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Leg Dominance may not be a Predictor of Asymmetry in Peak Joint Moments and Ground Reaction Forces during Sit to Stand Movements

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Abstract

Sit-to-stand transfer is a common prerequisite for many daily tasks. Literature, often assumes symmetric behavior across the left and right side. Although this assumption of bilateral symmetry is prominent, few studies have validated this supposition. This pilot study uniquely quantifies peak joint moments and ground reaction forces (GRFs), using a Euclidian Norm approach, to evaluate bilateral symmetry and its relation to lower limb motor-dominance during sit to stand in ten (10) healthy males. Peak joint moments and GRFs were determined using a motion capture system, and inverse dynamics. This analysis included joint moment contributions from all three body planes (sagittal, coronal, and axial) as well as vertical and shearing GRFs. A paired, one-tailed t-test was utilized, suggesting asymmetrical joint moment development in all three lower extremity joints as well as ground reaction forces ($P<.05$). Furthermore, using an unpaired two-tailed t-test, asymmetry developed during these movements does not appear to be predictable by participants' lower limb motor-dominance ($P<.025$). Consequently, when evaluating sit-to-stand it is suggested the effects of asymmetry be considered in the interpretation of data. The absence of a relationship between dominance and asymmetry prevents the suggestion that one side can be tested to infer behavior of the contralateral.

Keywords: biomechanics, kinetics, motion analysis, sit-to-stand, bilateral-symmetry

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Introduction

Rising from a chair or sit-to-stand is a critical prerequisite for many daily tasks. Sit-to-stand often precede walking and thus is a functional requirement for an independent lifestyle.[1, 2] Therefore, an accurate understanding of the biomechanical requirements to successfully accomplish this task is necessary for rehabilitation and therapeutic programs for patients with limited lower extremity function.

Research and clinical based evaluations are incorporating sit-to-stand as an assessment tool for lower extremity impairment. Boonstra *et al* and Christiansen *et al*. have utilized sit-to-stand symmetry to evaluate knee function following arthroplasty. Both researchers found vertical-ground reaction forces to become more symmetrical with longer post-operative times.[3-5] Furthermore, Christiansen *et al*. were able to quantify the degree of asymmetry present in vertical ground reaction forces of a healthy control group.[5] Outside orthopedics, sit-to-stand symmetry has been used to assess movements in elderly populations, hemiparesis, and prosthetics among others.[2, 6-8] Although asymmetry is often used as an indication of impairment, healthy populations do not necessarily exhibit perfect symmetry. Consequently, to enable sit-to-stand symmetry as an assessment tool for affected populations, and in depth understanding of healthy movements is necessary.

Researchers often captures joint moment data two dimensionally, or in the sagittal plane only, neglecting contributions from the coronal and axial planes on sit-to-stand biomechanics.[8-10] Similarly, when evaluating ground reaction forces (GRFs), few studies consider the shearing forces in the anteroposterior and medial-lateral directions; focusing only on vertical ground reaction forces, potentially neglecting relevant force data.[1, 4, 5] Furthermore, literature often assumes bilateral symmetry in healthy populations; where left and right side of the body are hypothesized to operate symmetrically with joint moments and GRFs assumed contralaterally equivalent.[10-13] However, asymmetry in lower limb kinetics has been widely demonstrated in healthy populations performing non- sit-to-stand related, tasks.[14-18]

Certain aspects of sit-to-stand symmetry have been addressed. Lundin *et al.* found significant differences between left and right sagittal joint moments at the hip in an elderly and young population with further asymmetry at the knees of the young group.[9] However, this investigation was limited to sagittal movement. Burnett *et al.* found no significant difference between dominant and non-dominant side peak vertical-GRFs.[1] These values were collected using a single force plate that was alternated between the participants' feet for each trial. If vertical-GRFs are asymmetrical but not related to lower limb dominance, peak values may be higher in the dominant side in one trial and the non-dominant in the next. This phenomenon would not be captured with one instrumented limb, and may not adequately capture asymmetry.

The objective of this pilot study was to evaluate peak joint moment and GRF bilateral symmetry, and the relation to lower limb motor-dominance during sit-to-stand in healthy participants. A Euclidian Norm approach was utilized for inclusion of off-sagittal joint moment and GRF data.

