Original Article

Intra-Rater Reliability and Minimal Detectable Change of Vertical Ground Reaction Force Measurement during Gait and Half-Squat Tasks on Healthy Male Adults

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Abstract

Background: **The understanding of vertical ground reaction force (VGRF) during walking and half-squatting is necessary and commonly utilised during the rehabilitation period. The purpose of this study was to establish measurement reproducibility of VGRF that reports the minimal detectable changes (MDC) during walking and half-squatting activity among healthy male adults.**

Methods: **14 male adults of average age, 24.88 (5.24) years old, were enlisted in this study. The VGRF was assessed using the force plates which were embedded into a customised walking platform. Participants were required to carry out three trials of gait and half-squat. Each participant completed the two measurements within a day, approximately four hours apart.**

Results: **Measurements of VGRF between sessions presented an excellent VGRF data for walking (ICC_{Left} = 0.88, ICC_{Right} = 0.89). High reliability of VGRF was also noted during the half-squat activity (ICC_{Left} = 0.95, ICC_{Right} = 0.90). The standard errors of measurement (SEM) of VGRF during the walking and half-squat activity are less than 8.35 Nm/kg and 4.67 Nm/kg for the gait and half-squat task respectively.**

Conclusion: **The equipment set-up and measurement procedure used to quantify VGRF during walking and half-squatting among healthy males displayed excellent reliability. Researcher should consider using this method to measure the VGRF during functional performance assessment.**

Keywords: *Gait, reproducibility, healthy, squat, forces, rehabilitation*

Introduction

In clinical practices, gait and half-squat activities are often used during early lower-limb rehabilitation programs (1,2) as it involves multiple-joints coordination and generate low-impact force on the injured lower limb (3). Gait and half-squat are closed kinetic chain exercises responsible for the development of general lower limb strength at the hip, thigh and trunk (3,4). As gait and half-squat activities are commonly utilised during rehabilitation, there is a definite need to establish better understanding on the reliability of vertical ground reaction force (VGRF) in gait and half-squat activities.

The VGRF measurement of gait and half-squat is a significance performance indicator following rehabilitation programs (5). The measurement of VGRF during functional tasks provide clinicians with information on impact loading distribution absorbed by each limb during gait and half-squat activities (6). Attenuation of

VGRF during daily routine is associated with the increased risk of re-injury for the injured knee and contributing to early post-traumatic osteoarthritis (PTOA) (7,8). Clinicians should be able to identify the patients at risk of re-injury and possibility to have PTOA in the future by monitoring VGRF during gait and half-squat tasks at early phase of rehabilitation. An awareness of VGRF in healthy population help clinicians to make decision on the current treatment intervention in clinical population and make necessary adjustments for a more targeted rehabilitation. Thus, early detection of VGRF is vital to reduce the risk of secondary injury and unnecessary force exposure that causes PTOA in later stage of life.

Numerous studies has examined ground reaction force (GRF) during gait (9), stairs ascent and descent (10), and sports activities (11). Although the GRF data was described extensively in the literature, there is limited evidence on the reproducibility of VGRF measurement during gait on healthy male population. Only one study is available to measure the reliability of peak VGRF during barefoot walking in treadmill involving healthy male individuals (12). Nevertheless, the study utilised different instruments, laboratory set-up and gait procedure compared to the current one. The reliability of clinical measurement is highly influenced by various factors such as participant's characteristics, research methodology, instrument set-up, and rater experience (13). There is a need to verify each instrument and measurement trustworthiness of VGRF during gait and half-squat tasks before it can be utilised for research or clinical purposes (14). Furthermore, there is paucity of evidence that examines the reliability of VGRF in healthy male individuals during barefoot walking and half-squat tasks. The reliability assessment of VGRF during gait and half-squat tasks need to be established first before such methodology can be implemented in research purpose (14).

To date, there are no study that has presented the standard error of measurement (SEM) and minimal detectable changes (MDC) on healthy male participants during gait and half-squat activities. Hence, this study is determined to report the SEM and MDC that would be useful for researchers and clinicians.

The SEM is commonly used to measure absolute reliability and to inform about the precision of measurement score in repeated testing conditions (15). The SEM provides absolute reliability score in the same units for measurement of VGRF; A smaller SEM score indicates the measurement of VGRF to be more reliable (15). SEM score could possibly ease the interpretation of measurement error in research and clinical setting as it uses similar unit with measurements of variable of interest (15,16). Furthermore, adding the MDC score is dependable upon reason with its relevancy in clinical practice, thus, it could assist clinician in monitoring the effectiveness of treatment intervention. MDC is the score detected using instruments with the obtained score exceeding the SEM value (17). The MDC score indicates the observed true difference in performance between evaluations as true indicator of treatment effectiveness and not because of error in measurement (17,18). MDC score in healthy population is necessary as it help clinicians to have a target score to refer while monitoring the performance of clinical population with a better anticipation of clinical meaningful differences about the treatment given to the clinical population (19).

