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ORIGINAL ARTICLE

Giyilebilir hareket analiz sisteminin (G-walk) sağlıklı yetişkinlerde yürüyüş ve sıçrama değerlendirmesi üzerine güvenilirliğinin araştırılması

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Amaç: Giyilebilir hareket analiz sistemleri kliniklerde yürüyüş ve sıçrama performansının değerlendirilmesinde yaygın olarak kullanılmaktadır. G-walk cihazı bu amaçla kullanılan cihazlardan biridir. Bu tür cihazları klinik değerlendirme için kullanmadan önce güvenilirliğinin belirlenmesi büyük önem taşımaktadır. Bu çalışmanın amacı, sağlıklı yetişkinlerde yürüyüş ve sıçrama parametreleri için G-walk giyilebilir hareket analiz sisteminin test-tekrar test güvenilirliğini incelemektir.
Yöntem: Çalışmaya kırk dokuz (30 kadın, 19 erkek, 23,58±2,65 yaş) sağlıklı gönüllü katıldı. Katılımcıların yürüyüş ve sıçrama parametreleri G-walk cihazı kullanılarak değerlendirildi. Yürüyüş parametreleri için; hız, kadans, adım uzunluğu, adım süresi, duruş süresi, salınım süresi, çift destek, tek destek süreleri ve pelvik açılar değerlendirildi. "Counter movement jump", "squat jump" ve "countermovement jump with arms thrust" sıçramaların maksimum yüksekliği değerlendirildi. Test-tekrar test analizi için sınıf içi korelasyon katsayısı (ICC) yöntemi kullanıldı (p<0,05).
Bulgular: Pelvik açılar haricindeki yürüyüş parametresi ölçümlerinin tümünün yüksek veya mükemmele yakın test-tekrar test güvenilirliğine (ICC: 0,728-0,969) sahip olduğu, pelvik açıların ölçümlerinin ise orta derecede test-tekrar test güvenilirliğe sahip olduğu (ICC: 0,463-0,659) bulundu. Tüm sıçrama parametrelerinin ölçümlerinin mükemmele yakın test-tekrar test güvenilirliğe sahip olduğu göründü (ICC: 0,900-0,986).
Sonuç: Bu çalışmanın sonucunda G-walk cihazının yürüyüş ve sıçrama değerlendirmesinde kullanılacak güvenilir bir cihaz olduğu ortaya konmuştur. G-walk cihazının taşınabilir, kullanımı kolay ve uygun maliyetli olmasının yanı sıra sağlıklı yetişkinlerde yürüyüş ve atlama performansını ölçmede güvenilir olduğu bulunmuştur. Bu çalışma clinictrials.gov üzerinde kaydedildi: NCT04310982
Anahtar Kelimeler: Yürüyüş analizi, Güvenirlik, Giyilebilir elektronik cihaz.

The reliability of a wearable movement analysis system (G-walk) on gait and jump assessment in healthy adults

Purpose: Wearable inertial sensor systems are generally used in the assessment of gait and jump performance in clinics. G-walk is one of these devices however, before using this device for clinical interpretation, the reliability of this device must be defined. The aim of this study was to investigate the test–retest reliability of the G-walk wearable movement analysis sensor system for gait and jump assessments in healthy adults.
Methods: Forty-nine healthy volunteers (30 females, 19 males, 23.58±2.65 years of age) participated in the study. The jump and gait parameters of the participants were evaluated using G-walk. The gait parameters were; speed, cadence, stride length, stride duration, stance duration, swing duration, double support, single support and pelvic angles during gait. The maximum height of the following jumps was assessed; counter movement jump, squat jump and countermovement jump with arms thrust. The intraclass correlation coefficient (ICC) method was used for test-retest analysis (p<0.05).
Results: All gait parameter measurements had high or excellent test–retest reliability (ICC:0.728-0.969) with the exception of pelvic angles during gait. The assessment of pelvic angles had moderate test–retest reliability (ICC: 0.463-0.659). All of the jump parameters' measurements had excellent test–retest reliability (ICC: 0.900-0.986).
Conclusion: In conclusion, this study shows that the G-walk is a reliable device for assessing gait and jump. Alongside being portable, easy to use and affordable at cost, the G-walk was found to be reliable in measuring gait and jump performance in healthy adults. The study was registered on clinicaltrials.gov: NCT04310982
Keywords: Gait analysis, Reliability, Wearable electronic device.

