unweighted, knee OA group had significantly shorter double support percent compared to the weighted, knee OA group. (D) Load rate, or the slope of the vertical GRF curve between heel strike and the 1st peak in vertical GRF. The y-axis is the change in force normalized to the subject's weight divided by the change in time (N/kg/s). The weighted, healthy group and the unweighted, knee OA group had a significantly lower load rate compared to the unweighted, healthy group. Data are shown with mean $\pm$ one standard deviation. Brackets indicate statistically significant differences where $p < 0.05$. Results are presented for four groups: 1) black = unweighted, healthy group; 2) white = weighted, healthy group; 3) gray = unweighted, knee OA group; and 4) stripes = weighted, knee OA group.

Table 1

The inclusion and exclusion criteria for subjects used in our study. These criteria were formed in order to have an age group representative of the general knee OA population, however those subjects with other medical comorbidities were excluded so that the results were easier to interpret. Subjects were excluded if they were not physically capable of performing the challenges in the study or had previous or current cardiovascular, orthopaedic, or neurologic issues.

<p>Inclusion</p> <ul style="list-style-type: none"> • Age: 40–85 • BMI: < 40 • Ambulatory (including those who use a cane or a walker) • Able to walk for 5 minutes at self-selected speed • Able to walk up to 2 × 30 second bursts at fastest tolerable speed on treadmill without assistance.
<p>Exclusion</p> <ul style="list-style-type: none"> • Congestive heart failure • Any other heart problems or heart murmur • Peripheral artery disease with claudication • Cancer • Pulmonary or renal failure • Unstable angina • Uncontrolled hypertension (> 190/110 mmHg) • Dizziness &/or neurological disorder (stroke, Parkinson's, etc.) • Pregnancy • Joint replacement or pacemaker with metallic parts • OA due to significant bony deformity • ACL deficient knees • Diagnosed arthritis of other lower extremity joints • Any reason why they should not exert themselves physically • Other orthopaedic condition affecting ambulation • If answers YES to 2 of these: <ul style="list-style-type: none"> – Smokes – Diabetes – Family history of heart disease prior to age 55 – Unmedicated high cholesterol • Joint injections within 6 months • Lower extremity surgical procedure that would affect ambulation

Table 2

The table shows a comparison of general subject characteristics. Data is presented as mean $\pm$ one standard deviation. An asterisk denotes a significant difference between the groups.

General Subject Characteristics		
	Healthy	Knee OA
Number	20	20
Percent Female (%)	60.0	70.0
Age (years)	63.6 $\pm$ 10.0	62.45 $\pm$ 8.73
Height (m)	1.69 $\pm$ 0.08	1.69 $\pm$ 0.10
Weight (kg) *	70.6 $\pm$ 12.9	86.8 $\pm$ 15.4
BMI (kg/m ²) *	24.7 $\pm$ 3.60	30.5 $\pm$ 4.31
Weighted BMI (kg/m ²)	29.1 $\pm$ 4.03	35.3 $\pm$ 4.82
Quadriceps Strength (Nm/kg) *	1.81 $\pm$ 0.42	1.31 $\pm$ 0.50
Hamstring Strength (Nm/kg) *	1.02 $\pm$ 0.32	0.73 $\pm$ 0.24
Self-Selected Walking (m/s) *	1.32 $\pm$ 0.17	1.17 $\pm$ 0.13
KOOS Pain *	97.5 $\pm$ 4.82	65.8 $\pm$ 23.0
KOOS Symptoms *	96.8 $\pm$ 3.93	63.9 $\pm$ 24.9
Percent Weighted (%) *	17.8 $\pm$ 2.18	15.9 $\pm$ 1.42
Amount Weighted (kg)	12.49 $\pm$ 2.09	13.70 $\pm$ 2.27

*
p = 0.05

Table 3

This table displays all the variables that were analyzed during this study. The values are shown as mean $\pm$ one standard deviation. Significance during post-hoc t-tests is denoted by letters representing which group the comparison took place between ([a] unweighted healthy, [b] weighted healthy, [c] unweighted knee OA, [d] weighted knee OA). Significance was set at $p < 0.05$.

Gait Variables	Unweighted Healthy	Weighted Healthy	Unweighted Knee OA	Weighted Knee OA
Ankle Dorsiflexion Angle at Initial Contact (degrees)	1.04 $\pm$ 3.08	1.21 $\pm$ 2.44	2.27 $\pm$ 4.14	2.13 $\pm$ 4.68
Knee Flexion Angle at Initial Contact (degrees)	3.35 $\pm$ 6.74	3.73 $\pm$ 6.88	6.12 $\pm$ 10.10	6.89 $\pm$ 10.14
Hip Flexion Angle at Initial Contact (degrees)	27.37 $\pm$ 6.89 ^b	29.27 $\pm$ 7.35 ^a	33.29 $\pm$ 9.61	34.08 $\pm$ 9.81
Step Length (cm)	45.58 $\pm$ 3.60	45.58 $\pm$ 3.60 ^d	42.30 $\pm$ 6.41	41.82 $\pm$ 5.42 ^b
Initial Double Support Percent (percent)	13.92 $\pm$ 1.22 ^{b,c}	15.20 $\pm$ 1.32 ^{a,d}	15.89 $\pm$ 2.22 ^{a,d}	16.72 $\pm$ 2.02 ^{b,c}
Peak Braking Force (N/kg)	-0.14 $\pm$ 0.02	-0.13 $\pm$ 0.01	-0.14 $\pm$ 0.03	-0.14 $\pm$ 0.03
Peak External Hip Flexion Moment (Nm/kg)	0.53 $\pm$ 0.13	0.52 $\pm$ 0.09	0.60 $\pm$ 0.18	0.56 $\pm$ 0.21
Peak External Knee Flexion Moment (Nm/kg)	0.41 $\pm$ 0.15	0.38 $\pm$ 0.14	0.38 $\pm$ 0.17	0.39 $\pm$ 0.19
Knee Flexion Excursion (degrees)	13.34 $\pm$ 4.50	13.41 $\pm$ 5.54	12.06 $\pm$ 4.47	11.82 $\pm$ 4.61
Load Rate (N/kg/s)	7.23 $\pm$ 1.71 ^c	6.65 $\pm$ 1.16	6.09 $\pm$ 1.01 ^a	6.11 $\pm$ 1.50

^aSignificant difference compared to Unweighted Healthy

^bSignificant difference compared to Weighted Healthy

^cSignificant difference compared to Unweighted Knee OA

^dSignificant difference compared to Weighted Knee OA