The wide use of VGRF in clinical and performance analysis in pathological condition warrant the need of investigation for this parameter on healthy participants. To date, the intra-rater reliability, SEM and MDC value for VGRF in gait and half-squat tasks has not been published. The information about the reliability of VGRF in healthy population is required for clinicians to develop better understanding of VGRF in pathological population. As a result, this study's aim is to examine the intra-rater reliability of VGRF measurement in repeated testing condition during gait and half-squat activities among healthy male participants.

Materials and Methods

Participants

Fourteen healthy male adults in the average age of 24.88 (5.24) years old was recruited for this study. Table 1 presents the demographic characteristics of participants. Each participant was screened according to inclusion criteria: (1) age not exceeding 45 years; (2) no history

Table 1: Characteristic of the participants

Parameters	Healthy (n = 14)
Age (year)	24.88 (5.24)
Weight (Kg)	62.47 (8.92)
Height (m)	1.66 (0.06)
Body Mass Index (BMI) (Kg/m^2)	22.62 (3.34)

Values are expressed as mean (SD).

of injury or surgery to back or lower limb; (3) no known musculoskeletal condition; (4) body mass index (BMI) not exceeding 35 Kg/m2; and (5) limb length differences not more than 2 cm. The university research committee approved the study and ethical approval was attained from the institution. All participants were informed about the protocol of study and a written consent was obtained prior to measurements from each participant.

Instrumentations

This study was conducted in a motion analysis laboratory that was equipped with sixth camera (Model Osprey) with three-dimensional (3D) motion analysis system (Motion Analysis Corporation, USA). The motion analysis system was synchronised with the force plate instrument. The VGRF data were acquired from the two force plates (Model FP4060, Bertec Corporation, USA) set at 600Hz sampling rate that was embedded into the customized sixth meters walking platform. The VGRF data of walking and half-squatting tasks were collected using Cortex software (Version 5.3.1.1543, Motion Analysis Corporation, USA). Butterworth low-pass filter was applied with a cut-off frequency of 6 Hz to reduce noise.

Data reduction and analysis were done using Visual 3D software (Version 5.0, C-Motion, USA). Vertical GRF data were normalised to participants' body weight. Next, the vertical GRF data was time-normalised to 100% of gait and half-squat cycle respectively. The purpose of normalisation is to objectively compare the results across the participants' group (20). Raw data were obtained in Visual 3D software that was later saved in text file and exported to Microsoft Excel 2010 for visual inspection. Further data analyses were done using SPSS statistics (Version 22, IBM Corporation, Chicago). Initial contact of early stance phase detection during the walking tasks were measured at the first point when VGRF values exceeds force threshold of 30N, while the peak VGRF for half-squat cycle was determined by the highest VGRF that occurred at any time during the half-squat cycle.

Measurement Procedure

Measurements of kinetic variables were conducted repeatedly in the same day with approximately at least 4 hours apart from the initial measurement. Participants' demographic details, weight, height, and body mass index (BMI) were attained before they proceed for gait and half-squat assessment. Participants were required not to wear shoes (barefooted) during the assessment as the variation in footwear may influence the movement characteristics during functional task (21). Force plates were calibrated every time before the start of measurement at each session for each participant. All participants underwent measurement of VGRF in two conditions: (1) gait assessment on walking platform and (2) half-squat assessment.

Gait assessment

Therapist provided specific verbal instructions accompanied with demonstrations to each participant prior to the implementation of familiarisation protocol for gait assessment. During the familiarisation trial, participants were required to identify the starting position of the gait, in order for each foot to make contact with the correct force platform. Successful gait trial is defined when a foot make a full contact on the force platform. Each participant began walking at self-selected speed with three-point gait before making contact on the force platform. Each participant was required to perform three successful gait trials in the first measurement session, with one-minute rest between each trial. The entire procedure was repeated in the second measurement session. The VGRF were measured during initial contact event of gait cycle. The average score of VGRF from the first and second measurement of gait was used for further analysis.

