# Impact of Total Knee Arthroplasty on Dynamic Fall Response

by

Estefania Meza

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved July 2019 by the
Graduate Supervisory Committee:

Claire Honeycutt, Chair
William Andrew Hodge
Thurmon E. Lockhart

ARIZONA STATE UNIVERSITY

August 2019

ABSTRACT

Falls are the leading cause of fatal and non-fatal injuries in the older adult population with more than 27,000 fall related deaths reported every year[1]. Adults suffering from lower extremity arthritis have more than twice the likelihood of experiencing multiple falls resulting in increased fall-related injuries compared to healthy adults. People with lower extremity end-stage osteoarthritis(KOA), experience a number of fall risk factors such as knee instability, poor mobility, and knee pain/stiffness. At end-stage knee OA, the space between the bones in the joint of the knee is significantly reduced, resulting in bone to bone frictional wearing causing bone deformation. In addition, an impaired stepping response during a postural perturbation is seen in people with OA related knee instability. The most common treatment for end-stage knee osteoarthritis is a surgical procedure called, total knee replacement (TKR). It is known that TKR significantly reduces pain, knee stiffness, and restores musculoskeletal functions such as range of motion. Despite studies concluding that knee OA increases fall-risk, it remains unknown if standard treatments, such as TKR, can effectively decrease fall-risk. Analyzing the compensatory step response during a fall is a significant indicator of whether a fall or a recovery will occur in the event of a postural disturbance and is key to determining fall risk among people. Studies have shown reduced trunk stability and step length, as well as increased trunk velocities, correspond to an impaired compensatory step. This study looks at these populations to determine whether TKR significantly enhances compensatory stepping response by analyzing trunk velocities and flexions among other kinematic/kinetic variable analysis during treadmill induced perturbations and clinical assessments.

# DEDICATION

This thesis is dedicated to my parents
Maria and Arturo Meza;
Who gave me everything and taught me to be the person I am today.
Jonathan, my family and everyone who was a part to making this possible.

Thank you all for helping me achieve my dreams.

# ACKNOWLEDGMENTS

I would like to express my deep gratitude to the outstanding faculty who supported me in completing my master's degree and thesis. I would first like to thank my thesis advisor Dr. Claire Honeycutt of the School of Biological and Health Systems Engineering at Arizona State University. She is an inspirational leader and I am very appreciative of her dedication and problem solving skills into helping me achieve my goals. Her insightful mentorship and opportunities provided by the Human Mobility Lab have given me the necessary tools to tackle any challenges ahead. I am proud to have been a part of the Human Mobility Lab and would like to thank all the lab members who provided their time and effort into helping me with the completion of this study.

I am also most grateful to Dr. Andrew Hodge and Dr. Thurmon Lockhart, who graciously contributed their time in serving on my thesis committee.

I would like to acknowledge and thank Dr. Andrew Hodge and The Institute for Mobility and Longevity for providing the resources and funding to make this study happen.

Lastly, I would like to thank my mother and father, for their constant support and for giving everything they had for me to be able to achieve my dreams. Jonathan Bazua, thank you for your unconditional support and pushing me to achieve greatness from the start. This is all for you guys, *los amo*!

I am deeply thankful for all who have supported me along my educational path, especially those who have supported me in completing my thesis. Thank you!

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# INTRODUCTION

Falls are the leading cause of fatal and nonfatal injuries in the older adult population with more than 27,000 fall related deaths occurring annually[2][3][4][5]. In addition to an increasing death rate associated with falls, fall injuries are among the 20 most expensive medical conditions and account for up to 30 billion dollar related costs[6]. Osteoarthritis (OA) is among the most common form of arthritis affecting over 14 million in the people in the United States alone. Of those 14 million, 6 million older adults currently suffer from symptomatic knee osteoarthritis (KOA)[7][8][9][10][4][11][12][13]. Adults suffering from arthritis have more than twice the likelihood of experiencing multiple falls resulting in increased fall related injuries compared to healthy adults. Additionally, patients diagnosed with knee OA and knee pain have an increased risk for hip fracture[14].

Because incidents of KOA increase with age, it is predicted that occurrences of OA will continue to rise due to aging population therefore, increasing fall related injuries and deaths as a result[12][3][7][5]. With more than half the KOA population experiencing falls annually, it is important to determine what mechanisms and factors lead people to an increased fall risk in order to ultimately decrease the number of falls in these populations.

People with lower extremity OA experience pain and stiffness, poor mobility, lower extremity strength and balance, knee instability, slower gait, and a combination of fear of falling, all of which are established fall risk factors[15]. Lower extremity OA also reduces a person's independability causing for considerable activity limitations[16][11][8][9].

At end-stage knee OA, the space between the bones in the joint of the knee are significantly reduced, resulting in bone to bone frictional wearing causing bone deformation. The cartilage between the knee bones is reduced causing joint space to decrease which accounts to the pain and stiffness experiences by people with KOA. The most common and selected treatment for end-stage knee osteoarthritis is total knee replacement (TKR) with over one million procedures performed each year in the United States alone[7][17][18]. The procedure consists of the removal of damaged portions of bones around the knee joint and replaced with an artificial joint made of components such as metals, plastic and/or, ceramic[19]. It is known that TKR's significantly reduce pain, knee stiffness, and restore musculoskeletal functions such as range of motion and increase quality of life however the relationship and effects of TKR to falls is unknown.

During a fall, static and dynamic balances determined between the Center of Mass (COM) and the Base of Support (BOS) are essential to obtain stabilization when exposed to a perturbation type movement[11]. Previous studies have established that the ability to recover when experiencing a fall, is indicative of the position of the center of mass during the perturbation[9]. Change-in-support (CS) reactions require rapid movement of the body's center of mass where recovering balance requires keeping the COM within the boundary of the BOS. Changing the base of support occurs by taking a step in the direction of the perturbation[20][21][17]. Fall recovery depends on the ability to step to adjust the BOS, in other words known as compensatory stepping. Compensatory stepping has been identified as a critical reaction for fall recovery and prevention and is necessary in a high COM displacement scenario where stepping allows for a stable and controlled trunk movement (i.e. decreased trunk flexion angle and velocity)[22][5][21][23][20].

Studies have shown trunk stability and step length during the compensatory stepping response to be determinants fall risk[24][25][5]. Correspondingly, reduced trunk stability and shorter step length among other kinematic variables lead to impaired compensatory step and increase the likelihood of a fall during a postural or balance perturbation[26][27].

Falls occurring from external disturbances require a large and rapid compensatory stepping response. A successful compensatory responses is characterized by a long step, coordinated movement between COM, rapid step initiations, and trunk control. Biomechanical mechanisms involved in lab induced perturbations have shown successful characterization of compensatory responses and directly simulate external balance disturbances such as over ground trips[28][24][26][5]. This method of analyzing fall dynamics has successfully been able to distinguish fall risk and characteristics as well as its repeatability has been looked as potential intervention means to decrease fall risk[28].

Studies have shown that OA related knee instability leads to a compromised compensatory step response and is a significant indicator of whether a fall or a recovery will occur due to the symptoms associated to OA such as, decreased range of motion, pain and, quality of life. However the underlying causes and biomechanical responses that account for the increased risk of falls in people with OA as well as fall risks/rates among this population is not yet fully understood[8].

Despite these previous studies concluding increased fall risks within OA, there is currently a gap in knowledge in determining whether if total knee replacements effectivity decrease fall risk[7][11]. Previous studies have suggested TKR's provide more variable results such that frequency of falls are increased in comparison to age matched groups due to limited knee flexion and ankle plantar flexion[29][30][31]. Therefore no clear distinctions can be made whether if TKR help decrease falls and whether if it has a positive or negative effect on compensatory stepping response.

