

# The Effect of Structural Leg Length Discrepancy on Vertical Ground Reaction Force and Spatial-Temporal Gait Parameter: Pilot Study

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**Abstract**—Numerous studies have established the correlation between weight distributions, vertical ground reaction force (VGRF) and temporal gait parameter with a certain level of magnitude LLD. However, very little descriptive data exists to relate to stability during walking gait. Moreover, there is no analysis of the same groups of subjects for the different aspects disorder. Therefore, this paper presents to investigate the influence of LLD on vertical ground reaction force (VGRF) and spatial-temporal gait parameter. VGRF and spatial-temporal gait parameter data were collected after they performed under two conditions: (1) Healthy subject as a mimic of LLD wearing a flat thin sandal with a thin flat insole from 0.5 cm to 4 cm, and (2) Patient with LLD (2 cm). In both (2 cm) true patient LLD and mimic of LLD shows the same pattern of weight distribution. The largest root means square (RMS) VGRF occurred at 2 cm LLD (515.47). A spatial, temporal parameter which is step length have observed the short leg about 9.4% and step time was 17.8% at 3.5 cm LLD. Mild leg length discrepancy affects the entire of kinetic (VGRF) and spatial-temporal gait during walking gait. Increasing load on the short leg, which helps us to explain why a mild leg length discrepancy where the primary impact on stability and limitation in physical ambulation.

**Index Terms**—Gait Analysis; Kinetics; Leg Length Discrepancy; Spatial-Temporal Parameter; Vertical Ground Reaction Force.

## I. INTRODUCTION

Leg length discrepancy (LLD) is the most common cause of limitations during walking and any other physical movement because of not equal length in both legs [1]. Asymmetry in walking often leads to unbalance of body stability indirectly cause more energy consuming, a risk to fall, primary fatigue condition and pain (hip, knee, ankle and lumbar spine) [2–5]. Persons who have LLD can be classified into five categories which are from; (1) congenital which those who have the LLD since childhood from the fetal growth, (2) fractures those who experienced from the previous injury, (3) tumours, those who undergo the bone infection, and (4) those who have neurologic condition example juvenile arthritis. Also, Resende et al. [5] reported that approximately 70% of the general population are having LLD and magnitude greater than 2 cm can change the biomechanical gait in 1 in 1000 people. The LLD can be classified into two, which are structural and functional LLD. In structural LLD, could be seen when a difference in length of the bones of the lower extremity exists where there's an actual discrepancy in the length of the patient's leg with one leg longer than the other

leg. On the other hand, functional LLD is caused by joint contracture which results in an apparent inequality in lower limb length without true osseous deficiency. Whereas, the treatment options for LLD depending on the magnitude discrepancy respectively. The magnitude of LLD <2 cm usually cured by nonsurgical treatment, for instance, internal lift or external lift. Surgical treatment starting at 3 cm to 6 cm either shortening or lengthening one of each other limb. While, <6 cm to 20 cm clinically the surgical combined for both limb and assists by prosthesis [1], [6]. Up to now, several studies have investigated the effects of LLD on stability during standing. Jeon et al. [7] found that the degree weight distribution was lower at unhealthy side than healthy side while quietly standing. Following that, Swaminathan et al.[4]reported 65% transfer to the short leg side for experiment 3.5 cm LLD during standing.

However, Fischer et al.[8] showed that reducing body weight load during overground walking on healthy subject's gait from 0% to 30% decreased. Furthermore, the study of vertical ground reaction forces has been a major area to described weight distribution during human locomotion. In an analysis in [3] found that shorter limb suffers a greater proportion of load transfer. Measuring completed VGRF is comprehensively used in any environment out of the laboratory as suggested by Fong et al. [9] Relationship of gait parameters also can be described on stability during walking. Resende et al. [5] and Walsh et al. [10] described step down distance results in a shorter time to peak force during the stance phase of gait on the longer limb to the shorter limb which may increase loading transfer at the shorter limb. Although some research has been carried out the effect of LLD for varied with biomechanical parameters (kinematic, kinetic and gait temporal distance), what remains unclear is precisely how reliable these parameters related with stability during walking. Therefore, this paper aims to investigate the effect of experimental LLD on stability during walking with the variation of LLD levels.