Half-squat assessment

Similarly, as gait assessment, therapist instructed and demonstrated to the participants on procedures of the half-squat activity. Each participant was allowed to do at least three trials before the actual VGRF measurement was recorded. During the half-squat assessment, the participants first positioned both their feet at the specified force platform and stood comfortably. No specific instruction was given to participants to control stance width during the half-squat assessment in order to stimulate a normal half-squatting behaviour among participants. Each participant was instructed to look at a specific point on the wall and to keep bilateral arm parallel to the floor throughout the half-squat cycle. This is done in order to maintain their balance. The half-squat position was pre-determined to the position of thigh approximately parallel to the floor (2) with knee joint not exceeding the position of the big toe. From the standing position, therapist provided clear verbal cue for the participants to start the movement. Participants were instructed to descend until they reach the point where the thigh is approximately parallel with the floor, maintaining the position for two second and returning to the starting position. Participants were permitted to rest adequately with at least one-minute rests between each trial. Bilateral GRF data from left and right lower limb were recorded simultaneously during the half-squat cycle. Half-squat cycle in this study was determined from the standing position (with bilateral arm parallel to the floor), ascending to the level of thigh equal to the floor and returning to the starting position. The average score for peak GRF was calculated for each limb using the same calculation in the walking assessment. A single therapist independently set-up the equipment and conducted the measurement in each session.

Data Analysis

Mean and standard deviation (SD) from each data point in gait and half-squat tasks were determined. Paired sample t test was used to compare the mean and SD of VGRF signal between the two test sessions. The significant results of paired t-test would determine the systematic bias of the measurement. To measure test-retest reliability, Intraclass Correlation Coefficient (ICC2,1) using two-way random effect model was computed to determine the intersession repeatability between measurements of VGRF among healthy male individuals. The ICC was categorized as follows: (1) poor (< 0.4); (2) fair to good (0.4–0.8); and (3) excellent reliability (> 0.8) (22). The SEM and MDC were calculated to observe the absolute reliability between two measurement sessions (15). The level of statistical significant was set at $P < 0.05$. SPSS version 22 (SPSS, Inc., Chicago) was used to calculate the statistics. The following equations were used to calculate SEM (15) and MDC (19):

$$\text{SEM} = \text{SD} \times \sqrt{(1\text{-ICC})} \quad (1)$$

$$\text{MDC} = \text{SEM} \times 1.962 \times \sqrt{2} \quad (2)$$

Results

The results from the paired sample t-test determined that no significant differences (P = 0.05) exist between measurements of the two test sessions. Excellent reliability was found for VGRF at initial contact event during walking for both limbs (ICC_{left} = 0.88, SEM_{left} = 6.02 Nm/kg; ICC_{right} = 0.89, SEM_{right} = 8.35 Nm/kg). The similar trend of excellent reliability of measurement VGRF was also noted during half-squat tasks for both limbs (ICC_{left} = 0.95, SEM_{left} = 3.88 Nm/kg; ICC_{right} = 0.90, SEM_{right} = 4.67 Nm/kg) (Table 2).

Discussion

This study assessed the reproducibility of vertical GRF measurement during functional tasks of gait and half-squat activity in repeated testing, on a same day with 4 hours apart among healthy male adult individuals. Gait and half-squat activities were mostly utilised during early rehabilitation program to improve lower limb muscle strength and coordination (3,23). The assessment of variability is important for clinicians and researchers to understand the VGRF associated with adopted measurement approach in relation with participant's performance during gait and half-squat activity (24).

An evaluation on equipment and measurement procedure are warranted to establish the trustworthiness of the data as proposed by the Guidelines for Reporting Reliability and Agreement Studies (GRRAS) protocol for reliability study (14). Our data analysis suggest that instrument, laboratory set-up and measurement procedure adopted in analysing VGRF during gait and half-squat condition were highly reliable. Other researchers also has reported high reliability of VGRF during other functional activities such as single leg squatting and single leg landing tasks (24) and

Table 2: Mean (SD), ICCs, SEM and MDC for walking and half-squat performance measurement between two test sessions among healthy participant

Tasks	Lower Limb	Session 1	Session 2	ICC	95% CI	SEM	MDC
		Mean (SD)					
Walking	Left	53.46 (15.01)	51.48 (20.34)	0.88	(0.678–0.961)	6.02	16.70
	Right	51.11 (25.70)	55.72 (26.88)	0.89	(0.716–0.966)	8.35	23.18
Half-squat	Left	16.52 (17.26)	17.06 (20.16)	0.95	(0.872–0.986)	3.88	10.76
	Right	36.90 (14.81)	34.47 (13.09)	0.90	(0.689–0.963)	4.67	12.96

Values are expressed as mean (SD) of vertical GRF (Nm/kg).

on various running conditions (25). The VGRF data in this study showed less variability. This is possibly because the GRF are the reflection of the total product of mass of the body time acceleration (24,26) and instantaneous measure throughout task duration. The potential influence factor is acceleration, as gravitational force was a constant force, and changes in body mass of participants were very less likely to occur within the four hours interval. It is important to note about the speeds of movement from first and second measurement session to ensure a reliable VGRF measurement.