This study evaluates TKR and KOA to determine the fall risk factors such as compensatory stepping, using kinematic and kinetic analysis during a lab induced perturbations and clinical assessments. For this study, it is hypothesized that subjects who have undergone a total knee replacement would have less fall risk than those in the KOA group due to musculoskeletal symptoms associated with KOA and symptom relief associated to TKR. To compare fall outcomes and compensatory responses among these populations, older adults with knee OA, lateral or bilateral TKR, are exposed to treadmill-induced perturbations requiring forward stepping to avoid a fall. Dynamic stepping response during conditions where falls occurred were analyzed by the subject's biomechanical response during a fall, and clinical scores/assessments in individuals with knee OA, and one or more TKR.

## METHODS

Nine subjects whom have undergone a total knee arthroplasty no more than a year prior to the study and have physician approval to return to daily activities were recruited. Eight end stage knee osteoarthritis subjects, whose diagnosis was approved by an orthopedic surgeon via physical assessment and ultrasound confirmation to ensure the subject was a candidate for TKR surgery. Subject detailed information can be seen in the table below. The study was approved by the Institutional Review Board and all subjects provided written informed consent prior to participation. Participants were required to participate in a two day session study, clinical testing session and treadmill induced perturbation session.

| | KOA n=8 | TKR n=9 |
|---|---|---|
| Age (mean(SD), years) | 63.5 (7.5) | 69.56 (10.3) |
| BMI (mean(SD), kg/m^s) | 29.1 (5.04) | 27.92 (4.2) |
| Gender (Female:Male) | 4:4 | 2:7 |
| Affected Knee | 7 bilateral | 2 bilateral |
| | 1 unilateral left | 6 unilateral right |
| | | 1 unilateral left |

Table 1- Subject mean age, BMI, and genders.

CLINCAL ASSESSMENTS

The subject's gender, age, height, weight, affected knee/knees were recorded. Clinical tests to measure performance, balance, knee condition, daily activities and, fear of falling were administered to each subject during the first session of the study.

The Timed up and Go test, a simple and functional walk test to determine fall risk by assessing mobility, dynamic stability and gait[32], was administered to each of the subjects. Subjects began the assessment by sitting in a standard arm chair and were instructed to get up and walk 10 meters, walk back and sit back down again while being timed[22].

The Incidental and planned activities questionnaire (IPEQ-W) provides an estimate of the subjects' physical activity in the past 7 days prior to experiment[33][34].

The Physiological Profile assessment (PPA) to was used to determine postural instability due to it being a reliable predictor of fall risk[25]. The test consists of various physiological assessments including, reaction time, visual acuity, knee-extension strength, proprioception, and cutaneous sensation, and postural sway however, only subtests shown in table 8 of this assessment were included in results of this study.

The Assessment of Quality of Life is a psychometric measure a person's health related quality of life in the form of a questionnaire[35].

Falls Efficacy Scale-International (FES-I) is an questionnaire assessment of a person's fear of falling due to balance impairments[36].

Knee Injury and Osteoarthritis Outcomes Score (KOOS) is a questionnaire consisting of 5 subscales; Pain, Symptoms and Stiffness, Function in daily living (ADL), Function in sport and recreation (Sport/Rec) and knee related Quality of life (QOL). High scores higher scores reflect few knee-related problems and symptoms[27][37]. This test is used to reinforce classification between the groups and determine severity and extent of subjects' knee condition.

A summary of Clinical assessments administered to subjects can be seen in Table 2.

| Clinical Assessment | Purpose | Activity |
| --- | --- | --- |
| Timed up and Go | Gait and balance analysis | Sit to walk<br>Walk to sit |
| The Incidental and Planned activities questionnaire (IPEQ-W) | Activity limitations | Questionnaire of activity during the past 7 days |
| The Physical Profile Assessment (PPA)[38]<br>• Knee-extension strength<br>• Reaction time | Knee extension strength<br><br>Reaction time | Assesses strength of knee flexors and extensors while sitting<br>Light stimulus and depression switch as response |
| The Assessment of Quality of Life (AQoL)[35] | Health related quality of life | Questionnaire |
| Falls Efficacy Scale-International (FES-I)[36] | Assess individual's fear of falling | Questionnaire |
| Knee Injury and Osteoarthritis Outcomes Score (KOOS)[37] | assess short and long-term knee condition severity/extent | Questionnaire |

Table 2- Summary of session one clinical assessments

FALL RISK PROTOCOL

Treadmill perturbation protocol:

Subjects received treadmill perturbations on a treadmill within the Gait Realtime Analysis and Interactive Laboratory (GRAIL) system (Motekforce Link, Netherlands) on varying levels. A modified Helen Hayes set of 41 markers, which includes the 29 markers of the Helen Hayes marker set in addition to 12 additional makers to ease data analysis were placed on landmarks on trunk, upper and, lower extremities[39]. A full-body harness was adjusted to every participant to ensure safety of the subject. The harness allowed the subject to be in normal stance position however fitted to allow for a normal and natural fall condition as well as given enough clearance to the ground to avoid knees and hands from coming into contact to the treadmill belt in case of a fall. The three-dimensional special locations of the markers were recorded using a 10-camera VICON 2.2 motion capture system tracks passive-reflective markers at 250 Hz and used for kinematic analysis.

The subject was instructed to stand still in a normal standing position before a perturbations can begin. A "get ready cue" was delivered verbally to the subjects and after a short delay(10-20sec) the dual belts on the instrumented treadmill moved posteriorly or anteriorly based on predetermined perturbation speeds with each levels defined by various speeds as shown in the table below:

| Perturbation. Level | Perturbation Direction | Stepping Direction | Speed |
|---|---|---|---|
| Level 1: P1 | Posterior | Anterior | 0.89 m/s |
| Level 2: P2 | Posterior | Anterior | 1m/s |
| Level 3: P3 | Posterior | Anterior | 1.3 m/s |
| Level 4: P4 | Posterior | Anterior | 1.67 m/s |
| Level 5: P5 | Posterior | Anterior | 2.2 m/s |
| Level 6: P6 | Posterior | Anterior | 2.89m/s |
| Level 1: A1 | Anterior | Posterior | -0.5 m/s |
| Level 2: A2 | Anterior | Posterior | -1m/s |
| Level 3: A3 | Anterior | Posterior | -1.5m/s |

Table 3- Perturbation levels and corresponding velocities. Levels P 1-6 refer to posterior directed perturbation causing anterior stepping while levels A 1-3 refers to anterior directed or backward stepping perturbations.

The directions of postural disturbances were delivered in anterior and posterior directions to maintain consistency with previous studies[10]. Posterior directions were meant to simulate over ground trips[40]. Six forward perturbations and three backward-directed perturbations of increasing difficulty were delivered to the subjects. The same perturbations levels and velocities were used for all subjects. Forward-directed perturbations were designed to be large enough to require a forward compensatory step to regain balance and avoid a fall. Anteriorly-directed perturbations, which required a backward step to avoid falling, were used to reduce anticipation of perturbation directions; therefore, only posteriorly-directed perturbations trials were analyzed further. The direction of the perturbation (anterior or posterior) was randomized throughout the experiment however, the level of the perturbations progressed from small (level 1) to large (level 6). The magnitude of the levels (speed) was predetermined off of previously conducted literature[10][41]. Perturbations were delivered starting from low to high level, until a given perturbation resulted in a fall. When a subject fell or failed to recover balance resulting from a given perturbation, the same level perturbation was repeated and the subject was given two additional times to attempt to recover. If the subject recovered from a given perturbation, the next higher level of perturbation was delivered. If the subject failed to recover after the additional two times from a same level perturbation, the experiment was concluded and the subject was assumed to fall in higher level perturbation conditions. Responses were classified as either a “Fall” or “Recovery”. A Fall was recorded if the subject became explicitly supported by the safety harness.

