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Toe-In during Sit-To-Stand Reduces Knee Adduction Moment in People with Moderate Knee Osteoarthritis

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SUMMARY

Purpose. Sit-to-stand (STS) is functionally more critical for the independency of people with osteoarthritis (OA). During STS, OA people experience a lot of pain from high sagittal torque. This study investigated the effect of toe-out (T-O) and toe-in (T-I) on knee adduction moment (KAM) and knee flexion moment (KFM) during STS in moderate knee osteoarthritis (KOA) and healthy age-matched people.

Methods. In this cross-sectional study, 19 volunteers with moderate KOA (KOA group) and 15 age-matched healthy individuals (control group) participated. KAM, KFM, peak times, and terminal knee flexion angle were measured using a motion analysis system during STS in normal foot progression angle (FPA), 10° of T-O, and 10° of T-I. The repeated-measures ANOVA was used to determine the effects of group and FPA condition and their interactions on the knee kinetic and kinematic parameters.

Results. T-I reduced the peak KAM significantly in both groups ($p = 0.025$ and $p = 0.05$, respectively). Irrespective of the group, T-O and T-I significantly reduced the peak time of KAM and KFM ($p = 0.003$ and $p = 0.035$, respectively). People with KOA had significantly higher terminal knee flexion than healthy subjects in all FPA conditions.

Conclusions. Ten degrees of toe-in reduced KAM in healthy and KOA people during STS; it may effectively diminish the medial knee contact force in people with KOA.

KEY WORDS

Osteoarthritis; knee joint; foot progression angle; adduction moment; flexion moment; sit to stand.

INTRODUCTION

Osteoarthritis is a chronic degenerative and multifactorial joint disease (1). Knee osteoarthritis (KOA) is the commonest cause of disability in the elderly (2). Worldwide, KOA has a prevalence rate of 7.9%. Prevalence in Iran is 15.3% for urban areas and 19.3% for rural areas, much higher than in other communities. For instance, the prevalence of KOA in India is 5% and 4% in urban and rural areas, respectively. The overall figure for Pakistan is 1.8%. Lastly, 3.1% of Australian aborigines suffer from KOA(3).

People with KOA often complain of pain, decreased range of motion (ROM), muscle weakness, joint stiffness, and instability, which limit their daily physical activities (4): this deprives them of their independence, leading to decreased quality of life (5). The abnormal distribution of force plays an essential role in the degeneration of the medial compartment of the knee joint (6). Given that it is not possible to directly measure knee contact force (KCF), knee adduction moment (KAM) has been introduced as a surrogate measure of KCF (7). Maximum external knee flexion moment (KFM) has garnered the attention of researchers because it is consistent with the onset of KOA (8). Using a musculoskeletal model revealed that the simultaneous application of KAM and KFM provides a more accurate estimate of the internal loading of the knee joint (9).

KAM reduction has been considered in some conservative therapeutic methods, such as gait retraining strategies (10). Gait retraining, either toe-out (T-O) or toe-in (T-I), has been shown to reduce KAM. Even one T-O gait retraining session permanently reduced the KAM's second peak (11). In addition, a significant relationship has been reported between foot progression angle (FPA) and KAM reduction at the end of the stance phase in healthy individuals and people with varying degrees of KOA.

A study has shown that T-I (an average of 5°) reduces the first peak of KAM by 13% without increasing KFM (10). Another study found that one month after T-I gait retraining, the participants continued to walk with reduced FPA and KAM compared to the initial measurements, indicating that they got used to the new gait pattern due to pain reduction (12). These findings suggest that T-I gait retraining may be helpful as a nonsurgical treatment for individuals with KOA.

Although gait retraining has been extensively researched, its effect on daily functional activities such as sit-to-stand (STS) has not been explored precisely. The maximum knee excursion, where the maximum KFM occurs during the stance phase of gait, is 20° (8), much smaller than the knee angle used in STS. Therefore, it is necessary to identify biomechanical differences in the sagittal plane by selecting a more appropriate function with high mechanical demand and a more comprehensive ROM. Since the STS task takes place mainly on the sagittal plane, it can more effectively demonstrate the kinetic and kinematic discrepancies between healthy individuals and people with KOA (2). STS is functionally more significant than walking, or stair climbing due to the knee joint's greater sagittal torque and ROM. The good ROM of the joint and the proper strength of the muscles involved in the torque play a vital role in completing an STS task at the right pace (13). STS is frequently entailed in daily activities and induces high-impact force and pain in KOA people. FPA modification as a conservative therapeutic method may affect this contact force which can be surrogated by the knee joint adduction moment. So, this study aimed to investigate the effect of 10 degrees of T-O and T-I on KAM, KFM, and the peak time during STS. The present study's objective was to explore the effect of FPA condition on KAM and KFM in KOA and healthy age-matched people.