Methods

Ten male participants were selected for inclusion in this study (mean age: 25.4 ±4.2 years, mean height: 1.77 ±0.09 meters, mass: 70.5 ±8.7 kilograms). Males were selected to remove possible biomechanical gender differences present in non- sit-to-stand related motion analysis.[19] Subjects reported no prior or current physical conditioning or injuries that may affect their sit-to-stand movements. Ethics approval was obtained through the institution's ethics review board. All participants gave informed consent prior to participating. Five right and five left handed participants (self-reported) were selected to increase the chances of equal numbers of right and left, lower limb motor-dominant participants.

To determine lower limb motor-dominance, participants completed a questionnaire following the 11-item Chapman Inventory for foot preference two weeks before, and on the date of testing.[20] To verify questionnaire results, participants performed the top 4 tasks most closely correlated with lower limb motor-dominance, the foot selected to perform each task was recorded.[20] As intended, results confirmed five left foot dominant and five right foot dominant participants were selected.

1.5 cm diameter spherical reflective markers were used to define 8 body segments (feet, shanks, thighs, pelvis and torso) according to the Helen Hayes protocol.[21] Additional markers were adhered between the clavicles, centered on the sternum and affixed to the C7, to capture torso position.

Markers position was captured using an 8 camera, Eagle Digital Motion Analysis system (Motion Analysis Corp., Santa Rosa, CA, USA) sampling at 120Hz. Two AMTI (Advanced Mechanical Technology Inc., Newton, MA, USA) force plates sampling at 2400Hz were utilized to capture GRFs.

A backless, armless, 48cm tall, chair was positioned such that the participant could place one foot approximately centered on each force place.[5] Subjects were instructed to sit comfortably toward the front of the chair, and symmetricity of the initial posture was visually verified prior to each trial. Participants folded their arms across their chest and rose at a self-selected pace when prompted. The use of upper extremities during the sit-to-stand task was not permitted. This procedure required 10 trials for each participant.

Marker motion data was imported into Visual 3D software (C-Motion Inc., Germantown, MD, USA) where inverse dynamic calculations were performed. Each participant's body-segment properties were input according to height and mass dependant, 50th percentile anthropometric data.[22(pp 83-93), 23(pp 591-611)] A 4Hz, fourth-order, Butterworth filter was utilized in Visual 3D to smooth raw force and motion data.[22(pp 68-73)]

Joint moments were quantified in all 3 planes at the ankle knee and hip and normalized by each participant's body mass and body height; additionally, GRFs were recorded and normalized by body mass.[19]

To determine total joint moments and GRFs, the Euclidian Norm was utilized by treating the anteroposterior (ap), medial-lateral (ml) and superior-inferior (si) moments (Eq. 1). Similarly this procedure was used for three dimensional GRF data (Eq. 2). Peak motor-dominant and non-dominant joint moment and GRF values were identified as the maximum value occurring at each joint for each sit-to-stand trial.

$$M_{total} = \sqrt{M_{ap}^2 + M_{ml}^2 + M_{si}^2} \qquad (1)$$

$$GRF_{total} = \sqrt{GRF_x^2 + GRF_y^2 + GRF_z^2} \qquad (2)$$

Asymmetry was defined as a difference in the peak value of one side relative to the contralateral for each trial. The larger of the two peak values was grouped into one category and the smaller in another. If sit-to-stand is a statistically symmetric movement, the means of these two categories should show no significant difference. A paired one-tailed t-test was conducted to indicate a significant difference, or asymmetry ($P<.05$). This procedure was applied to the lower extremity joint moments and GRFs. Symmetry index (relative difference) calculations were performed on the means of the large and small groups. [24]

To evaluate side favoritism in terms of consistency, the side at which the larger peak value occurred for each sit-to-stand movement was defined as favored. It was recorded whether the motor-dominant or non-dominant side was favoured for the ankle, knee, and hip joint moments as well as GRFs of each participant's 10 trials. The percentage of these 10 trials each side was favored was then calculated. The Symmetry Index of each participant's joint moments and GRFs was calculated based on the average between-side differences.[24]

To test if asymmetry was influenced by side motor-dominance, the normalized left joint moments (and GRFs) were subtracted from the right, and the average difference recorded for each participant. Therefore, consistently producing a larger joint moment on the right side would yield a negative average value, inversely a positive value for a larger left side. An unpaired, two-tailed t-test was conducted on the average difference values of the right foot dominant participants compared to the left foot dominant participants. $P < .025$ was assumed to indicate a significant difference and therefore a relationship between lower extremity motor-dominance and asymmetry.

