

EVALUATION OF ASYMMETRY IN GROUND REACTION FORCES AND MUSCLE ACTIVITY DURING THE STANCE PHASE OF GAIT IN ASYMPTOMATIC SUBJECTS

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INTRODUCTION

Walking is a fundamental and universal activity of daily living for humans [1]. Still, conflicting results have been reported regarding the inherent symmetry or asymmetry of biomechanical gait parameters such as ground reaction force (GRF) and electromyography (EMG) in asymptomatic subjects, perhaps due to unclear definitions or using only a single gait variable [1]. Determining whether biomechanical differences exist between the non-dominant (ND) and dominant (D) sides of the body is critical [2] as gait asymmetry may indicate a potential biomechanical susceptibility toward the development of other joint pathologies. The objective of this study is to quantify symmetry of GRF and EMG variables between the ND and D sides of the body in asymptomatic subjects during the stance phase of gait. The research is specifically aimed at determining ranges of symmetry that can be used as criteria for comparisons of healthy and impaired individuals.

METHODS

8 male and 4 female subjects, with an average age of 23.7 years, participated in the study. In order to be included in the study, subjects could not be experiencing any joint pain which would potentially alter their natural gait. Average (\pm SD) height and weight of the subjects was 173.1 (\pm 11.6) cm and 75.9 (\pm 18.6) kg, respectively. 11 of the 12 subjects were right-handed. All subjects voluntarily agreed to participate in the study and signed the IRB approved consent form prior to participation.

Subjects walked 10-12 meters at a self selected pace and contacted a force plate (Bertec Corp.) approximately midway through the trial. 3 trials were conducted with the ND foot contacting the force plate, and 3 trials were collected with the D foot contacting the force plate. GRF data was sampled at 1000 Hz and normalized to subjects' height and weight. The peak vertical component of the ground reaction force (VGRF) during heelstrike

(HS) and toe-off (TO) was determined.

Additionally, EMG activity from 4 bilateral muscle groups: erector spinae (ES), rectus abdominis (RA), rectus femoris (QUAD), and hamstring (HAM) was collected using bipolar, 10 mm surface electrodes (Noraxon, U.S.A. Inc.). Electrode placement and collection of maximum voluntary contractions (MVC) for normalization purposes was conducted according to Cram et al. [3] (Table 1). Raw EMG signals were sampled at 1000 Hz and preamplified (10 M Ω). Post-processing of the EMG signal included a series of 3rd order Butterworth band pass (10-450 Hz) and band stop (58-62 Hz) filters. The EMG signal was normalized to the peak MVC value. RMS amplitude during the stance phase was calculated for each muscle.

A symmetry index (SI) of VGRF and RMS measures was calculated by dividing the value for the ND side by the value for the D side (Table 1) and statistical differences were determined with a paired t-test at an alpha level of 0.05. A value of 1 would indicate perfect symmetry while positive values would indicate a gait pattern that favors the ND side. Acceptable ranges of the SI were determined by taking the mean \pm 2 SD. Additionally, intra-subject standard deviations (ISSD) were calculated to assess the reliability of the VGRF and RMS as measures of symmetry.

RESULTS AND DISCUSSIONS

There were no statistical differences between the ND and D peak VGRF values at HS ($p = 0.83$) or TO ($p = 0.17$). The average (\pm SD) of SI₁ (HS) and SI₂ (TO) were 0.999 (\pm 0.063) and 0.971 (\pm 0.091), respectively. Thus, the acceptable range of VGRF SI at the commencement and completion of stance phase would be 0.845 – 1.097 and 0.789 – 1.153, respectively (Figure 1). Essentially, neither the ND nor D leg was preferably used with respect to VGRF in asymptomatic subjects, and based on this variable asymptomatic subjects maintain a rather

symmetric gait, presumably throughout the entire stance phase. Additionally, the average ISSD for SI₁ and SI₂ were quite small (0.049 & 0.074, respectively) which indicate that the SI for these particular variables is reliable and appropriately used in symmetry analysis of human gait. Utilizing a different formula for SI, Herzog et al. [4] reported similar findings in which normal subjects showed less than 4% deviation from perfect symmetry for a number of gait variables associated with VGRF.