METHODS

Subjects

This cross-sectional study was conducted at the motion analysis laboratory of the Physical Therapy Department of the Tarbiat Modares University. The Medical Ethics Committee of Tarbiat Modares University approved the study (IR.MODARES.REC.1398.057 – Date of approval: May 20, 2019).

The participants were recruited using advertising literature from the Health Center of the authors' affiliated institutions. Forty volunteers, 20 KOA, and 20 healthy people announced their willingness to participate in the study. The inclusion criteria were 25 ≤ BMI ≤ 35, 45-65 years old, not participating in regular or musculoskeletal strengthening programs, and no intra-articular injection in the last six months. The KOA group had grade II or III unilateral KOA, as evidenced by radiographically assessment based on the Kallgren and Lawrence criteria. The exclusion criteria were obvious deformity (especially knee valgus of exceeding 15 degrees, knee varus of more than five degrees, calcaneal eversion, calcaneal inversion, and flat foot), a history of central nervous system disease, lower extremity trauma or surgery, lower extremity joint replacement, and rheumatoid arthritis. In addition, participants who were unable to perform STS without assistive devices were left out. One KOA volunteer was excluded from the study due to severe varus, and five healthy subjects were also excluded due to flat feet (two persons), patellofemoral pain (one person), and lumbar pain (two persons). Finally, 34 volunteers, 19 with KOA (KOA group, ten women and nine men), and 15 healthy age-matched people (control group, five women and ten men), were eligible to enter the study. After being informed about the study, all subjects gave their written consent to the experimental procedure.

Procedure

All assessments were performed in the motion analysis lab from 9 a.m. to 1 p.m. A Vicon motion analysis system (Vicon, Oxford, UK) captured the kinematics parameters using eight cameras (Vero, 2.2 MP, UK) with a sampling frequency of 120 Hz. A standard Plug-In-Gait lower body marker set was used, containing 16 retro-reflective markers. The markers adhered bilaterally on the 2nd metatarsal head, calcanei, malleoli, tibia, femur, femoral epicondyle, and anterior and posterior superior iliac spines. After a static calibration trial, the participants were asked to walk at a comfortable preferred speed along the 5.3 m laboratory walkway. During ordinary walking, the subject's normal FPA was calculated as an angle between the connecting line of the second metatarsal head marker and calcaneus marker and the forward progression line of the body during foot flat. After that, STS was performed at three angles (normal or original FPA, 10-degree T-O, and 10-degree T-I). STS task was performed three times for each FPA, and the KAM (peak and peak time) and KFM (peak and peak time) were measured.

The maximum isometric force of the lower limb muscle groups was measured using a digital handheld dynamometer (Lafayette Instrument Co., Lafayette, IN, USA). The isometric strength of the hip's abductors, adductors, extensors and flexors, knee extensors and flexors, and dorsi and plantar flexors of the ankle were measured bilaterally. Each of the muscular groups was tested three times bilaterally with one minute of rest between repeated tests. The maximum isometric force was recorded for five seconds. The mean of the three repeated tests was considered the muscle strength value. The procedure, which included test positions, stabilized regions, and dynamometer placements, was based on Bohannon *et al.*'s study (14).

STS test

The participants were asked to sit on a height-adjustable stool without back support and armrest to perform the STS. The stool was placed next to the force plate (9286B; Kistler Co., Winterthur, Switzerland) and not on it. The stool height was adjusted in 90/90 flexion of each participant's knee/hip joints while the feet were apart on the force plate. The subjects put their hands on the waist and performed a vertical upward movement into a standing position without moving their feet from the situation.