## KINEMATIC ANALYSIS

The first step was quantified with kinematic analysis. Step initiation or step start (SS) and heels strike or step end (SE) were calculated visually as well as supported using ground reaction forces normalized to the subject's body weight. The following metrics were quantified during the first compensatory step: Trunk flexion and velocity, Step length, Dx, Step Width, Step Time, Reaction time and, Propulsive impulse of the stepping leg. The dependent variables used to evaluate stepping response is as follows:

Dependent Variables:

- Reaction time: Time from perturbation onset to the start of the step
- Step duration: Time from Step Start to Step End
- Step length: Anteroposterior distance between the center of stepping foot and base foot at SE.
- Trunk flexion: Overall sagittal plane angle of trunk vector relative to the initial position of the trunk at perturbation onset at SS and SE. Positive values indicates a forward trunk angle while negative indicates backward angle.
- Trunk flexion velocity: Time derivative of the Trunk flexion at SS and SE.
- Dx: Anteroposterior distance between center of mass (COM) position and the edge of base of support (stepping leg toe marker) at SS and SE. Positive values indicating COM to be within boundary of the base of support.

A 12-segment rigid body model was constructed using the attached marker positions of subjects and kinematic variables were computed using custom software (MATLAB, Mathworks, Natick MA). The joint angles, body segment translations, treadmill (ground reaction force, and number of steps taken) were recorded during the experiment. Ground reaction force (GRF) data of each leg was collected through force plates (Bertec, Columbus, OH) embedded in each belt of the instrumented dual-belt treadmill at 2000

Hz. A 4th order Butterworth filter with a 20 Hz cutoff frequency was applied through MATLAB software.

STATISTICAL ANALYSIS

To test the hypothesis, an ANOVA using Generalized Linear Mixed effects Model (GLMM) was performed with conditions (TKR, KOA) and perturbation level (1-6) as independent variables, and previously defined kinematic measures as dependent variables. Subjects were considered as a random factor. Tukey post-hoc tests were conducted to further determine significant differences. Statistical analysis were performed using R (R Development Core Team, 2006). Significance level was considered as $p < 0.05$*. All variances reported are standard deviations.

# RESULTS

Kinematic/kinetics:

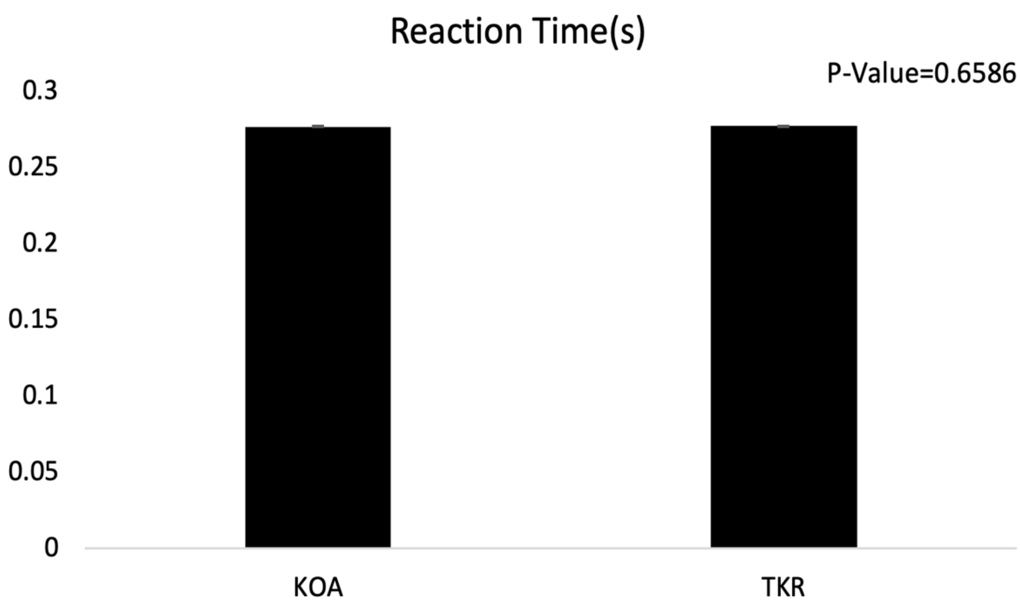


Figure 1a- Reaction time(s) (P=0.6586)

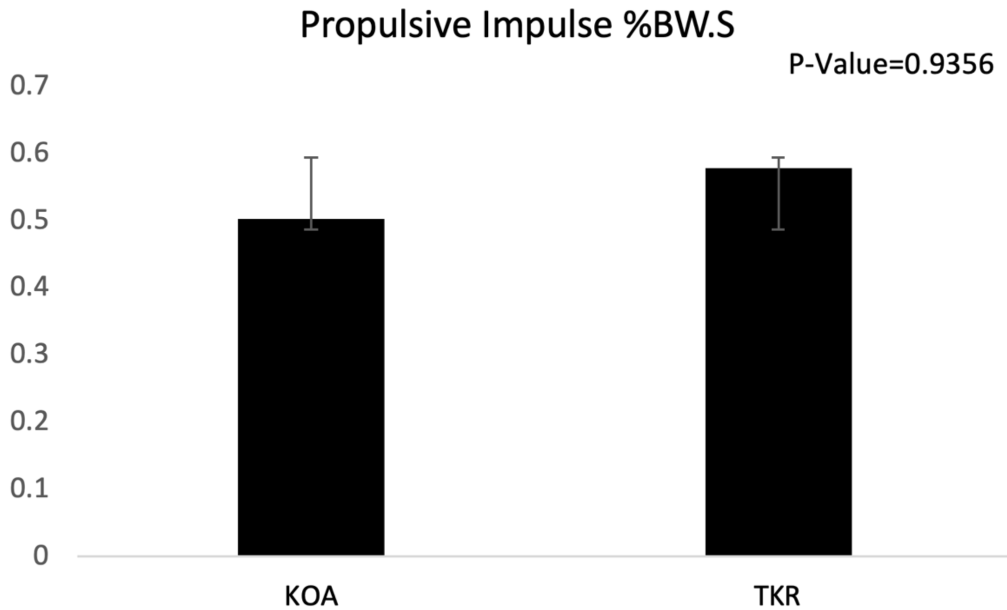


Figure 1b- Propulsive impulse (%BW.S)(P=0.9356)

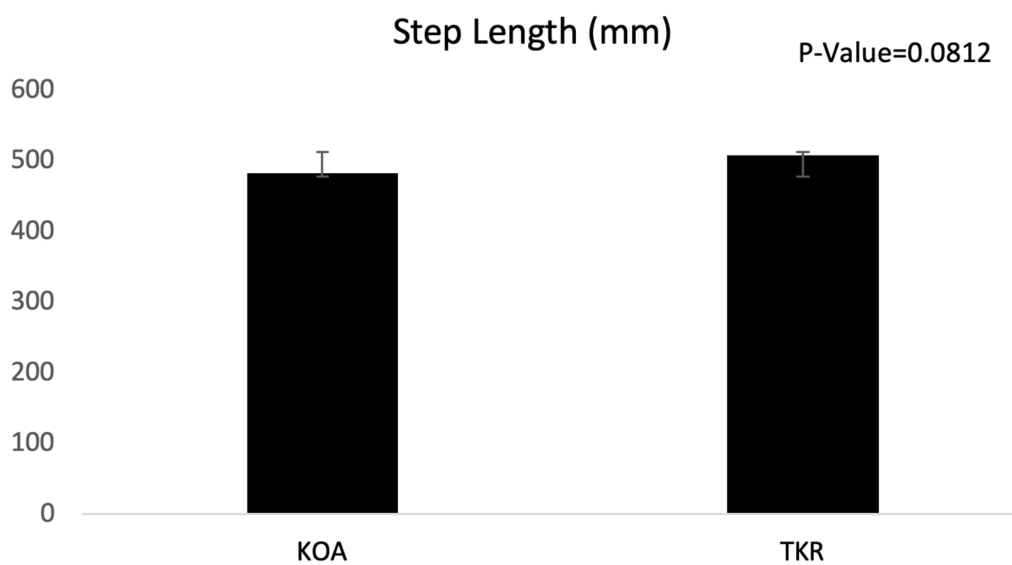


Figure 1c- Step Length(mm) (P=0.0812)