## II. METHOD

### A. Subjects

The present pilot study recruited two adult male subjects: one normal subject which free from any clinical gait abnormalities as a mimic LLD experiment and one patient with LLD (Left leg= 96 cm and Right leg= 98 cm) due to the car accident in the past years before testing. The right leg is dominant LLD for both subjects. Table 1 lists all the

participants' demographic data. The inclusion criteria only for normal BMI, having Malaysian shoe size about 7 to 8 (men), for data collection during walking. Before the experiments, subjects were explained about the procedure of the experiment and signed the written informed consent approved by the ethics committee.

Table 1  
Subjects' Demographic Data for Pilot Study

Category	Age (years)	Height (cm)	Mass (kg)	BMI (kg/m <sup>2</sup> )	Condition
Patient	31	168.7	66.6	23.4	LLD-RT
Healthy	24	169.5	64.1	22.3	Mimic
					LLD-RL

LLD-RT: Leg length discrepancy right tight; LLD-RL: Leg length discrepancy right leg; BMI: Body Mass Index.

**B. Experiment Setup and Procedure**

Initially, the subjects were asked to wear tight sports' attire and then measured height and weight by using weight balance scale. Tape measure method was applied to measure anatomical leg length (from the anterior superior iliac spine to the medial malleolus). Before data collection, a modified markers placement recommended from C-motion marker (Helen Hayes) set guidelines were applied to construct a biomedical model segment [11]. Figure 1 demonstrated the placement of 30 passive markers that were used on foot, shank, thigh, pelvis, and thoracic trunk segments including lumbar while four sets of cluster tracking markers (four passive markers in each set) as a reference for every motion and to determine the coordinate for each segment. A pair of sandal that made of high-density ethylene vinyl acetate was attached to the feet bilaterally for both subjects with Velcro (TM) straps.

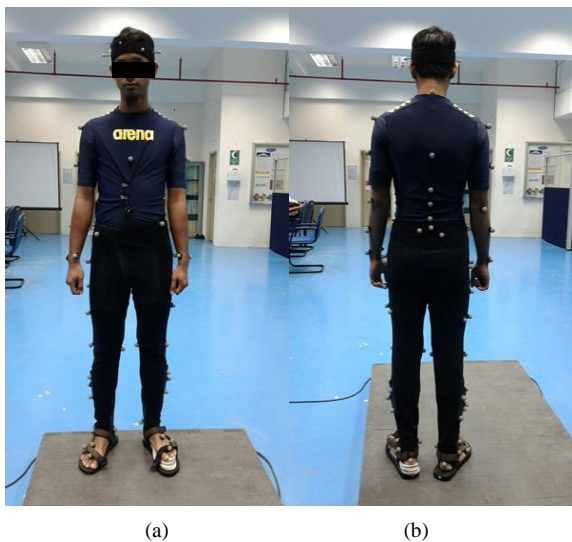


Figure 1: Anatomy marker placement in (a) Front view (b) Back view

The subjects walked in 1 minute for familiarisations with their self-selected comfortable speed along the 7 m distance on the track lab. Moreover, to ensure the good reliability of walking before each condition, about three to five successful normal trials were conducted [10]. The subjects performed the walking trials under two condition as described: (1) healthy subject as a mimic of LLD: a) wearing a flat thin sandal for both legs with a thin flat insole from 0.5 cm to 4 cm with 0.5 cm each interval. (2) Patient with LLD (2 cm) wearing a flat thin sandal for both legs as a control. Then, as

for validation of the mimic LLD's subject in this present study, insole was inserted under the right foot as shown in Figure 1 [5]. After the appliance was fitted, the subjects attended to walk in 1 minute to become acclimated for each insole thickness and repeated with each 0.5 cm increment on the right leg up to 4 cm. The subject did not complain any discomfort feeling.