The participants were asked to perform STS at a comfortable, ordinary speed in three FPA conditions: Normal FPA (original FPA), T-O FPA (10 degrees of T-O related to normal FPA), and T-I FPA (10 degrees of T-I from normal FPA). A sheet of squared paper was used on the force plate to plot FPA individually (**figure 1**). The sampling frequency of the force plate was 1,000 Hz. The affected feet in the KOA group and the nondominant foot in the control group were adjusted on the scaled paper. Thus, the STS test was carried out three times in each FPA condition. A sample of KAM and KFM in the KOA and control groups are shown in **figure 2**. The terminal knee flexion angle (TKFA) at the end of STS, the peak KAM and KFM, and their peak times were measured during STS. The assessor was blinded to grouping.

Figure 1. A squared paper on the force plate to set the foot progression angle (FPA).

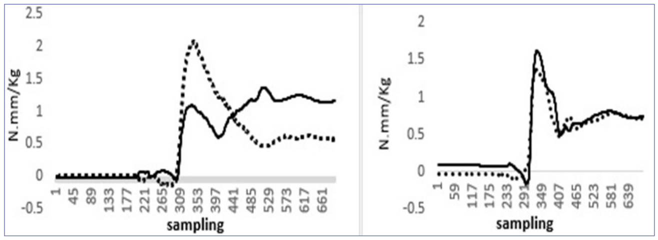

Figure 2. A sample of knee adduction moment (dashed line) and knee flexion moment (solid line) in the normal FPA during sit-to-stand in the KOA group (left) and the control group (right).

FPA: foot progression angle; KOA: knee osteoarthritis.

Data analysis

The normal data distribution was confirmed using the Shapiro-Wilk test ($p > 0.05$). Anthropometric parameters and muscle strength calculated in the KOA and control groups were analyzed using a regular t-test. The repeated-measures ANOVA and Bonferroni *post-hoc* test were used to determine the effects of group and FPA condition and their interactions on the knee kinetic and kinematic parameters during STS. Statistical significance was set at $p \leq 0.05$. SPSS 22 (IBM, NY, USA, 2013) was used for the statistical analysis.

RESULTS

Anthropometric data included age, height, weight, BMI, lower limb length, and normal FPA, and are shown in **table I**. In this regard, there was no significant difference between the two groups ($p > 0.05$).

The values of the MVIC are reported in **table II**. There was a significant decrease in the strength of the hip flexors and extensors, hip abductors and adductors, knee extensors, and ankle plantar flexors in the KOA group compared to the control group. However, ankle dorsiflexion's difference was insignificant ($p = 0.059$).

As **table III** shows, T-I decreased KAM in both groups. Reduction of KAM was significant in both control ($p = 0.050$) and KOA ($p = 0.025$) groups. In the KOA group, peak KAM decreased significantly with T-I compared to normal FPA ($p = 0.042$) and T-O ($p = 0.02$). In the control group, peak KAM showed a significant decrease in T-I compared to T-O ($p = 0.006$). Moreover, the peak time of KAM showed a significant change in the control group ($p < 0.001$), and KOA group ($p = 0.025$). In the KOA group PTKAM in T-O showed a significant decrease compared to normal FPA ($p = 0.034$). In the control group, the peak time of KAM decreased significantly in both T-I ($p = 0.013$) and T-O ($p = 0.003$) compared to normal FPA. Furthermore, the maximum KFM and the peak

Table I. Anthropometric data in the two study groups (mean ± SD).

Variable	Control n = 15	KOA n = 19	P-value
Male/Female	5/10	10/9	NA
Age (year)	51.7 ± 5.23	50.05 ± 6.73	0.63
Height (cm)	167.33 ± 9.44	164.68 ± 7.48	0.36
Weight (kg)	76.67 ± 11.67	76.84 ± 11.3	0.96
BMI (kg/m²)	27.10 ± 2.67	28.13 ± 3.31	0.33
Leg Length (cm)	88.47 ± 6.85	85.37 ± 4.33	0.11
Original (normal) FPA (°)	-8.40 ± 5.95	-8.50 ± 6.45	0.96

SD: standard deviation; KOA: the knee osteoarthritis group; NA: not applicable.

Table II. The maximum isometric voluntary contraction (MVIC) of the lower limb muscles in the two groups (mean ± SD).

