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The Lower Limb Joints Test-retest Repeatability in the Sagittal, Frontal and Transverse Planes of Movement during Stair Ascent and Descent among Young, Healthy Individuals

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Abstract

Introduction: The repeatability of both kinetics and kinematics of the knee joint among healthy individuals has been evaluated previously with measurement error, hence, it was important to use the same previous method to evaluate the repeatability of the hip and ankle joints as well in the sagittal, frontal, and transverse planes among healthy individuals during stair climbing the force plates attached interlaced stairway.

Methods: five males and five females (32.1 ± 6.8 years) participated in this study to climb three-step stair over two visits. Five good trials with complete three-dimensional kinematics and kinetics data from each session were used in this study.

Results: The Intraclass Correlation Coefficients (ICC’s) for the hip and ankle joints' were between 0.83-0.99 for kinetics, and between 0.86-0.99 for kinematics data among healthy individuals. Furthermore, the standard error of measurement was up to 2.5° and 0.3 Nm/kg, whereas the root mean square deviation was up to 3° and 0.25 Nm/kg.

Conclusion:. This result could help researchers to have a baseline for future studies.

Keywords

Interlaced stairway; Repeatability; Biomechanics; Hip; Ankle

Introduction

The gait cycle during stair climbing has been evaluated to differentiate between healthy and pathological groups [1-3]. Generally, old individuals complain from pain and difficulties during stair climbing due to muscles weakness, joints' instabilities, joints' stiffness, sports injuries, knee osteoarthritis [1-3].

Hence, various studies have examined the effects of using different orthotics intervention to increase stability, range of motion, knee flexion, and speeds; and to reduce loads and moments over the lower limb joints (the hip, knee, ankle joints) during stair climbing [4-7]. Nevertheless, few studies have provided a precise baseline about the hip, knee, ankle joints' biomechanics during stair climbing for orthotists and therapists to compare their results with that baseline when working with pathological groups.

Alfatafta et al. [8] evaluated the inter-sessions repeatability of the knee joint's biomechanics (kinetics and kinematics) during stair climbing. The results show that the repeatability of the knee joint is high in the sagittal plane and moderate in the frontal and transverse planes with measurement error up to four degrees [8].

That study was the first study that has evaluated the measurement error with using Intraclass Correlation Coefficients (ICC), the Root-Mean-Square Deviation (RMSD), and Standard Error of Measurement (SEM). Other studies examined the lower limb joints' repeatability during stair climbing, but without evaluating the measurement error or providing comprehensive data that could be used as a baseline for orthotists later-on [9-13].

Hence, the primary aim of this study is to evaluate the repeatability of the hip and ankle joints' biomechanics (kinematics and kinetics) during stair climbing among healthy individuals in the same way that the knee joint was evaluated previously [8]. The results of this study will help orthotists and therapists to build up compressive data that could be used as a baseline when working with pathological groups or when examining the effects of orthotics' interventions during stair climbing.

Methods

Participants

Ten-healthy participants (five male, five Female; age 32.1 ± 6.8 years; mass 69.3 ± 10.5 kg; height: 168 ± 0.7 cm) participated in two sessions within a week. The recruited participant must be able to climb a stair without pain or assistive devices. Also, they must not have any previous lower limbs surgery, pathologies, or injuries. This study was approved by the Research and Governance Ethical Committee of the University of Salford, UK.

Similar to Alfatafta et al. [8] study, the Force Plate Attached Interlaced Stairway (FPAIS) design [14] with a three-step (AMTI: Advanced Mechanical Technology Incorporation, Watertown, USA, Force plate model-BP600400) was used to examine the Ground Reaction Force (GRF) at 1000 Hz frequency **(Figure 1)**. Also, infrared Qualisys OQUS cameras (16 cameras, Sweden) were used to capture motion at 100 Hz [5,8] sampling rate.

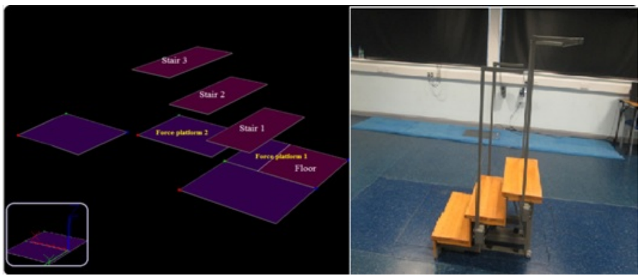

Figure 1: The settings of the AMTI Force Plates Attached Interlaced Stairway (FPAIS) in the walkway and the virtual set-up for the biomechanical calculations in Visual3D

Procedure

All participants signed informed consent sheet firstly. After that, the participants were asked to visit the gait lab for experimental. Each participant was asked to be in bare feet and wore shorts to allow attachment of reflective markers and cluster pads over the flowing landmarks according to the Calibrated Anatomical Systems Technique (CAST) [8,15].