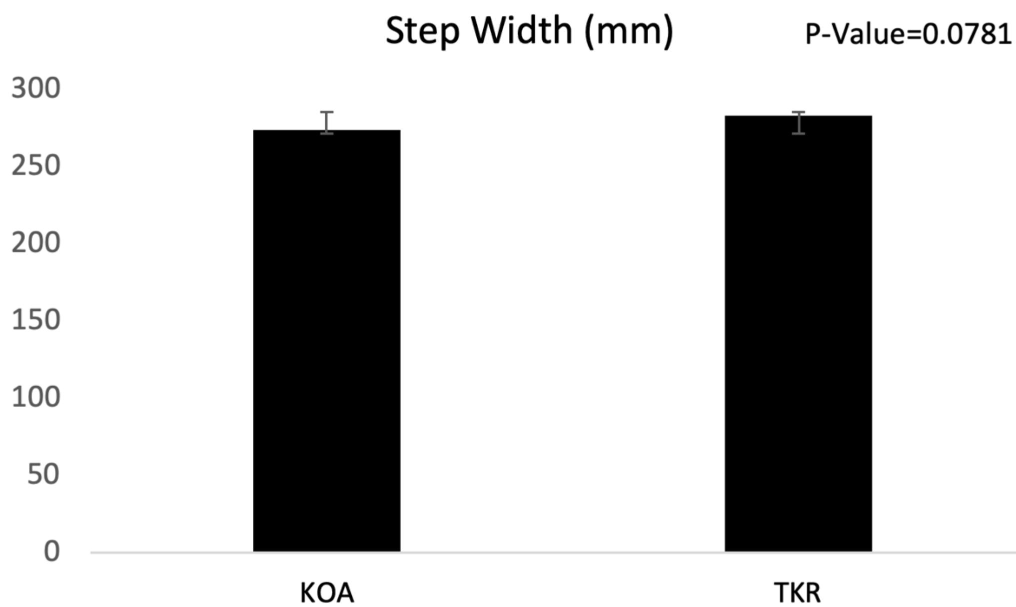

Figure 1d- Step Width(mm) (P=0.0781)

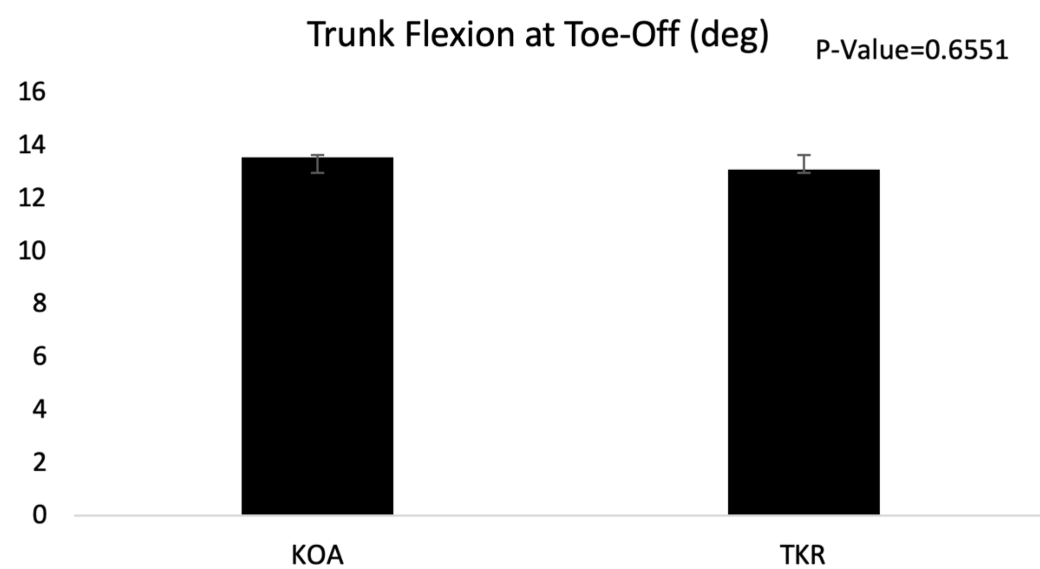


Figure 1e- Trunk Flexion at TO (P=0.6551)

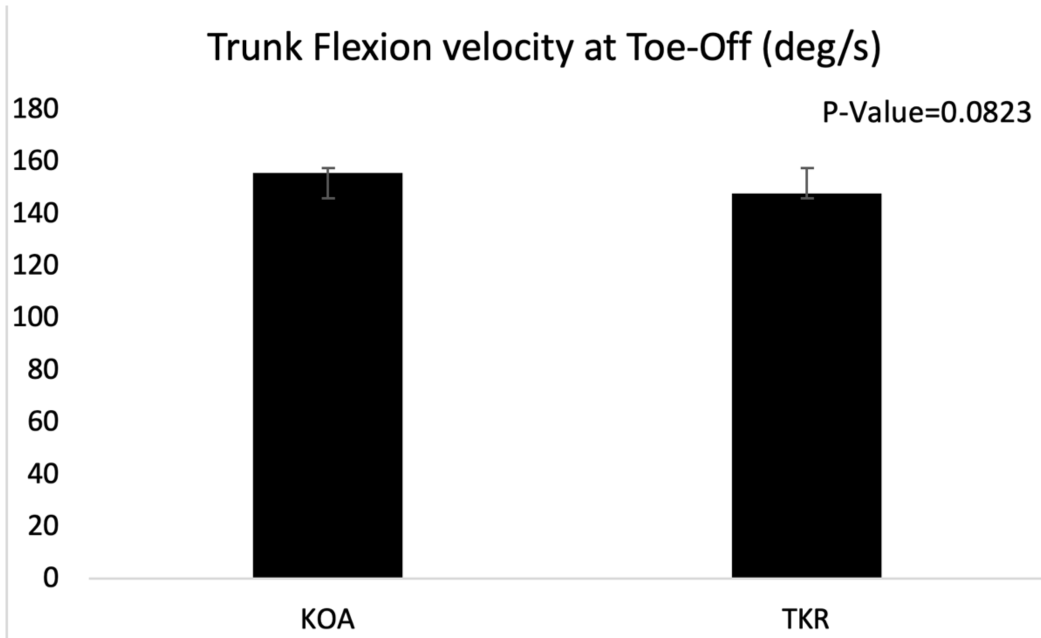

Figure 1f- Trunk Flexion Velocity at TO (P=0.0823)

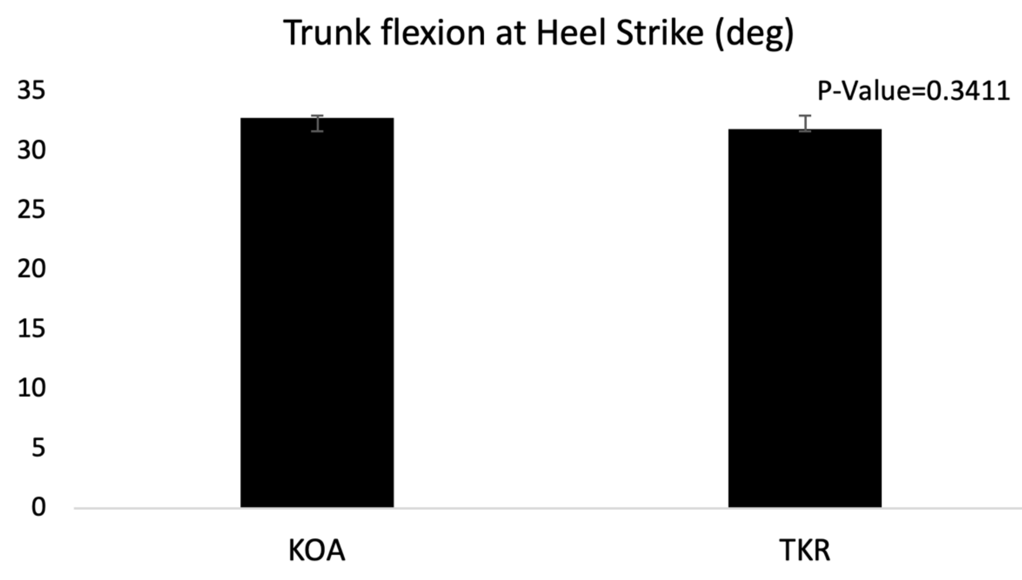


Figure 1g- Trunk Flexion at HS (P=0.3411)