**C. Data Processing and Analysis**

To begin this process, a static calibration was conducted, and all reflective markers were detected using Qualysis Track Manager (QTM) with 5-camera Oqus motion analysis system. To analyse three-dimensional (3D) vertical ground reaction force (VGRF) in detail, it is worthwhile to proceed walking at 7 s capturing period with the default sampling frequency (200 Hz) walked on the two Bertec Corporation force platform subsequently. The kinetic parameter force that is exerted by the ground in opposition to the body weight on it was used to identify weight distribution (WD). Markers were labelled and fill gap marker trajectories were interpolated when necessary. Data from QTM were exported to a biomechanics processing in Visual 3D Software. Markers at the head and arm were neglected for processing.



(a)



(b)

Figure 2: The experimental environment of the present study (a) Equipment layout (b) Reflection of the markers during the experiment

Before analysing force between LLD's patient and mimic of LLD, the VGRF data was computed during stance phase for both legs conditions: (1) right leg presented as a long leg and (2) left leg for short leg as to compensate similarly with true LLD's patient. The force is used to compare the body balance stability for LLDs on the healthy side and unhealthy side. The raw VGRF data were filtered by using low pass filter with a set of frequency 6 Hz. The 3D angular computations with the right-hand rule are used to determine cadence rotational sequence X-Y-Z. Normalisation was performed using a range of normalisation parameters [12].

$$F_z \cong \sum_{i=1}^N m_i \cdot (a_{zi} + g) \quad (1)$$

where the summation of all body segments mass with  $m_i$  denotes  $i$ -th segment mass, and  $a_{zi}$  denotes  $i$ -th segment centre of mass acceleration.  $F_z$  represents the sum of all segments mass with acceleration products, which represent the force of the body weight for Figure 3.

### III. RESULT AND DISCUSSION

The present study set out with the aim of assessing the importance of weight distribution, VGRF and a spatial-temporal parameter for the effect of LLD on postural stability during walking. Due to the fundamental precondition for balance ambulation, the percentage of weight distribution on the long leg was lower than short leg during walking. Therefore, improving this ability is one of the primary treatment goals in physical rehabilitation. Meanwhile, initial treatment can avoid patients suffer from unstable in weight bearing on the unhealthy side. Very little was found in the literature on the question of weight distribution can affect the stability during walking for LLD [4], [7]. Hence, weight distribution across the two legs of body weight was measured in this study during walking. Weight distribution indicates that the short leg tended to carry more weight rather than the long leg, which similarly observed by Swaminathan et al. [4].

The differences between LLD patient and mimic of LLD on vertical acceleration were shown in Figure 3 during the stance phase. The result obtained from the VGRF was compared as a validation for a mimic experiment. When compared to the true patient (2 cm) LLD matched for normal BMI and sex in our study presented no significant difference in the weight distribution result for mimic 2 cm LLD (healthy subject). From the graph, a clear trend shown in both legs for LLD patient and mimic LLD. The pattern shown was very closed while only slightly different from peak value during left heel strike (1.3%) and right toe off (1.2%). Both subjects generated almost symmetrical propulsive force, where mimic LLD was generated 8.5% during heel strike at the short leg and 91.3% at long leg during toe off. Contradicts from true LLD which shown 9.8% at short leg during heel strike and 90.1% at long leg during toe off. However, the graph is acutely altering because of the behaviour of the subject and leg position during contact with the ground. Supported by Park et al. [13] studied the effect of LLD on gait and Cobb's angle when the subject was standing straight. They reported that weight transfer on the shorter leg rather than, the longer leg at 2 cm. The pattern of the graph was similar that led the experiment can be continued for varying levels of LLD.