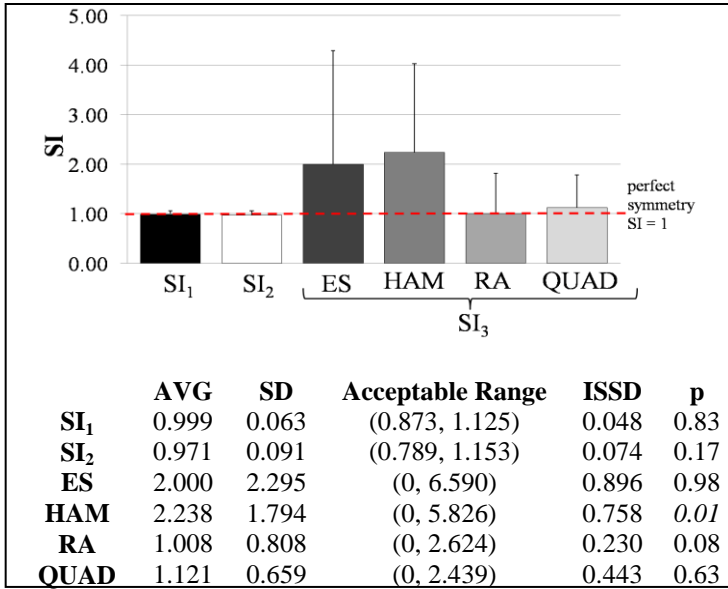


Figure 1: Summary of symmetry evaluation of VGRF (SI₁ & SI₂) and RMS (SI₃)

As can also be seen from Figure 1, the average SI values for the RA and QUAD muscle pairs are approximately equal to 1, indicating symmetry between the ND and D sides of the body. Differences in RMS during stance were not significant ($p > 0.05$), and average ISSD values demonstrate reliability of these measures between subjects. However, ES and HAM average SI values show greater muscle activation of the ND side relative to the D side, with the HAM RMS differences being significant ($p = 0.01$). Still, the increased average ISSD values indicate that intra-

subject reliability may be questionable for these parameters. A brief discussion of several previous studies involving EMG analysis of the back and lower extremities during gait may be useful in partially explaining these findings. First, Thorstensson et al. [5] concluded that the main function of the ES is the restriction of unnecessary trunk motion while hamstring activity was greatest during deceleration in the swing phase [6] and thus, may not be as useful for quantifying symmetry during stance as was postulated in the current study. Conversely, a recent study by Sherburne et al. [7] found that the quadriceps were the primary contributors to support and stabilization of the knee during forward propulsion which may explain to some degree the symmetry between the ND and D limbs in the current study.

CONCLUSIONS

Asymptomatic subjects showed high levels of symmetry during stance phase with respect to VGRF at HS and TO. Symmetry between the ND and D QUAD muscles was also found. Acceptable ranges of asymmetry were established, and future research will consider the application of similar methodologies among symptomatic subjects.

REFERENCES

1. Sadeghi H, et al., *Gait and Posture*. **12**:34-45, 2000.
2. Teichtahl AJ, et al., *Arch Phys Med Rehabil*. **90**: 320-324, 2009.
3. Cram JR, et al., *Intr. to sEMG*. 336-369, 1998.
4. Herzog W, et al., *Med. Sci. Sports Exerc*. **21**: 110-114, 1989
5. Thorstensson A, et al., *Acta Physiol Scand*. **116**: 13-20, 1982
6. Dubo HI, et al., *Arch Phys Med Rehab*. **57**: 415-420, 1976
7. Sherburne KB, et al., *J Orth. Res*. **24**: 1983-1990, 2006

Table 1: Description of symmetry indices, electrode placement, and MVC tasks

GRF		EMG			
HS Symmetry Index (SI ₁)	TO Symmetry Index (SI ₂)	Symmetry Index (SI ₃)	Muscle	Electrode Placement	MVC
$\frac{\text{Peak VGRF}_{\text{ND, HS}}}{\text{Peak VGRF}_{\text{D, HS}}}$	$\frac{\text{Peak VGRF}_{\text{ND, TO}}}{\text{Peak VGRF}_{\text{D, TO}}}$	$\frac{\text{RMS}_{\text{ND, stance}}}{\text{RMS}_{\text{D, stance}}}$	RA	3 cm apart, 2 cm lateral from the umbilicus over the muscle belly	resisted torso flexion
			ES	Parallel to the spine, 2 cm apart, 2 cm from the spine over the muscle mass	resisted torso extension
		QUAD	2 cm apart, approx. half the distance between the knee and iliac spine	resisted knee extension	
		HAM	3 cm apart, approx. half the distance from the gluteal fold to the back of the leg	resisted knee flexion	