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Knee extensor moments during Sit-Stand-Sit cycle and its correlation with foot placement: Laboratory Report

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Abstract:

Individuals with neurological impairments experience difficulties in achieving sit-stand-sit manoeuvre. Foot placement was found to result in alterations to knee moments throughout sit-stand-sit cycle. This study aimed to investigate the relation between foot position and knee extensor moments of both limbs during Sit-Stand-Sit cycle. Two healthy right-footed female volunteered to participate in this study, which was carried out in the human movement laboratory at the Nottingham City Hospital, Nottingham, United Kingdom. Muscle strength was assessed by isokinetic dynamometer and a three-dimensional motion analysis system was used to assess knee moment. Regarding muscle strength, torque values were higher in the dominant side, also both subjects had high symmetry in eccentric values, while for concentric values subject 2 had low symmetry. Higher knee extensor moment values were reported for dominant limb when feet were symmetrical and dominant foot was placed posteriorly. But when the non-dominant foot was behind, knee extensor moments were greater for the non-dominant side. In conclusion, placing the limb in the more anterior position during Sit-Stand-Sit cycle result in an increase of the knee extensor moment of the contralateral side. Also a linear relationship revealed between muscle strength and knee moment symmetry. These results could be translated for neurological patients to increase knee moments, decrease moment asymmetry and avoid the learned nonuse syndrome.

Key Words: *Foot Position, Knee Moment, Sit To Stand*

Introduction

A prerequisite for active life and mature performance of most daily life activities is the ability to smoothly move body mass from a stable sitting position to a less stable standing position (SitTS), and the opposite (standTS), in an energy efficient way.[1] Sit-to-stand was described as "a complex multi-joint action that may be representative of a class of actions in which the lower limbs provide support, propulsion and balance as the body mass is raised and lowered over the fixed feet".[2] The two main components of the sit-stand-sit movement are rising and descending phases; between this is a relaxed time.[3] Specifically, four phases compromises STS: flexion momentum phase whereby forward momentum results from trunk and pelvic motion; momentum-transferred phase when the centre of mass (COM) travels anteriorly and vertically; extension phase through the occurrence of peak knee extension moments,[2,4] hip and knee full extension, and the speed of hip joint movement decelerates to reach 0°/sec; finally the stabilisation phase when the end of motion occurs.[5]

The successful completion of the sit-stand-sit cycle is related to several internal and external determinants. For example, internally, joint moment and muscle strength plays a critical role in this process,[6] whilst externally; the influence of chair height and foot position has been reported.[1,7,8] A review conducted by Janssen et al.[9] categorised these determinants into three groups: chair-related (seat height); subject-related (age and muscle strength); or strategy-related determinates (foot placement). In this review only five experimental studies investigated the impact of foot repositioning on sit-stand-sit, compared to twelve studies concerning chair height influence. Individuals with neurological impairments experience difficulties in achieving sit-stand-sit manoeuvre.[10,11,12] For patients to overcome this dysfunction, they must adopt different strategies to compensate and achieve this movement. Cheng et al.[13] reported the average time required to accomplish the STS task is 1.8 seconds for able-bodied individuals and between 2.7sec (non-fallers) to 4.3sec (fallers) for stroke survivors. Falls whilst SitTS or StandTS, accounted for more than one third of the total falls in stroke population.[13] Concerning foot placement, the difference between elderly and young people is that the dorsiflexion angle at the beginning of the STS in elderly tends to be reduced compared with younger individuals.[14] The former foot placement in elderly persons increases the horizontal distance that required to locate the centre of mass (COM) over the feet which results in more hip flexion and momentum generation to avoid increasing extensor moments. Farqalit and Shahnawaz[15] reported that foot positioning in SitTS with the affected extremity behind enhances SitTS performance, balance and mobility for chronic stroke population.[15] Although this study was a double blinding randomized trial and included 40 participants, male participants contributed approximately 73% of the total sample size, which limits the generalisability of the results. Moreover, Brunt et al.[7] found that placing the dominant or unaffected limb anteriorly in healthy and hemiplegic individuals increases quadriceps activity and force production. On the contrary, Camargos et al.[16] conflicts the previous study and suggests that positioning the affected foot posteriorly is not beneficial for STS performance. The latter study was at high risk of type two error since the sample size was small (n=12).