Firstly, the participants were then asked to ascend and descend the stair for one minute to ensure that they felt comfortable and were able to use the stair properly. Then, the recording was started by asking the participants to climb the three-step with feet over feet technique and self-selected walking speed.

When they reached the third step (the last step), they were asked to stop for a few seconds and then turn around and descend the two steps until they reached the floor. The test was repeated five to seven times to avoid fatigue.

Because the interlaced stairway design has two platforms, kinetics data was measured between the first and third step during stair ascent and between the second step and floor during stair descent.

Therefore, the gait cycle during stair ascent starts when the foot touches the first step and ends when the ipsilateral foot contacts the third step. While the gait cycle during stair descent begins when the foot touches the second step until the same foot contacts the floor. The test was repeated after one week for all participants under the same conditions. One hour was required to collect data for each session.

To accept the trail, the foot must touch the stair structure not the edge, markers are clear, and the gait cycle time of the trial not more ±5% beyond the mean of both ascent and descent's time. The walking variability was expected to below as the participants with no neuromuscular pathologies.

Data processing and analysis

Similar to Alfatafta et al. [8] study, the data were collected by Visual3D software (v 5.00, C-Motion Inc., Rockville, USA). Through that software, seven lower limb segments were built using a six-degree of freedom model.

This model was used for each segment to examine the linear and angular movement as well as kinematics. The kinetics data were measured by a Cardan sequence of x-y-z, the kinematics data were calculated by A Butterworth fourth order bi-directional low pass filter (6 Hz frequency), and force was calculated by analogue signals (25 Hz frequency) [8,15-17].

The key variables that were measured in this study are the average maximum and minimum of the hip and ankle angles and moments in the sagittal, frontal, and transverse planes. The average maximum or minimum for selected data for a single participant was calculated firstly for every single trial, and then the average of five trials was calculated. This process was repeated for each participant, and then an average of all of the participants was calculated together to gain one graph which represented the results of all of the participants.

The results were calculated by SPSS (version-20, IBM SPSS, Chicago, USA). The Intraclass Correlation Coefficients (ICCs) type (3, k) (average measurement of five trials was calculated) and their 95% CI boundaries [13], SEM, and RMSD were calculated. Fleiss' classification was used to define the value of ICCs [8,16].

Results

The hip kinematics during stair ascent and descent

The ICC's of the hip angles in the sagittal (Flexion: positive), frontal (Adduction: positive), and transverse (medial rotation: positive) planes were identified as 0.91-0.99 during stair climbing **(Table 1)**. Also, RMSD was up to 3.2 ± 3.3° and SEM was up to 2.7°.

The ankle kinematics during stair ascent and descent

The ICC's of the ankle angles in the sagittal (Dorsiflexion: positive), frontal (Adduction: positive), and transverse (medial rotation: positive) planes were between 0.83-0.99 during stair climbing **(Table 1)**. In further, RMSD was up to 2.6 ± 1.0° and SEM was up to 1.8°.

The hip kinetics during stair ascent and descent

The results show that the ICC of the hip moment in the sagittal plane (Flexion moment: positive), frontal (Adduction: positive), and transverse (medial rotation: positive) planes were between 0.83-0.99 during stair climbing. Moreover, RMSD was up to 0.18 ± 0.31 Nm/kg and SEM was up to 0.15 Nm/kg **(Table 2)**.

Table 1: The repeatability of the hip and ankle joints' kinematics during stair climbing. ROM: Range of Motion in the sagittal plane.

Variables (Angles)	Ascent Mean (± SD) (°)	Ascent ICC	95% CI of ICC		SEM (°)	Descent Mean (± SD) (°)	Descent ICC	95% CI of ICC		SEM (°)
			Lower Bound	Upper Bound				Lower Bound	Upper Bound	
Hip flexion	67.5 ± 12.5	0.958	0.83	0.99	2.5	41.3 ± 11.4	0.987	0.947	0.997	1.3
Hip extension	6.6 ± 8.5	0.961	0.843	0.99	1.7	-10.5 ± 5.6	0.924	0.695	0.981	1.5
Hip adduction	9.4 ± 3.8	0.929	0.713	0.982	1	8.5 ± 2.4	0.983	0.93	0.996	0.3
Hip abduction	7.1 ± 5.4	0.979	0.914	0.995	0.8	8.0 ± 2.7	0.95	0.797	0.987	0.6
Hip medial rotation	13.8 ± 3.6	0.99	0.995	1	0.4	20.7 ± 7.5	0.976	0.903	0.994	1.2
Hip lateral rotation	1.5 ± 9.4	0.935	0.739	0.984	2.4	19.6 ± 9.5	0.915	0.656	0.979	2.7
Ankle dorsiflexion	26.3 ± 2.7	0.83	0.314	0.958	1.1	34.8 ± 5.5	0.94	0.881	0.993	1.3
Ankle plantarflexion	14.9 ± 6.2	0.967	0.868	0.992	1.1	21.5 ± 5.8	0.976	0.9.5	0.994	0.9
Ankle eversion	8.2 ± 2.8	0.864	0.452	0.966	1	5.7 ± 3.7	0.876	0.513	0.97	1.3
Ankle Inversion	6.4 ± 3.7	0.944	0.774	0.0.986	0.8	9.2 ± 3.0	0.879	0.513	0.97	1
Ankle medial rotation	14.0 ± 4.8	0.954	0.814	0.989	1	14.0 ± 6.2	0.913	0.722	0.983	1.8
Ankle lateral rotation	4.0 ± 7.8	0.957	0.826	0.989	1.6	13.2 ± 7.7	0.956	0.823	0.989	1.6
Hip ROM	60.6 ± 5.4	0.98	0.92	0.99	0.63	28.9 ± 6.4	0.97	0.91	0.99	1.1
Ankle ROM	40.9 ± 8.2	0.92	0.7	0.98	2.3	58.5 ± 6.1	0.97	0.89	0.99	1