On the other hand, we could determine the VGRF from 0.5 cm up to the 4 cm level of LLD. The evidence that, the shorter leg exhibited more forces when the leg discrepancy was simulated. Based on Figure 4, it can be seen that the trend of the graph shown almost linearly increasing at the short leg. However, linearly decreasing at the long leg. The most obvious finding to emerge from the analysis is that at 2 cm level of LLD presented the highest VGRF at the short leg which supported by [13]. In a meanwhile, the short leg produced less force at 3 cm while at 1 cm shown no difference in walking capacity stated by the same author. However, contradicts from Swaminathan et al. [4] where short leg carries more weight at 3.5 cm. This posture is also likely to cause primary fatigue, the risk to fall, reduced walking

capacity, limping and patient satisfaction towards their postural stability during walking. Consequently, the value of VGRF decreases at 2.5 cm and 3 cm from short leg, due to the subject's alignment during walking. But since the force exerted still more than the long leg, it is shown that the leg shortening strongly affected on desired outcomes and patient satisfaction than leg lengthening.

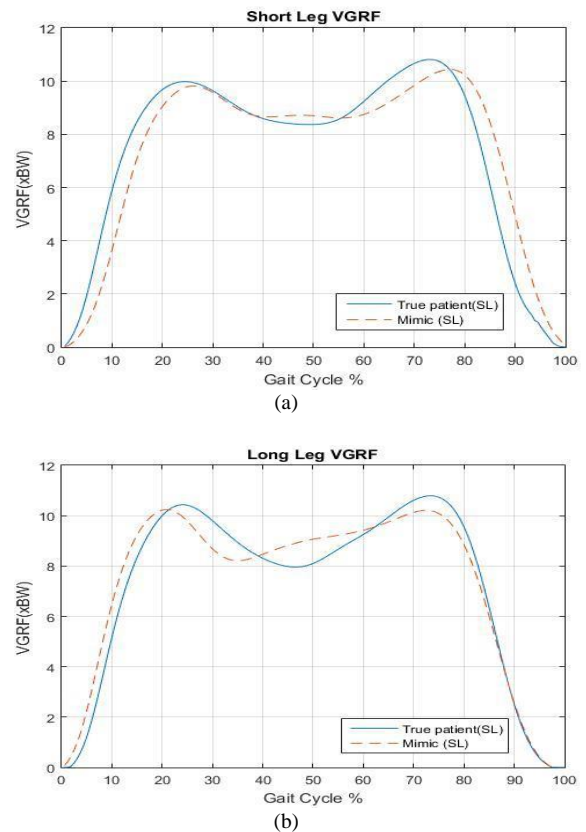


Figure 3: VGRF between mimic subject and true patient for 2 cm LLD (a) Short leg (b) Long leg

Increased activation in the VGRF in this study corroborates these early findings for LLD cases. It is encouraging to compare this figure (refer Figure 4) with spatial-temporal parameter (step length and step time) that found by Balasubramaniam et al. [14] who finds that step lengths have strongly related to the force exerted during walking. Overall, there are two major trends of step time values as shown in Figure 5. Both graphs are similarly constant trends. At a glance, it is interesting to note that in all nine levels of LLD in this study, at the 0.5 cm exhibited smallest VGRF at the shorter leg. This finding was supported by the subject walking with less step length and less in step time in the short leg. Step length is shown higher at the longer leg during 2 cm walking. Note that the subject was performed in natural walking.

However, at the shorter leg, the trends of step length shown to increase similar to VGRF graph constantly. In the meantime, the trends of long leg shown significance at the 0.5 cm only. As revealed in the graph step length and step time, the symmetrical level (0 cm) shown contradicts compare with asymmetrical level. Hence, it seems possible to hypothesised these results, thereby enhance the need to develop compensatory strategies to overcome these deficits on body postural stability. Overall, the results of this study limited to only one subject as a pilot study during walking. Noticed that

a significant increase in VGRF and spatial-temporal parameter with each increase in induced LLD. It is possible even minor difference may be biomechanically important. Hence, it can thus be suggested that further studies are warranted on these aspects with more subjects to confirm this.