In terms of knee joint moments, foot placement was found to result in alterations to knee moments throughout sit-stand-sit cycle. In able-bodied individuals, placing ankle joint of one limb in more extended position increases knee extensor moments of the contralateral limb by 66%.[17] Additionally, Roy et al.[18] studied the knee extensor moments in different foot positions during SitTS and StandTS tasks; their results support conclusions of the previous study. StandTS movement employs eccentric contraction of knee extensors[1], however, Roy et al.[18] measured only concentric strength of knee extensors. Based on the literature, the effect of foot placement on knee extension moments and asymmetry between sides is poorly investigated, particularly during StandTS movement. This study purposed to investigate the relation between foot position and knee extensor moments of both limbs during Sit-Stand-Sit cycle; hypotheses follow: (1) Placing the limb in the more anterior position during Sit-Stand-Sit cycle will increase the knee extensor moment of the contralateral side. (2) Placing the dominant limb anteriorly during Sit-Stand-Sit cycle will result in the least asymmetrical knee extensor moments between both sides among all foot positions.

Materials and methods

Participants: Two healthy (female, mean age 25.5 years, height 1.7m, weight 72.8kg) right-footed participants, with no diagnosed musculoskeletal or neurological pathology, volunteered to participate in this study after providing informed consent (Table 1). This experiment was carried out in the human movement laboratory at the Nottingham City Hospital (University of Nottingham).

Table 1: Characteristics of the subjects

Characteristics	Subject 1	Subject 2
Gender	F	F
Age (years)	25	26
Height (m)	1.73	1.63
Weight (kg)	88.5	57.25
BMI (kg/m^2)	29.6	21.5
BMI: Body Mass Index, F: Female, m: meter, kg: kilogram		

Procedures: Measurement of muscle strength: To assess muscle performance, isokinetic dynamometer with a computer that displays and stores the data used frequently which was considered as a gold standard.[19] Test-retest and interrater reliability of measuring concentric and eccentric knee extensor peak torque by isokinetic dynamometer is very high (ICC, 0.88 to 0.95).[20,21] The reliability of concentric strength measurement is higher than an eccentric one.[22] Additionally, the construct validity was reported to be good.[23] A Cybex dynamometer (Figure 1) was used in this study to measure maximal concentric and eccentric knee extensor torque (Nm: newton meter) of both limbs out of five repetitions at 60degree/sec angular velocity. Definite weights were used by the manufacturer every six months to calibrate this device. Subjects were seated with 95° hip flexion and 90° knee flexion. Stabilisation straps were placed across thighs, pelvis and trunk to minimise the effect of body movement on knee extensor torque.[24] The anatomical axis of knee joint was aligned with the mechanical axis of the dynamometer; a padded attachment at the end of the lever arm placed above the malleolus. The range of motion was 0° to 110° knee flexion to ensure sufficient ROM. Subjects were instructed to contract the knee extensors and put maximum effort into the movement. Verbal encouragement "Push as hard as you can" was given. Before testing, each subject had three practice trials to become familiar with the instrument.

Measurement of knee extensor moment during Sit-Stand-Sit cycle: Frykberg et al.[25] and Roy et al.[18] employed a three-dimensional motion analysis system integrated with AMTI force platforms (Advanced Mechanical Technology Inc.) implemented in the floor under each foot to measure kinetic and kinematic data. The computer-based force platforms measures ground reaction force under each foot during Sit-Stand-Sit cycle.[26] This system utilises infrared markers placed on the bony landmarks of both lower extremities to represent body segments. Inter and intra-rater reliability of a 3D motion analysis system is higher in the sagittal plane (CMC 0.85-0.87).[27] It was found to be highly reliable to measure proximal joints such as knee joint[28,29] and kinetic rather than kinematic data.[30] Although this technique is considered a gold standard, no studies investigated its validity or reliability in Sit-Stand-Sit.