MVIC (kg)	KOA group n = 19	Control group n = 15	P-value
Hip flexion	10.75 ± 3.03	13.57 ± 3.30	**0.001**
Hip extension	9.17 ± 2.08	13.01 ± 3.25	**< 0.001**
Hip abduction	9.76 ± 1.65	13.57 ± 3.39	**0.001**
Hip adduction	8.41 ± 2.16	10.92 ± 2.89	**0.007**
Knee extension	8.33 ± 2.10	11.08 ± 3.56	**0.008**
Knee flexion	6.92 ± 1.89	10.01 ± 3.41	**0.006**
Ankle dorsiflexion	7.52 ± 2.28	9.20 ± 2.70	**0.059**
Ankle plantar flexion	9.30 ± 1.57	12.02 ± 2.71	**0.001**

KOA: the knee osteoarthritis group.

Table III. The knee kinetic and kinematic parameters in the STS test in the control and KOA group (mean ± SD).

Variable	Control group n = 15	P-value	KOA group n = 19	P-value
peak KFM N (Nm/kg)	0.99 ± 0.72		0.51 ± 0.77	
peak KFM T-I (Nm/kg)	0.83 ± 0.58	0.1	0.48 ± 0.77	0.060
peak KFM T-O (Nm/kg)	0.90 ± 0.68		0.64 ± 0.87	
PT KFM N (s)	2.60 ± 0.45		2.57 ± 0.55	
PT KFM T-I (s)	2.09 ± 0.39	0.132	2.34 ± 0.56	0.072
PT KFM T-O (s)	2.33 ± 1.04		2.29 ± 0.46	
peak KAM N (Nm/kg)	1.77 ± 0.34		1.89 ± 0.73	
peak KAM T-I (Nm/kg)	1.65 ± 0.39	0.050	1.75 ± 0.62[*]	0.025
peak KAM T-O (Nm/kg)	1.90 ± 0.49[€]		1.92 ± 0.74	
PT KAM N (s)	2.48 ± 0.43		2.41 ± 0.54	
PT KAM T-I (s)	2.01 ± 0.39[$]	< 0.001	2.27 ± 0.53	0.025
PT KAM T-O (s)	1.96 ± 0.36[¥]		2.15 ± 0.47[¥]	

KFM: knee flexion moment; N: normal FPA; T-I: toe-in; T-O: toe-out; PT: peak time; KAM: knee adduction moment; KOA: the knee osteoarthritis group; *significant between N and T-I (p = 0.042) and also T-O and T-I (p = 0.02); €significant between T-O and T-I (p = 0.006); [$]significant between N and T-I (p = 0.013); [¥]significant between N and T-O (p = 0.003).

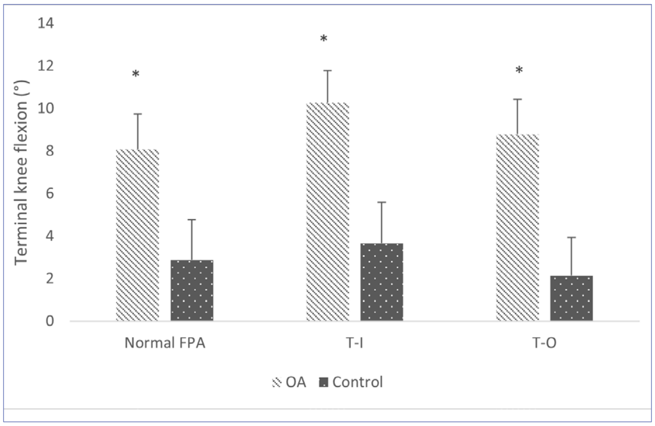

Figure 3. Comparison of the terminal knee flexion angle during sit-to-stand.

N: normal FPA; T-O: toe-out; T-I: toe-in; FPA: foot progression angle; KOA: knee osteoarthritis; *significant change compared to the control group at the same FPA.

time of KFM showed no significant changes in both group. In all FPA conditions, the TKFA was significantly higher in the KOA group than the control group; on the other hand, the TKFA was higher in all FPA conditions compared to the same in the control group (**figure 3**).

The univariate analysis revealed that the main effect of the group was significant for the maximum KFM (p = 0.017). Thus, regardless of the FPA condition, the maximum KFM was significantly lower in the KOA group (**figure 4A**). The maximum KAM was higher in the KOA group in all FPA conditions, although this difference did not reach significance (p = 0.520, **figure 5A**). T-I decreased the maximum KAM during STS, and T-O increased it compared to STS in normal FPA; the main effect of the group and FPA were insignificant. Moreover, irrespective of whether the knee joint is healthy or osteoarthritic, the peak times of KFM (p = 0.035, **figure 4B**) and KAM (p = 0.003, **figure 5B**) occurred significantly sooner in the T-O and T-I than in normal FPA.