Results

Joint moments at the ankles, knees and hip, as well as GRFs, were found to develop statistical asymmetry in their peak values ($P<.05$). The symmetry index values suggest that, the peak hip and ankle joint moments can be expected to produce the largest discrepancy between sides (19.1% and 18.6% respectively). The knee joint moments developed a symmetry index of 3.8% and 9.4% was determined for GRFs (Table 1).

(Insert Table 1)

No relationship was determined between lower limb dominance and sit-to-stand asymmetry. From the favoritism analysis, no discernible pattern was observed between a participant's dominant lower limb, and the consistency of larger (or smaller) peak joint moment (or GRFs) being developed at that side. Although many participants favored one side for all 10 trials (100% favoritism), others showed little to no discrimination. The individual participants' symmetry index values also show wide variations. At the ankle, values ranged from as low as 7.59% to as high as 40.05%. The knee, hip and GRF also showed much fluctuation between participants, with again, no discernible pattern emerging between participants or side dominance (Knee: 9.57-26.81%, Hip: 8.59-37.26%, GRF: 3.44-17.71%) (Table 2). Results of the unpaired two-tailed t-tests further supported this lack of relationship; with left to right side difference for all three lower extremity joint moments (and GRFs) failing to reach a significance difference between left limb and right limb dominant participants ($P<.025$) (Table 3).

(Insert Table 2)

(Insert Table 3)

Discussion

Bilateral symmetry is a common assumption in the study of healthy sit-to-stand tasks.[10-13] Although prominent in literature, only a few studies have been performed to investigate the validity of this supposition.[1,9] This study found lower extremity peak joint moments and GRFs, in a healthy participant group, to exhibit asymmetry during sit-to-stand movements. However, previous work has failed to achieve such statistical significance in GRFs as well as ankle joint moments.[1,9] Lundin *et al.* found significant differences between left and right sagittal joint moments at the knees and hips of a young, healthy participant group.[9] Likewise, our analysis found these two joints to behave asymmetrically, however; additional asymmetry was found in the ankle joint moments. Furthermore, Burnett *et al.* reported no significant differences between the left and right side in their vertical-GRF data, yet our GRF data suggest statistically significant asymmetry.[1] Two variations in experimental protocol may account for theses disagreements in results, the first, of which, may lie in the statistical analysis. This study categorized joint moment and GRF results into a large or small group for each trial; asymmetry was captured as an independent variable; removing dependence on the limb at which a result occurred. It eliminates the effects of averaging seen by comparing the left and right side, and addresses symmetry on a per-trial basis. Secondly, the uncovering of additional asymmetry at the ankle joint moments and GRFs may be attributed to the inclusion of off-sagittal data, and shearing-GRFs respectively.

Using the Euclidian Norm allows for the inclusion of movement in all three planes. Although sit-to-stand research can be found in literature, these analyses are often restricted to two dimensions.[1,4,8-10] It is important to acknowledge the potential limitations for exclusion of off-sagittal data. This may be particularly relevant in the study of affected populations were compensatory and asymmetrical movements are more prevalent.

Peak joint moment and GRF asymmetries did not exhibit a relation to lower limb dominances. Therefore, asymmetry may not predictable by evaluating footedness alone. Further investigation is necessary to accurately predict the causes of asymmetry. As a result, it is important that both limbs be evaluated at the same time. Due to the unpredictability of asymmetry, it is possible that one side will develop higher joint moments (or GRFs) in one trial and the contralateral in the next trial. If only one side is instrumented per trial, and no accurate prediction of asymmetry is available, the total biomechanical requirements of the sit-to-stand movement may be misrepresented. From our data, this misrepresentation may be as much as

40% for peak joint moment at the ankle, 26% at the knee and 37% at the hip. Therefore the assumption of bilateral symmetry holds limitations. It must be recognized that healthy populations do not exhibit perfect symmetry, and no robust method of predicting peak values on one side through measurement of the contralateral is evident.