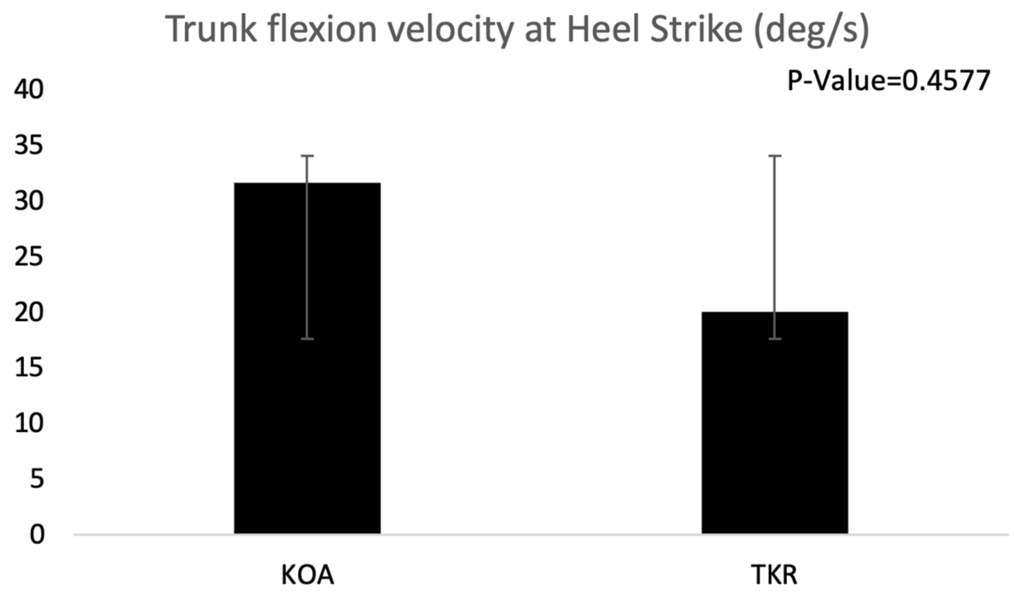


Figure 1h- Trunk Flexion Velocity HS (P=0.45771)

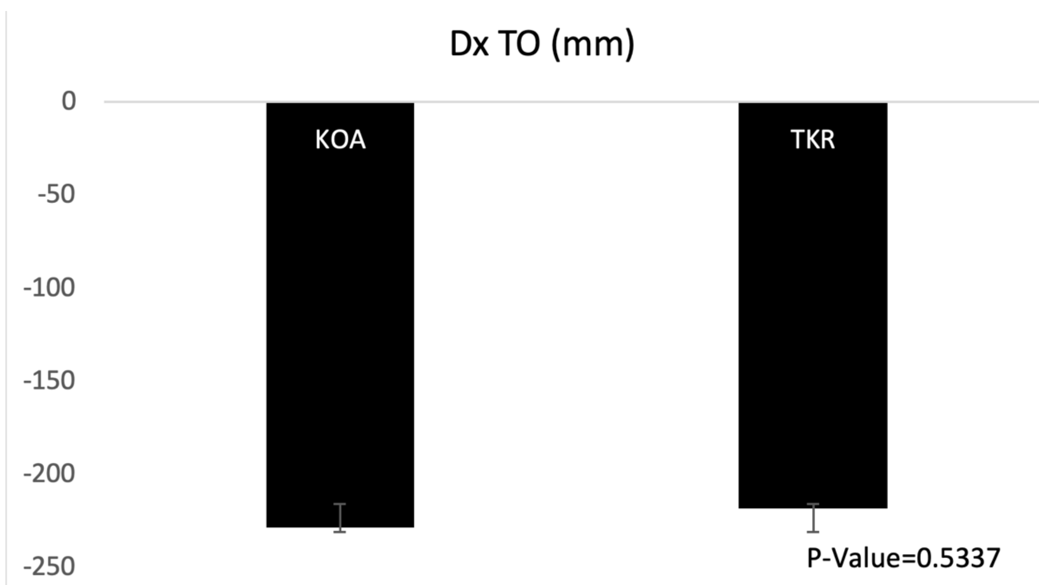


Figure 1i- Dx TO(mm) (P=0.5337)

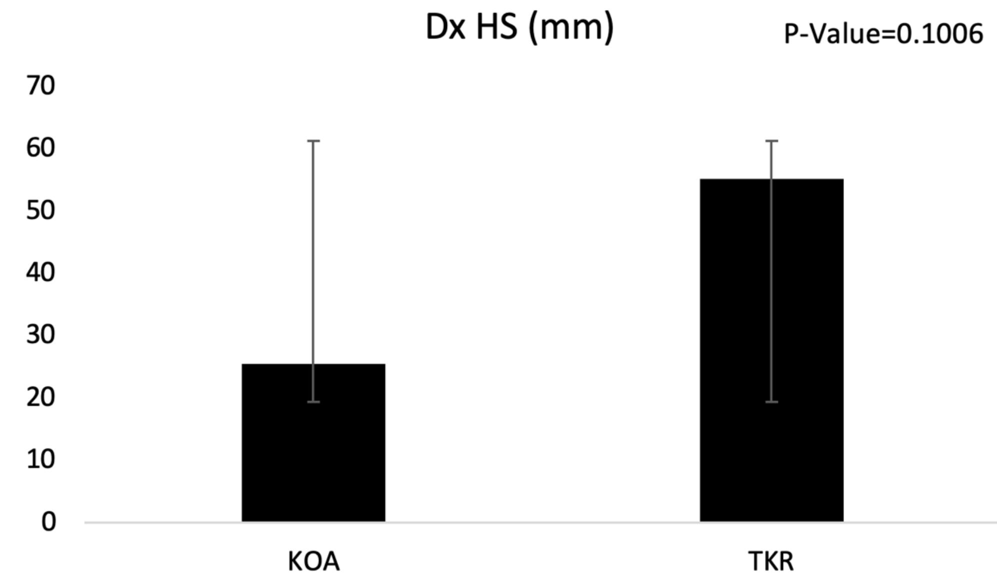


Figure 1j- Dx HS(mm) (P=0.1006)

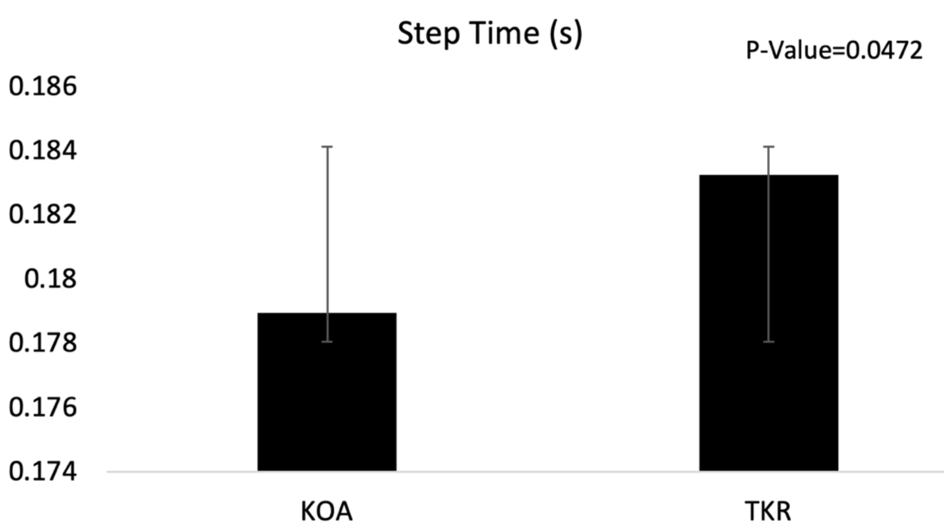


Figure 1k- Step Time (s) (P=0.0472)