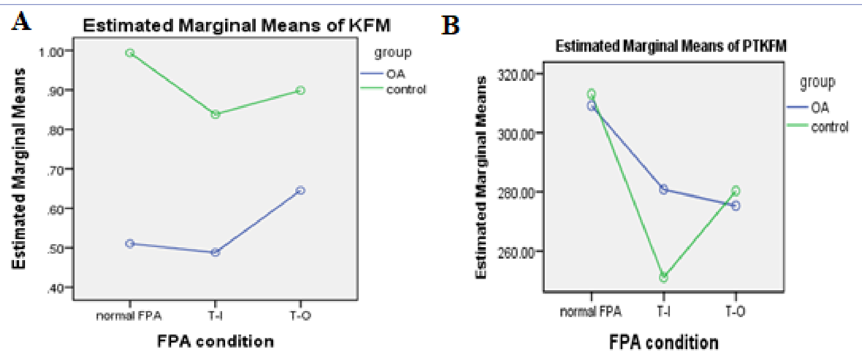

Figure 4. (A) The peak KFM in the three FPA conditions during the STS in the KOA and control group; the main effect of the group being significant (p = 0.017); **(B)** The peak time of KFM in the three FPA conditions during the STS in the KOA and control group; the effect of FPA being significant (p = 0.035).

KFM: knee flexion moment; FPA: foot progression angle; KOA: knee osteoarthritis.

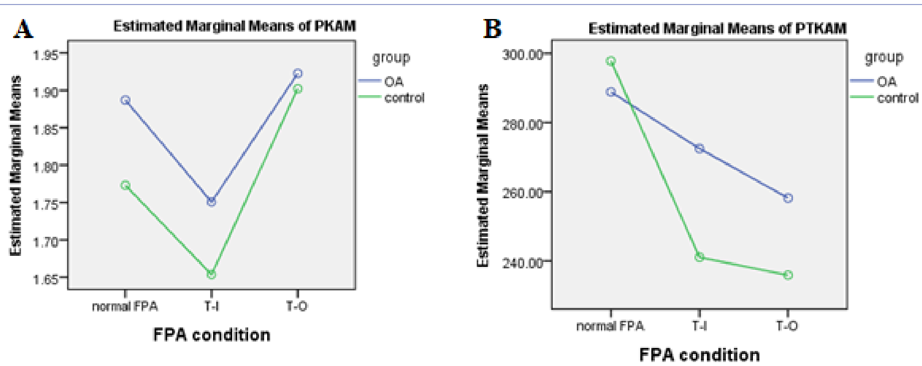

Figure 5. (A) The peak KAM in the three FPA conditions during the STS in the KOA and control group; no significant difference (p > 0.05); **(B)** The peak time of KAM in the three FPA conditions during the STS in the KOA and control groups, the effect of FPA being significant (p = 0.003).

KAM: knee adduction moment; FPA: foot progression angle; KOA: knee osteoarthritis.

DISCUSSION

This study aimed to investigate the effect of 10 degrees of T-O and T-I on KAM and KFM and their peak times during STS in the KOA and healthy age-matched people. Overall, the results showed an increase in the KAM and a decrease of KFM during STS in the KOA people compared to the age-matched healthy group; however, the rise in KAM was insignificant. A key finding of the present study was that T-I decreased the peak KAM during STS in both KOA and healthy age-matched groups. In addition, T-O and T-I decreased the peak time of the KAM and KFM when compared with STS in the normal FPA. Furthermore, people with KOA had a significantly higher TKFA in all FPA conditions than healthy control subjects. The higher TKFA may be due to an attempt to decrease the load on the knee articular surface and, consequently, pain during the loading phase of STS because Thomas *et al*. showed a condition-related variation in the knee kinematics for changing the joint loading. They concluded this behavior can have a profound influence on the initiation and progression of osteoarthritis of the knee (15). In the current study, the peak KAM in the KOA group was higher than in healthy individuals in all three FPA conditions, but this difference was insignificant. This finding accords with Sonoo *et al.*, where no significant differences were reported between the KOA and healthy individuals in terms of KAM (2). Of course, it should also be noted that the role of KAM is less through STS than walking (12).