Figure 1: Isokinetic knee moment assessment

CODA motion analysis system (Figure 2) was used and calibrated in the same day of conducting this study with a calibration frame to define the axes, origin of the laboratory and the location of the force platforms. The CODA motion bilateral gait marker set was used to place the reflective markers on both limbs. The subjects sat on a backless, armless and adjustable plinth with one foot positioned on each force plate and keeping arms crossed over chest to eliminate the use of the upper limb during task execution at a comfortable, self-paced speed. The plinth level adjusted to height of 42.4cm for both participants in all trials that were consistent with the mean of lower leg length of both participants (42.6cm, SD 0.5). Participants were barefoot 21.5cm apart and dressed in shorts. They were instructed to stand when were told “Stand now” and sit when told “Sit now”. One trial of SitTS and StandTS tasks for the three foot positions performed: symmetrical (S) both feet backward; asymmetrical with dominant foot backward (AS-D); asymmetrical with non-dominant foot backward (AS-ND) with a short pause between the two tasks. The backward foot angle was at 15° dorsiflexion. To ensure consistency between subjects, placing the markers and motion analysis measurement were conducted with the same examiner.

<u>Data analysis</u>: Peak isokinetic moment values were normalised to the subjects’ body weight to eliminate body weight influence and enable comparisons with knee extension moments and between subjects.[31] Net knee moments were recorded by CODA and converted to a proportion of peak isokinetic knee moments. To measure lack of symmetry between knee extension moments of both legs, asymmetry ratios were calculated with this formula:

$$\textbf{\textit{Knee moment asymmetry}} = \frac{\textit{knee moment of non-dominant limb}}{\textit{Knee mooent of dominant limb}}$$

This formula was used by Camargos et al.[16] and Lecours et al.[32] to measure asymmetry between both sides, in which the value of 1 represented perfect symmetry. The mean for all the previous data was calculated.

Figure 2: Knee extensor moment assessment during SitTS and StandTS (AS-D condition)

Results

Muscle strength: Absolute and normalised torque values were higher in the dominant side, reflecting that participants had a weaker non-dominant limb and this was not concentric or eccentric strength dependent (Table 2). Regarding subjects comparison, subject 1 generally had more muscle strength. Furthermore, when comparing strength asymmetry by calculating strength ratio (ND/D), both subjects had high symmetry in eccentric values (0.9) while for concentric values, subject 2 had low symmetry (S1:0.98, S2:0.6).

Table 2: Absolute & normalised torque values for dominant & non-dominant sides.

Subject	Concentric				Eccentric			
	(Nm)		(Nm/Kg)		(Nm)		(Nm/Kg)	
	D	ND	D	ND	D	ND	D	ND
1	167	163	1.89	1.84	285	262	3.22	2.96
2	130	81	2.27	1.41	157	142	2.74	2.48
Mean	148.5	122	2.08	1.63	221	202	2.85	2.72
Ratio	0.8				0.9			
D: dominant, ND: non-dominant. Nm: Newton meter, Kg: Kilogram.								

Knee extensor moments during SitTS and StandTS: Higher knee extensor moment values were reported for dominant limb in S and AS-D conditions. However, in AS-ND condition knee extensor moments were greater for the non-dominant side. These results were not task dependent (Figure 3).