Figure1(A-K)- Mean kinematic/kinetic values of dependent variables. Error bars represent standard deviations.

| | KOA | TKA | P-Value |
|---|---|---|---|
| Reaction Time(s) | 0.277(0.031) | 0.277(0.032) | 0.6586 |
| Push-off Impulse | 0.502(0.310) | 0.578(0.341) | 0.9365 |
| Step Length (mm) | 481.9(176.9) | 506.5(187) | 0.0812 |
| Step Width (mm) | 273.3(57.0) | 282.8(88.2) | 0.0781 |
| Trunk Flexion at Toe-Off (deg) | 13.6(4.5) | 13.1(5.54) | 0.6551 |
| Trunk Flexion velocity at Toe-Off (deg/s) | 155.8(43.2) | 147.5(57.3) | 0.0823 |
| Trunk Flexion at Heel Strike (deg) | 32.7(10.7) | 31.8(15.3) | 0.3411 |
| Trunk Flexion velocity at Heel Strike (deg/s) | 31.7(79.7) | 20(70.2) | 0.4577 |
| Dx TO (mm) | 228.8 (106.2) | -218.4(101) | 0.5337 |
| Dx HS (mm) | 25.4(113.0) | 55.1(129.9) | 0.1006 |
| Step Time (s) | 0.179(0.029) | 0.183(0.032) | 0.0472 |

**Table 4:** TKR vs KOA compensatory stepping response. Variables were measured during the first compensatory stepping response to an anteriorly-directed perturbation. Reported values are mean (standard deviation). * = P-value < 0.05

No difference was found for majority of variables however, averaged push off impulse associated to perturbation was slightly higher in the TKR group 0.578±0.3 compared to KOA 0.502±.3 but not significant (P=0.936). The same can be seen in averaged step length, step width, step time and Dx, even though not statistically significant. Trunk flexions and velocities were slightly higher in KOA compared to TKR, which has been translated before as higher trunk flexion angles/velocities to trunk instability. Overall no significance was found among the two groups except in step time, where TKR had 2% higher reaction time (P=0.047), described as having a slightly longer reaction to a perturbation. Table 4 summarizes kinematic and kinetic values by group, variances are reported as standard deviations.

Comparing kinematic variables to recovery compensatory stepping responses by stroke subjects[24], there is a 11% differences in reactions time, 3-8% differences in step lengths, 6-10% for trunk flexion angles at toe off. Kinematic comparisons to healthy young and older adults can be found in Table 5 and Table 6. Comparing recovery trunk kinematics to older adults[28], overall there were no significant changes in kinematics, in terms of overall range of TKR, KOA, and healthy adult kinematics. Trunk flexion angle differences were 4-8% when comparing KOA to healthy recovery compensatory stepping and TKA to healthy CSR, respectively. Trunk flexion velocities are different across comparing different populations with 48-67% differences seen when comparing this knee study to healthy older adults study.

| | **Stroke**[24] | | **Healthy young**[42] | | **Healthy older adults**[28] | |
|---|---|---|---|---|---|---|
| | Fall | Recovery | Fall | Recovery | Fall | Recovery |
| Reaction Time(s) | 0.266 (0.019) | 0.250 (0.018) | | | 0.28 (0.05) | 0.24 (0.03) |
| Step Length (mm) | 367.8 (22.6) | 524.0 (21.2) | 666 (146) | 782 (8.9) | | |
| TFA TO (deg) | 17.9 (0.9) | 14.5 (0.9) | | | 18.9 (7.2) | 12.6 (4.7) |
| TFV TO (deg/s) | 208.3 (7.3) | 205.1 (6.8) | | | 175.5 (64.3) | 155.5 (42.6) |
| TFA HS (deg) | 44.2 (1.7) | 41.7 (1.6) | 288 (9.0) | 14.5 (6.2) | 45.8 (13.6) | 30.3 (8.8) |
| TFV HS(deg/s) | 42.5 (7.2) | -6.5 (6.7) | 71.3 (50.5) | -38.4 (24.2) | -12.1 (36.1) | 60.9 (36.1) |
| Dx TO (mm) | -179.2 (9.3) | -145.5 (8.7) | | | | |
| Dx HS (mm) | -69.9 (17.9) | 83.3 (16.8) | 16.5 (6.9) | 26.7 (7.1) | | |
| Step Time (s) | 0.195 (0.014) | 0.299 (0.013) | 0.42 (0.04) | 0.043 (0.03) | | |

Table 5- kinematic results from prior studies to compare to present study. Trunk flexion angle (TFA) at toe off (TO) and heel strike (HS).

| | KOA | TKA |
|---|---|---|
| Reaction Time(s) | 0.277 (0.031) | 0.277 (0.032) |
| Step Length (mm) | 481.9 (176.9) | 506.5 (187) |
| TFA TO (deg) | 13.6 (4.5) | 13.1 (5.54) |
| TFV TO (deg/s) | 155.8 (43.2) | 147.5 (57.3) |
| TFA HS (deg) | 32.7 (10.7) | 31.8 (15.3) |
| TFV HS(deg/s) | 31.7 (79.7) | 20 (70.2) |
| Dx TO (mm) | 228.8 (106.2) | -218.4 (101) |
| Dx HS (mm) | 25.4 (113.0) | 55.1 (129.9) |
| Step Time (s) | 0.179 (0.029) | 0.183 (0.032) |

Table 6- kinematic results from present study

CLINCAL SCORES

Clinical scored administered and described previously in table 2, were scored and mean values/ percentages of each group are reported in table 7. For the subtests within the Physical Profile Assessment (PPA), reaction time was higher in KOA 396.17± 83.8 compared to TKR 380.33±48.8, even though not significantly(P=0.636). On the other hand, when comparing knee strength overall was lower in KOA groups compared to TKR, with only significance in left knee strength being 36% higher (P=0.04). IPEQ-W assessment, reported KOA having 46% less overall activity I.E exercise, walks. compared to TKR (P=0.03). TUG, FES-I and, AQoL scores were overall lower in KOA group but not significantly different (P=0447, P=0.123, P=0.07, respectively). KOOS scores show overall lower KOA scores by 12% (P=0.006) and subscales of assessment can be seen in Figure 2.