Furthermore, increasing the lateral lean of the trunk to the healthy side may prevent KAM changing (16). Finally, we excluded the participants with varus and valgus deformities; these deformities in the knee joint significantly affect KAM. The knee varus is one of the best predictors of increasing the KAM (17). The lower KFM in people with KOA may be a cautious behavior to decrease knee contact force and knee pain during STS. Electromyography for recording trunk and lower limb muscle activities during STS might help clarify detailed strategies. Of course, in the present study, we showed a significant reduction of MVIC in the KOA people, so they probably have to co-contract muscles around the knee joint that will increase the knee contact forces (18).

During STS with T-I, a significant decrease in KAM was observed in both groups. Khan *et al.* showed that T-I reduced the adduction moment impulse at all walking speeds and that the T-I gait pattern at the highest walking speed reduced the peak of KAM (19). Also, Booij *et al.* showed that the T-I gait causes the most significant instantaneous reduction in KAM (20). Unlike some studies that have shown a decrease in KAM with T-O during walking, in the present study, KAM increased with T-O during STS, which was more significant than T-I in both groups. Turkot *et al*. examined FPA conditions during STS in healthy young people and explored the effect of T-O (10°, 20°, and 30°) in one foot or both feet on the reduction of KFM. They attributed the decrease in KFM to shifting weight to the contralateral leg due to the unusualness of the task (21).

Theoretically, T-I reduces KAM by displacing the center of pressure laterally and the center of the knee joint medially in the early stance (22). Further, T-I causes the external shift of the center of pressure with external heel rotation around a relatively fixed position of the forefoot (10). This outward shift can also be observed in T-O but with the external displacement of the forefoot. It is important to note that the current study explored the immediate effect of FPA conditions. So, long-term retraining should be considered to determine the impact of gait retraining on essential daily activities such as STS by forming adaptive patterns (23); STS is vital to the indecency of older adults with KOA. Given that T-I during the STS activity reduced KAM in the present study, and this parameter reflects increased internal loading in the tibiofemoral joint, it may be advisable for KOA patients with severe pain during STS to adopt the T-I condition during this activity.

We found that the main effect of the FPA condition was significant in decreasing the peak time of the KAM and KFM. Regardless of the knee joint condition (healthy or OA), the peak time of the KAM and KFM in T-O and T-I decreased compared to normal FPA. This reduction might be related to performing an unusual task that needs more caution to control balance. It may be associated with the early recruiting of fast motor units to maintain balance and perform an unusual sit-to-stand task. Unfortunately, we could not compare this result with other studies because the peak time of KAM and KFM during STS has not been subjected to scientific research, a fact mentioned by Sonoo *et al*. (2). Athletes and people undertaking intense physical activity are at high risk to develop early KOA (24), we suggest the investigation of gait retraining, especially with 10 degrees of toe-in in these target groups with KOA. Pain decrease and improvement of quality of life in these highly active people are very important. They are younger and more cooperative in the exercise program, and they may report better results.

A limitation of the present study was the small sample size. Also, it is better to consider trunk changes during STS; unfortunately, we used the Plug-In-Gait lower body marker set and neglected the flexion of the trunk during STS. Another limitation was the lack of simultaneous recording of electromyography, which will be very important in determining the muscle strategy of KOA and healthy people during STS in different FPA conditions. In the present study, we investigated the immediate effect of FPA modification on knee moments. In future studies, the effect of adaptations made in FPA following long-term gait retraining should be considered on the knee moments and contact forces in functional activities such as STS and stair climbing in KOA people.

CONCLUSIONS

The results revealed that people with KOA had significantly higher terminal knee flexion during STS in all FPA conditions. This may be due to an attempt to decrease the load on the knee articular surface and, consequently, the pain during STS. In addition, the immediate effect of FPA modification at 10 degrees of T-I in both healthy and KOA groups reduced KAM during STS, which may effectively diminish knee joint loading. Therefore, adopting a T-I condition during STS can be recommended in KOA patients with severe pain. The shorter peak time of KAM and KFM in healthy and KOA people during STS at 10° T-I and T-O may indicate early recruitment of faster motor units to control balance while performing an unusual task.

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DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

GT: conceptualization, design. FF, SG: data acquisition. FF, SG, GT: data analysis and interpretation, writing – original draft. GT: writing – review & editing. All authors: manuscript approval.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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