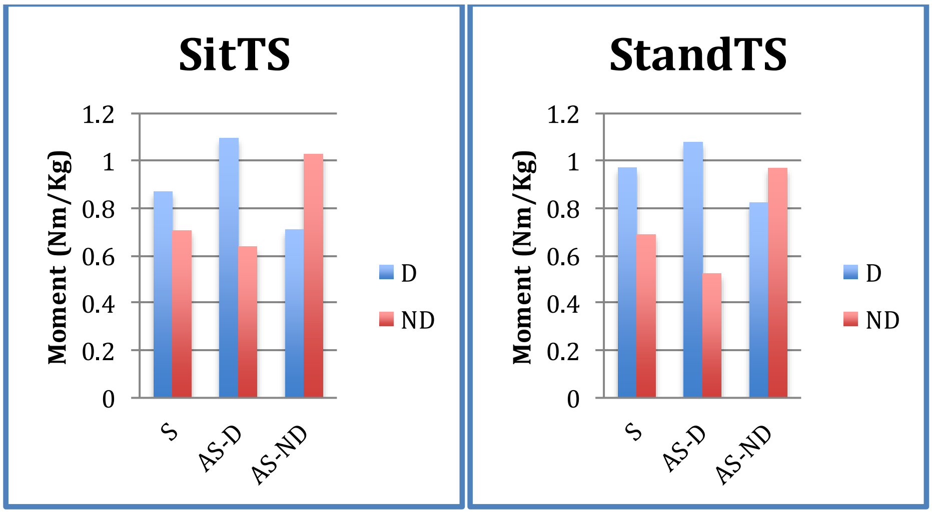

Figure 3: Graph showing knee extensor moments for both sides during SitTS and StandTS in different foot positions.

Knee extensor moment asymmetry in different foot placements: Concerning foot placement comparisons in SitTS, ratio values revealed the lowest level of asymmetry in S condition, whilst in StandTS, the lowest knee extensor moment asymmetry was found in AS-ND condition (Table 3).

Table 3: Knee moment asymmetry during SitTS and StandTS in different foot positions

	SitTS (Ratio)			StandTS (Ratio)		
Subject	S	AS-D	AS-ND	S	AS-D	AS-ND
1	0.8	0.7	1.2	0.8	0.9	1.1
2	0.8	0.5	1.7	0.6	0.2	1.2
Mean	0.8	0.6	1.5	0.7	0.5	1.2

Knee moments as a proportion of isokinetic measurement: The highest mean values recorded for the non-dominant limb were in AS-ND condition approaching (65.4%, 36.1%) and for dominant side in AS-D condition (52.6%, 37.1%) during SitTS and StandTS respectively (Tables 4 and 5).

Table 4: Knee extensor moments as a proportion of peak isokinetic moments during SitTS in different foot positions.

SitTS (%)						
Subject	S		AS-D		AS-ND	
	D	Nd	D	Nd	D	Nd
1	44.7	35.8	50.7	33.9	40.4	49.6
2	39.5	53.6	54.4	46.5	28.9	81.1
Mean	42.1	44.7	52.6	40.2	34.7	65.4

Table 5: Knee extensor moments as a proportion of peak isokinetic moments during StandTS in different foot positions.

StandTS (%)						
Subject	S		AS-D		AS-ND	
	D	Nd	D	Nd	D	Nd
1	28.4	24.9	26.2	25.5	24.9	30.6
2	37.6	25.9	47.9	11.8	30.9	41.6
Mean	33	25.4	37.1	18.7	27.9	36.1

Discussion

The results revealed that subject 2 has a weaker non-dominant limb concentrically, whilst eccentrically, subject 1 has higher values.[33,34] Regarding side differences, an increase in knee extensor moments of dominant side during sit-stand-sit cycle was obvious in AS-D condition compared to S and AS-ND ones. The reverse is true whereby knee extensor moments of non-dominant limb increases in AS-ND condition compared to the other ones. Results confirmed those found by Gillette and Stevermer[17] in healthy subjects and Roy et al.[18] in stroke population. Hence, this supports our first hypothesis. The evidence found that knee extensor moment asymmetry in asymptomatic subjects during SitTS task was higher in AS-D and AS-ND conditions than symmetrical foot placement[17,32]. Our findings support these results.