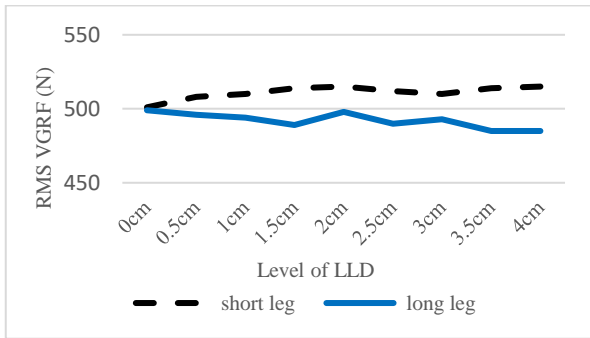
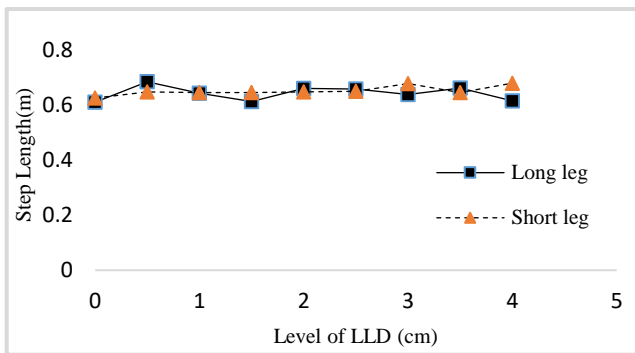
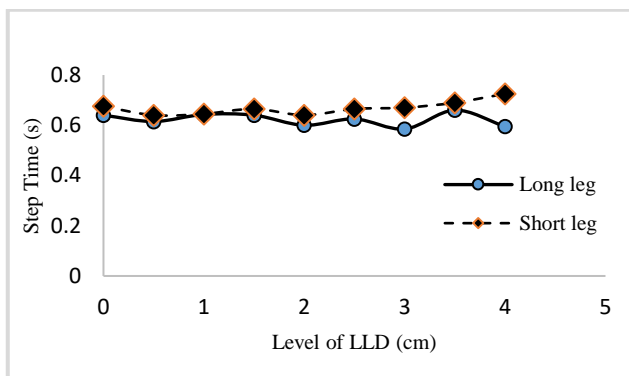


Figure 4: Experimental analysis of the effect of LLD level for short leg and long leg



(a)



(b)

Figure 5: Assessment of temporal gait parameter (a) Step length (b) Step time

#### IV. CONCLUSION

The present study was designed to determine the effect of weight distribution with VGRF, gait spatial-temporal parameter on body postural stability for LLD. Knowledge of the relationship between them is important for improvement of our understanding of the aetiology and treatment rehabilitation for LLD during the assessment of walking. From the mimic LLD (2 cm) indicated the result approximately same pattern with the true patient (2 cm) on the right leg. Therefore, further research was warranted for varying levels by using insole as a mimic of LLD. The result

of the pilot study indicated that greater the vertical ground reaction force exerted at shorter leg rather than longer leg which suggested that weight distributed more on one side. Despite biomechanical relations between foot placement and position that are expected, we believe that there are additional of behaviour during walking impairment underlying the alteration of graph VGRF. However, further research and experiment into VGRF are strongly recommended. Moreover, the relationship between VGRF and spatial-temporal parameter (step length and step time) can help understand compensatory strategies that described for each level of asymmetry walking. This may affect how the LLD patient is walking and still need to be acknowledged for further reveals more biomechanical parameters that described the stability of impaired ambulation for each level of LLD cases.

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