It should be noted that this study holds two primary limitations, with the sample size being the first. However, significant differences were found in the peak joint moment values for all three joints as well as GRFs, providing confidence that peak joint moments and GRFs during healthy sit-to-stand movements may in fact be asymmetric, and not necessarily related to motor dominance. A further limitation lies in the use of peak values to address asymmetry. Although this method is prominent in literature, consideration should be given to the time-dependant nature of sit-to-stand; recognizing peak values occur at a single point in time during the movement.

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Table 1 Statistical results of bilateral symmetry analysis

	Units	Large Group Mean	Large Group SD	Small Group Mean	Small Group SD	P-value	Symmetry Index (%)
Ankle JM	Nm/BMxBH	0.24	0.05	0.20	0.05	<0.001	18.6
Knee JM	Nm/BMxBH	0.43	0.07	0.41	0.07	<0.001	3.8
Hip JM	Nm/BMxBH	0.48	0.11	0.40	0.10	<0.001	19.1
GRF	Nm/BM	5.47	0.58	4.98	0.63	<0.001	9.4

Note. JM and GRF abbreviate joint moment and ground reaction force respectively. Means, standard deviations (SD), and P-values are reported (P<.05 assumed significant). Values are normalized to Kilograms of body mass (BM) and meters of body height (BH).

Table 2 Percent favoritism according to limb dominance and symmetry indexes values

	Ankle			Knee			Hip			GRF		
Participant	D (%)	ND (%)	SI (%)	D (%)	ND (%)	SI (%)	D (%)	ND (%)	SI (%)	D (%)	ND (%)	SI (%)
1 RFD	0	100	16.56	90	10	9.57	20	80	17.56	40	60	3.85
2 RFD	100	0	37.19	100	0	13.73	100	0	16.90	0	100	12.83
3 RFD	40	60	13.63	0	100	16.80	30	70	8.59	40	60	7.42
4 RFD	40	60	9.38	0	100	26.81	0	100	18.84	100	0	17.71
5 RFD	90	10	31.18	20	80	10.38	30	70	15.75	90	10	9.22
6 LFD	80	20	9.79	0	100	10.61	60	40	8.96	20	80	4.00
7 LFD	0	100	19.38	0	100	11.91	100	0	29.22	50	50	5.37
8 LFD	70	30	10.46	0	100	16.33	80	20	21.93	20	80	3.44
9 LFD	30	70	7.59	20	80	15.59	100	0	37.26	0	100	7.57
10 LFD	100	0	40.05	10	90	13.65	100	0	21.56	0	100	11.33
Average	55	45	19.52	24	76	14.54	62	38	19.66	36	64	8.27
SD	38.4	38.4	12.18	38.4	38.4	5.01	39.1	39.1	8.66	36.0	36.0	4.60

Note. Favoritism is reported as the percent of the 10 trials either the motor-dominant (D) or non-dominant (ND) side produced a larger peak value. Symmetry Indexes (SI) are reported at each joint as well as ground reaction forces (GRF). Results are grouped according to right foot dominant (RFD) and left foot dominant (LFD) participants.

Table 3 Asymmetry and its relation to limb dominance

	Units	Difference RFD		Difference LFD		P-value
		Mean	SD	Mean	SD	
Ankle JM	Nm/BMxBH	-0.01	0.05	0.01	0.04	0.42
Knee JM	Nm/BMxBH	0.02	0.06	-0.03	0.04	0.21
Hip JM	Nm/BMxBH	0.03	0.07	0.09	0.06	0.20
GRF	Nm/BM	-0.18	0.65	-0.24	0.25	0.80

Note. JM and GRF abbreviate joint moment and ground reaction force respectively. Means, standard deviations (SD), and P-values are reported ($P<.05$ assumed significant). Values are normalized to Kilograms of body mass (BM) and meters of body height (BH). RFD and LFD signify the right foot dominant and left foot dominant participant groups respectively.