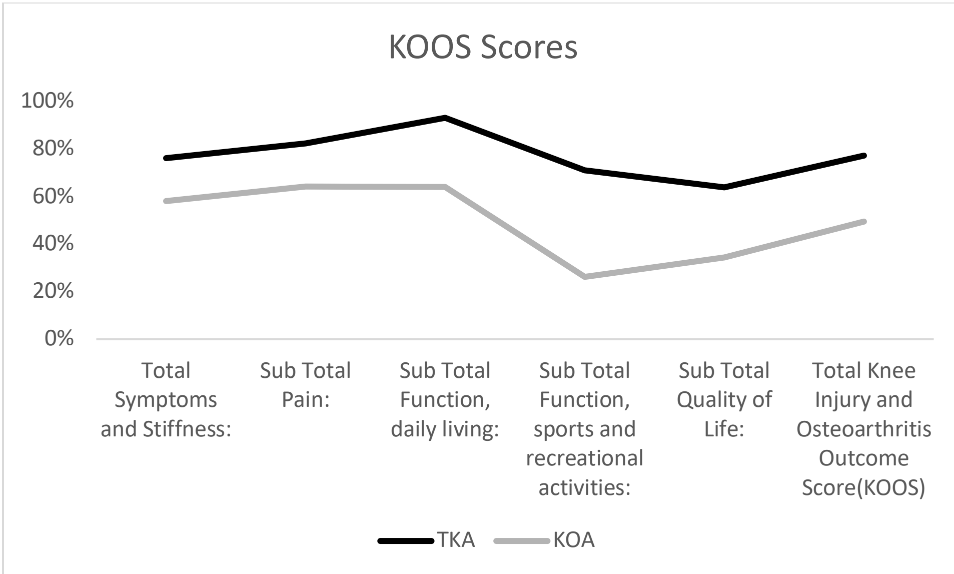


Figure 2- KOOS mean scores between TKR and KOA groups.

| **Clinical Assessment** | **KOA(n=8)** | **TKR(n=9)** | **P-Value** |
|---|---|---|---|
| Reaction Timed Test (ms) | 396.17 (83.8) | 380.33 (48.8) | 0.636 |
| TUG (s) | 9.07 (1.7) | 9.64 (1.7) | 0.447 |
| Knee Extension left | 2.63 (4.9) | 4.14 (4.9) | 0.043* |
| Knee Extension right | 3.47 (1.1) | 4.1 (1.1) | 0.479 |
| FES-I | 24.375 (9.1) | 18.67 (1.5) | 0.123 |
| KOOS Total Score | .49(1.5) | .77(0.2) | 0.006* |
| Symptoms and Stiffness | 2.35(1.6) | 3.04(1.3) | 0.167 |
| Pain | 2.56(1.2) | 3.29(1.0) | 0.1 |
| Daily Living | 2.56(1.0) | 3.72(0.5) | P<0.001** |
| Sports & Recreational Activities | 1.05(0.9) | 2.84(1.1) | P<0.001** |
| Quality of Life | 1.36(1.2) | 2.56(1. | 0.0328* |
| IPEQ-W | 34 (18.9) | 62.42(29.9) | 0.037* |
| AQoL | 83(7.1) | 89.63(6.6) | 0.07 |

Table 7- Summary of Clinical Scores by population. *P<0.05

FALL OUTCOMES

KOA group had a fall percentage of 66±35 while TKR had a total fall percentage of 63±39. No significance was found between the two groups. Figure 3 shows plotted results, where KOA had slightly lower fall trials compared to TKR, however not significant (P=0.788).

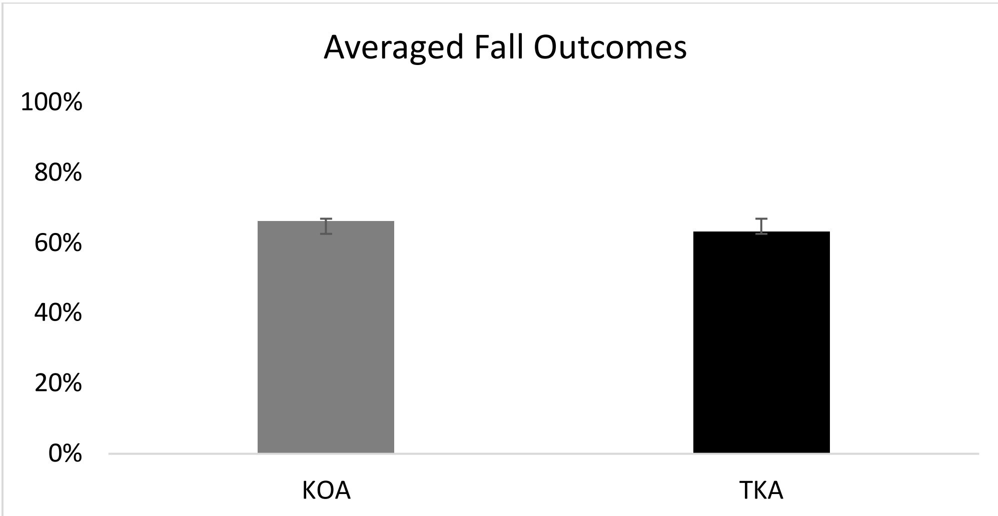


Figure 3- Fall outcomes per group

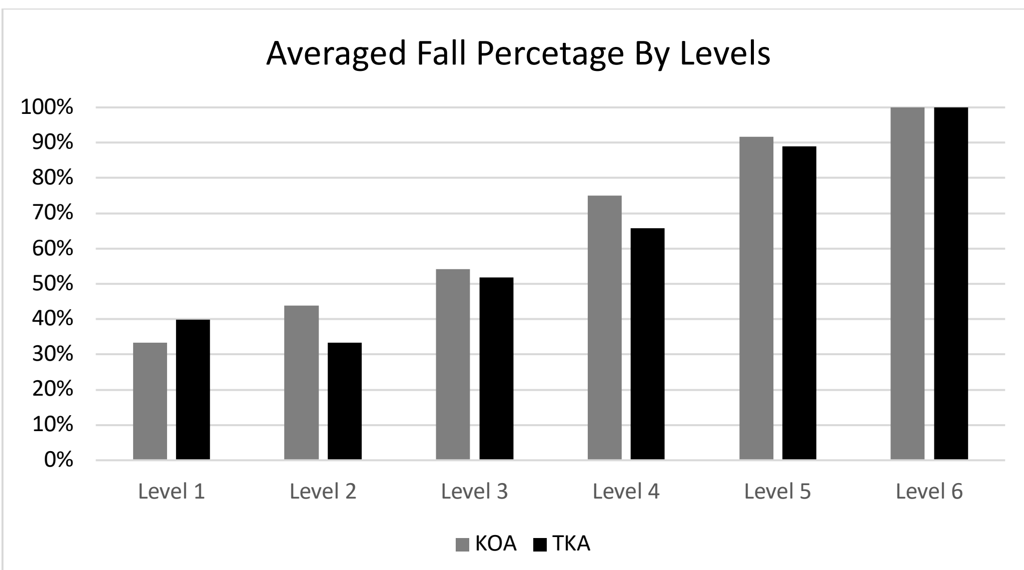


Figure 4- Fall outcomes by levels

Affected knee information:

| Subject | Knee Type | Affected Side | Right | Left |
|---|---|---|---|---|
| 46 | KOA | Unilateral Left | 100% | 0 |
| 56 | KOA | Bilateral | 27% | 57% |
| 30 | KOA | Bilateral | 40% | 60% |
| 32 | KOA | Bilateral | 88% | 13% |
| 35 | KOA | Bilateral | 0% | 100% |
| 36 | KOA | Bilateral | 82% | 18% |
| 48 | KOA | Bilateral | 43% | 57% |
| 4 | KOA | Bilateral | 64% | 36% |
| 39 | TKR | Bilateral | 100% | 0% |
| 40 | TKR | Unilateral Right | 0% | 100% |
| 42 | TKR | Unilateral Right | 7% | 93% |
| 45 | TKR | Unilateral Right | 11% | 89% |
| 47 | TKR | Unilateral Right | 35% | 65% |
| 51 | TKR | Bilateral | 75% | 25% |
| 53 | TKR | Unilateral Right | 100% | 0% |
| 2 | TKR | Unilateral Right | 100% | 0% |
| 29 | TKR | Unilateral Left | 89% | 11% |