Table 2: The repeatability of the hip and ankle joints' kinetics during stair climbing

Variables (Moments)	Ascent Mean (± SD) (Nm/Kg)	Ascent ICC	95% CI of ICC		SEM (Nm/Kg)	Descent Mean (± SD) (Nm/Kg)	Descent ICC	95% CI of ICC		SEM (Nm/Kg)
			Lower Bound	Upper Bound				Lower Bound	Upper Bound	
Hip flexion	0.18 ± 0.26	0.94	0.759	0.958	0.06	1.5 ± 0.12	0.903	0.6	0.976	0.03
Hip extension	0.65 ± 0.4	0.845	0.335	0.959	0.15	0.53 ± 0.19	0.931	0.724	0.983	0.04
Hip adduction	0.74 ± 0.39	0.843	0.637	0.961	0.15	0.08 ± 0.07	0.996	0.983	0.996	0

Hip abduction	0.05 ± 0.05	0.834	0.331	0.959	0.02	0.74 ± 0.26	0.992	0.968	0.998	0.02
Hip medial rotation	0.28 ± 0.17	0.9	0.598	0.975	0.05	0.16 ± 0.06	0.95	0.8	0.988	0.01
Hip lateral rotation	0.0 ± 0.03	0.928	0.711	0.982	0	0.13 ± 0.08	0.877	0.505	0.969	0.02
Ankle dorsiflexion	-0.10 ± 0.38	0.91	0.636	0.978	0.1	-0.05 ± 0.03	0.814	0.249	0.954	0.01
Ankle plantarflexion	1.14 ± 0.52	0.779	0.111	0.945	0.24	1.33 ± 0.27	0.851	0.399	0.963	0.1
Ankle eversion	0.06 ± 0.2	0.777	0.101	0.948	0.09	0.23 ± 0.18	0.968	0.973	0.992	0.03
Ankle Inversion	0.16 ± 0.10	0.97	0.88	0.993	0.01	0.06 ± 0.10	0.939	0.755	0.985	0.3
Ankle medial rotation	0.16 ± 0.07	0.97	0.879	0.993	0.1	0.15 ± 0.07	0.978	0.91	0.994	0.01
Ankle lateral rotation	0.0 ± 0.02	0.877	0.505	0.969	0	0.14 ± 0.07	0.974	0.869	0.994	0.01

Discussion

Climbing stairs is one of the most performed daily activities and challenging tasks for some individuals such as those with neuromuscular impairments or painful lower limb symptoms. Few studies [18-20] have focused stairway in the evaluation of the normal gait pattern using FPAIS and the effects of orthotics treatments during climbing FPAIS. Hence, it is vital to determine a precise baseline for the normal lower limb biomechanics using standard error of measurement. Similar to the knee joint, the repeatability in the sagittal plan is higher than the frontal and transverse planes [8,10]. In addition, based on Fleiss' classifications [16] the repeatability of all variables varies between moderate to excellent. However, the ankle joint was less repeatable joint compared to the hip and knee joints [8] due to the inconsistency of the ankle joint position in the same session. The movement pattern of the ankle joint was less consistent during stair descent compared to stair ascent. For instance, during the same session, the participants touched the stair with either ankle planterflexion or flat foot these changes in ankle position could alter the knee flexion angle position, and thereby the knee reliability will be less during stair ascent [8,9].

Conclusions

The knee repeatability was examined in the previous study to provide a baseline for orthotists and therapists who work with knee pathologies such as knee osteoarthritis. However, it is important to evaluate the repeatability of the hip and ankle joints were not examined during stair climbing. Hence, the results' of this study illustrate that the repeatability of the biomechanics of hip and ankle joints in healthy adult participants was a highly reliable with a small measurement error in the sagittal, frontal, and transverse planes during FPAIS climbing. The primary limitation of this study is the size of the group is small; however, the available articles also evaluated a small sample size. More studies are required with more participants including both the healthy and pathologies groups.

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