Furthermore, SEM score of gait and half-squat tasks would provide researchers to understand about the magnitude of error during measurement and enable an estimation on true changes on the task performance (15). The SEM in this study was reported in the actual unit of measurement, as the smaller SEM score indicates a more reliable measurement (15). In this study, the SEM score was less than 8.35 Nm/kg during gait assessment and below than 5Nm/kg during half-squat assessment for the within-day assessment. Paucity of evidence was noted on the available literature reporting SEM during gait and half-squat tasks among healthy individuals. Therefore, the reported SEM could be referred as a basis for those who intend to use the similar protocol in assessment of VGRF during gait among healthy male individuals. Within-day MDC estimated the minimal change in healthy male during gait varied between 16 Nm/kg and 23 Nm/kg for measurement of VGRF during walking for left and right foot respectively. Estimation of MDC during half-squat activity was less varied ranging from 10 Nm/kg and 13 Nm/kg for each left and right foot. Establishing MDC score in a healthy population would benefit clinicians on evaluating the functional task performance and monitoring patient progress throughout the rehabilitation program (17).

As proposed by (14) the GRRAS guideline, it is necessary to publish the reliability study of specific population in different and varied publications or opt to report as supplementary study based from original investigation and provide the details about measurement procedure that had been used in the study. The trustworthiness of data is at all times uncertain if measures were not taken to evaluate the reliability of equipment and the measurement procedure adopted of the specific population of interest (14). Therefore, in this study, establishing the level of reproducibility would warrant the researcher about the measurement quality of the conducted study. The current report is a supplementary study of a primary on-going study, exploring the movement compensation following anterior cruciate ligament reconstruction surgery. The main study intends to investigate about several biomechanical variables that assess movement compensation and analyse segment interaction incorporating multiple plane of motion analysis during functional activity.

In a clinical perspective, data presented in this study suggested that measurement procedure to evaluate VGRF during gait and half-squat activity produced high reliability, thus, permitting the usage in real clinical practices. The SEM and MDC data displayed in this study should be acknowledged and recognised as basic references in interpreting VGRF for gait and half-squat assessments in clinical population. Additionally, the measurement adopted in this study provides separate analysis of left and right leg, thus enabling measurement of VGRF symmetry between lower limbs during functional task. In future, comparison of findings across studies should be done cautiously since the reliability value, SEM and MDC, are specific to the methodological used (14,27). Factors such as age of the evaluated population, BMI, speed of movement, and physiologic differences between populations must be highlighted when interpreting the data. In this study, the intra-rater reliability assessment was conducted among healthy male participants, at an average age of 24 years old and a BMI of 22 kg/ms2. Gait speed was monitored for each trial and analysis found no significant differences between the two measurement sessions. All the mentioned factors could influence the overall result of reliability (20). It is also important to note that the reliability of VGRF measurement could be affected by several factors including rater experience and the population studied (14). In this study, only a single therapist was allowed in managing the measurement of VGRF during gait and half-squat condition in repeated measurement condition. This would thus reduce the potential biasness that could possibly occur due to possible differences that exists between rater. As the studied population comprises of a homogenous group of healthy male adults, the interpretation should be only limited to a similar population. Overall, the result of current study showed excellent reliability of VGRF and warrant methodological quality to measure VGRF during gait and half-squat screening. The inclusion of SEM and MDC score in the analysis will aid better interpretation in assessing the movement quality, particularly in rehabilitation program. However, due to sample size limitation, the results of the study should be interpreted cautiously.

Conclusion

The VGRF can be measured with high reliability within-day measurement sessions during gait and half-squat tasks among health male adults. The SEM and MDC added the values for this study and the reported score should be considered as the baseline references for future researches that investigate VGRF using the similar measurement protocol in clinical population.

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Conflict of interest

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Authors' Contribution

Conception and design, final approval of the article, administrative, technical, or logistic support: FZF, LHJ, BO, RS
Analysis and interpretation of the data, statistical expertise: FZF, LHJ, BO
Drafting of the article, collection and assembly of data: FZF
Critical revision of the article for important intellectual content: FZF, LHJ, BO, RS
Provision of study materials or patients: FZF, LHJ, RS
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