Table 8- Stepping leg percentage

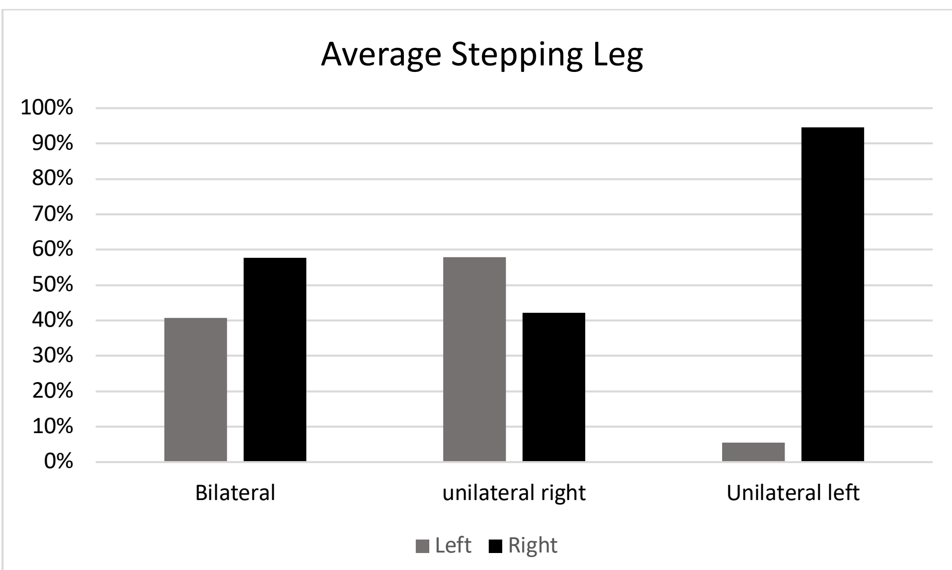


Figure 4- Percentage of stepping leg used during first step following a perturbation.

Table 8 and figure 4 indicates the percentage of right or left stepping leg in which subjects in the bilateral group show a variable responses in terms of leg of choice for compensatory stepping. Subjects who received a unilateral right TKR favored using left unaffected side for compensatory stepping. The same can be seen for subjects who received a left TKR.

## DISCUSSION

The objective of this study was to evaluate whether TKR significantly enhances compensatory stepping response by analyzing trunk velocities and flexions among other kinematic/kinetic variable analysis on KOA and TKR groups during treadmill induced perturbations and clinical assessments. From clinical scores, it was found that TKR have overall higher KOOS scores compared to KOA, which is what was expected due to pain and osteoarthritis related symptoms. This conclusion can also be supported by the IPEQ-W questionnaire, where TKR group had overall more exercise related activity compared to KOA. Despite multiple studies concluding that KOA results in an impaired compensatory stepping response, results from this study cannot be used to support this hypothesis even though results might be trending to support it. It is possible that people with recent knee replacements experience higher fall risks in the months following surgery due to muscle weakness[7]. Even though clear differences can be seen among TKR and KOA regarding clinical scores, there were no significant differences found in kinematic analysis to support TKR treatment enhances compensatory response stepping.

Even though overall no significance difference could be seen within kinematic and kinetic variables, p values for variables including, Step length, step width, trunk flexion velocity TO and, Dx HS,  are close to significance.

When comparing results from this study to other studies which have applied the same methodology for kinematic analysis of fall responses, results from this study (Table 4) seem to be consistent to former studies. Kinematic results from this present study are within the range of prior studies, in terms of percentage differences. Trunk kinematics, particularly trunk velocities have higher percentage differences compared to healthy older adult study, which can be due to differences in compensatory stepping strategies or differences in study protocol. It is important to note, perturbation speeds and levels were applied differently throughout mentioned prior studies therefore could be primarily the cause of the big differences seen in trunk velocities. Perturbations were different throughout the populations in terms of normalization of body height, weights and belt speeds and therefore results cannot be directly compared, but can be observed to ensure proper kinematic results are being seen in the present study, confirming protocol to have produced viable results.

Fall outcomes from Figure 3 show overall 3% higher fall percentage in KOA compared to TKR even though not significant (P=0.788). Taking all dependent variables as well as fall outcomes, absence of significant differences may be attributed to low amount of subjects. Figure 4 shows individual level fall outcomes, overall higher fall outcomes in KOA group compared to TKR with the exception of level 1 however, not statistically significant. Level 1 fall outcomes shown in Figure 4, could be higher with TKR group due to subjects not being familiar and exposed to such trips. Meaning, since a person does not experience training tripping responses in daily life, subjects may have not been familiar to a balance perturbation therefore respond by a unsuccessful compensatory step or potentially using the wrong stepping leg to perform a compensatory stepping response. Furthermore, the shift for fall outcomes after level 1 showing TKA having a lower fall percentage than KOA could be due to readjustment in compensatory stepping where subjects eventually correct for falls and thus fall less in higher perturbations. It is possible that TKR enhances the compensatory stepping response after they are "trained" by being exposed to the first level of perturbation. A training response may be occurring within these subjects, which would be in accordance to previous studies showing that compensatory stepping training improves kinematics of compensatory stepping responses and improves recovery successes, decreasing fall incidences[24][43].

There were many confounding factors present in the study. Differences in the affected knee in terms of bilateral vs unilateral would result in more variability in kinematics and overall performance. Variability among TKR groups was very high which may account for no significances being found. In order to account for a highly variable group, a greater amount of subjects in this groups would be necessary in order to fully capture the population effect on compensatory stepping.

## Limitations and Future Directions

The biggest limitation to this study was the low amount of subject in each population group, it is likely that with larger sample groups of 20+ subjects in each group, can be enough to establish significances and see a true difference among groups. It is also worth noting that the groups are not being compared to age matched control group. Therefore it is also possible TKR treatment does not effectively reduce fall risk, and therefore is the reason as to why no such differences were observed in this study. Further studies comparing to both KOA and age-matched control groups are needed in order to further establish relationship between these groups.

Data exclusion was also a major contributor to not finding significances and big limitation to the study. Almost half of all forward perturbation trials were excluded to due marker quality as well as inability to extract kinematic/kinetic data from particular trials.

Overall this feasibility study shows treadmill induced perturbations simulate over ground trips to understand dynamic responses during a fall. Even though no significant differences can be found for most kinematic variables, it can be seen that variables linked to compensatory stepping response characterizations are close to being significant.

Dynamic fall responses due to treadmill induced perturbations have been shown to simulate over ground trips from external environments[28]. Treadmill induced perturbations are critical protocol in order to truly understand and characterize fall risk. Biomechanical mechanisms associated to falls such as trunk flexion, reaction time, step length have been studied with treadmill perturbation protocols used in prior studies and have been established to be a viable method to study falls due to trips[28].

## CONCLUSION

This study looked at biomechanics response during falls, overall fall risk as well as clinical scores and assessments for total knee replacement and end stage knee osteoarthritis groups. It remains unknown as to if total knee arthroplasty effectively enhances compensatory stepping responses. Studies have shown lower extremity arthritis corresponds to an impaired compensatory response, therefore are classified as having high fall risk. It is important to know the impacts of total knee arthroplasty on end stage knee osteoarthritis to determine if TKR what kind of effects the treatment provides. Even though it has been established TKR reduces pain and improves overall knee range of motion, it might be possible that muscle weakness attributed to post surgery time might be a factor to falls. Lab induced perturbations and overall mechanism to study falls can be used to determine fall risk factors as well as a potential intervention tool to target fall risk.

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## BIOGRAPHICAL SKETCH

31 Estefania received her BSE in Biomedical Engineering from Arizona State University in 2017 and is currently pursuing a MS in Biological Design. She joined the Biological Design program in 2017, as recipient of the WAESO Louis Stokes Alliance for Minority Participation BD Fellowship. Estefania's graduate studies and research was advised under Dr. Honeycutt at the Human Mobility Lab at ASU. Her research concentrations have focused in the biomechanics fields relating to human movement analysis of a number of neuromuscular disorders. Particularly, she is interested in fall prevention and working with clinicians on finding rehabilitation strategies by studying biomechanical properties of gait and falls. After graduation, she plans to join the biomechanics industry and expand her research skills and knowledge into the rehabilitation and sport performance field.

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