The comparison of AS-D and AS-ND conditions showed that knee moment asymmetry in AS-D condition was less than AS-ND, which contradicts the values of Gillette and Stevermer[17]. However, the difference was not significant in their study. In stroke population, higher knee extension moment asymmetry detected in S (ratio: 0.46) and Asymmetrical with non-affected limb placed posteriorly strategies than when positioning the paretic side posteriorly (ratio: 0.93).[18,32] Generally, hemiplegic patients experienced the highest asymmetry in AS-UA strategy.

The results also revealed that during the execution of StandTS task knee moment asymmetry was lowest when the non-dominant foot was placed posteriorly and the opposite is true for AS-D condition that presented the highest level of moment asymmetry. These observations were consistent with the results reported by Roy et al.[18]. Hence, our second hypothesis is not confirmed completely regarding between tasks comparison.

There is some value in taking subject comparisons into consideration. Here subject 1 had higher level of knee extension moment symmetry ranging from 0.7 to 1.2 compared to subject 2 ratio 0.5-1.7 in all different foot positions. Less symmetry regarding subject 2 could be explained as a result of the weaker dominant and non-dominant knee extensor muscles, particularly during concentric contraction (81Nm) in comparison to subject 1 and normative data.[33,34] This emphasizes the linear relationship between muscle strength and knee moment symmetry that Roy et al.[18] highlighted, which states the more muscle strength an individual has, the more symmetrical their knee extensor moments. This is consistent with the critical role of muscle strength in weight bearing distribution symmetry[35] and the independent performance of Sit-Stand-Sit manoeuvre.[11,36]

Of equal interest, positioning foot posteriorly requires higher use of the total isokinetic muscle moment. This could indicate a relation with the increase in quadriceps activity and vertical ground reaction forces as approved previously[7,8] when placing the dominant leg in an anterior position, in turn forces healthy and hemiplegic individuals to use the other limb. Based on the literature, placing the paretic limb behind could increase knee moments, decrease moment asymmetry and avoid the learned nonuse syndrome in stroke population, which should provide therapists with a tool for designing rehabilitation programmes. Finally, the existent relation between muscle strength and moment symmetry should be taken into consideration.

Several limitations in this study should be taken into consideration. A small sample size is not representative of a population and subjects were young healthy females so the sit-stand-sit movement might not be a challenging task for them. The determination of bony landmarks, the sensors placements and peak knee moment on the screen were manual and based on visual inspection. Therefore this procedure could be a source of error leading to less accurate data. The utilisation of three-dimensional motion analysis also has its limitations. This equipment is time consuming and not cost-effective which limits the number of participants that can be analysed in such study. It is also a laboratory-based tool so clinical application is restricted. Soft tissue artefacts were found to have significant impact on knee extensor moments during sit-to-stand movement which contributes to systematic error.[37] Moreover, measuring only one joint and only in sagittal plane might underestimate the contribution of other joints (hip, ankle) or the same joint in different planes. Consequently, subjects could use these contributions to compensate for knee extensor weakness, particularly because participants in this study were healthy and strong enough to have strong hip or ankle muscles.[2,38] Further, only one trial for each foot position was recorded by CODA system whilst 10 trials are recommended to improve the reliability of data[39], also more statistical analysis could provide robust information and reveal underlying factors. Finally, people accomplish sit-stand-sit movement with arms free in daily living which results in more use of momentum-generation strategy that in turn could alter joint moment production when performing this task with unconstrained arms compared to the procedure used in this study.[24,40] Generalisability of our results is limited and many factors should be considered before interpretation. These limitations could be the reason for contradictory results regarding the second hypothesis.

Conclusion:

Repositioning foot anteriorly during Sit-Stand-Sit cycle results in an increase of the knee extensor moment of the contralateral side. Also a linear relationship revealed between muscle strength and knee moment symmetry. These results could be translated for neurological patients to increase knee moments, decrease moment asymmetry and avoid the learned nonuse syndrome.

Disclosure of interest: The authors declare that there is no conflict of interest.

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