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Gait analysis is an effective method used for a variety of purposes, including assessing neurological diseases, risk of falling, orthopedic disability and progress during rehabilitation.[1,2] Gait analysis is necessary to customize treatment, track individual progression, and prove therapeutic benefits and can also detect deviations and impairments underlying reduced function.[3] Thus may assist in clinical decision making in addition to quantifying the effectiveness of rehabilitation.[4] Basic clinic gait analysis are mainly observational or based on gait speed in a wide range of populations.[5] However, these tests are not sufficient to evaluate other spatiotemporal parameters, such as cadence, step length and derivative parameters, such as gait symmetry, which are considered essential for a complete and accurate assessment of gait.[3,6]

The power of leg muscles and performance of vertical jump are considered to be critical elements for maximum athletic performance, and also for carrying out daily activities and vocational tasks.[7] Additionally, jump performance measures can be used in; the prediction of injury risks, assessment of talent, and replication of competitive activities in athletes. Furthermore, vertical jumping performance can be associated with neuromuscular fatigue.[8] Therefore the measurement of vertical jump height is frequently used by many professionals working in various fields of sports.[9] Performance on a maximum vertical jump could be used as a functional test to assess lower limb strength.[10] Vertical jumping performance can be evaluated by both static squat jump (SSJ) and counter-movement jump (CMJ) tests.

The analysis of gait and jump performance must be applicable in a clinical setting. Thus; it needs to be easy to apply in a variety of life situations.[11] The assessments should be duplicable, constant, capable of differentiating between conditions which are normal and abnormal, and must also be inexpensive.[7] The gold-standard laboratory based assessment methods used in the assessment of gait and jump analysis are; 3-dimensional motion capture systems, optical encoders, position transducers or force plates.[12]

These techniques are highly accurate, however, they present common limitations that may restrict their clinical use. They require more time for setup and analysis, technical expertise and equipment than is available in the average physiotherapy department and are costly.[13] Due to these drawbacks, wireless inertial sensors (WIS), are now used in gait and jump performance assessment. WIS are; easy to use, lightweight and cost-effective. Since these devices are wireless, unrestricted movement is enabled.[14]

The BTS G-WALK sensor system (G-Walk) is a WIS which can be used in the determination of spatiotemporal parameters and also pelvic movements (rotation, tilt and obliquity) during gait.[14] The system, provides a series of parameters that analyze various movements including walking, running and jumping. The software used is BTS G-Studio. G-Studio is a simple and easy-to-use software that can manage different acquisitions and automatically elaborate and report different analysis protocols. Following each analysis, a report which contains all the above-mentioned parameters is created automatically by the software.[3]

The G-Walk was recently introduced as a multipurpose testing and treatment device for the assessment of gait and jump. Before using such devices for clinical interpretation, the reliability must be investigated. In literature there is one study evaluating the reliability of the G-Walk on gait. In this study by De Ridder et al., the concurrent validity of the G-walk on gait parameters in healthy individuals was assessed.[3] However it is unknown whether the G-Walk is reliable in the assessment of jump performance. The measurements obtained via this device must be precise, capable of differentiating between normal and abnormal conditions and should be able to produce similar results in each assessment.[7] As a portable low-cost device, G-Walk may be beneficial in the assessment of jump performance.

Therefore, the purpose of the present study was to investigate the test–retest reliability of the G-Walk wearable sensor system for gait and jump parameters in healthy adults.

METHODS

Participants

Forty-nine healthy participants (30

females, 19 males) completed the test-retest protocol with 7 days between tests. Participants were; 23.58±2.65 years of age, 62.9±10.08 kg of weight and 168.76±8.31 cm of height. Participants included in the study did not have any musculo-skeletal, neurologic or other pathology potentially altering their gait and jump performance. Prior to recruiting participants for our study, a power analysis was performed with the G-power program, version 3.1.9.5 and the target sample size was reached with a probability of 0,05 and 80% power. Informed consent forms were obtained from the subjects stating that they were willing to participate in this study. The ethics committee of Gazi University has approved this study with the approval number of 2019-345. The authors conformed to the ethical guidelines of the 1975 Declaration of Helsinki. This study was registered on clinicaltrials.gov with an ID of NCT04310982.

Study design and procedures

Upon arrival at the first test session, the participants filled out an informed consent and medical history form that included demographic information and answered questions determining inclusion/exclusion criteria for the study. The jump parameters and gait parameters of the participants were evaluated using the G-Walk sensor system (BTS G-Walk BTS Bioengineering Company, Italy). G-Walk is built with an accelerometer with 3 axes, 16 bit/axes with multiple sensitivity (±2, ±4, ±8, ±16 g), a magnetometer with 3 axes 13 bit (±1200 µT) and a gyroscope with 3 axes 16 bit/axes with multiple sensitivity levels (±250, ±500, ±1000, ±2000°/s). All data were collected using a frequency of 100 Hz. The acquired data is transmitted via a Bluetooth connection to a computer.

For the data analysis, all measurements are calculated based on the person's height and movements. Therefore, it is necessary to enter the height of the person prior to assessment. The height of the subjects is used by the calculation algorithm to properly identify the gait and jump parameters. The device was worn on the waist of the person being evaluated via an elastic belt and the center of the device was located at the fifth lumbar vertebrae.[14] To be sure of correct placement of the device, the processes of the posterior superior iliac spines of the individual being assessed was palpated to determine the L4-L5 intervertebral space. After the G-Walk was positioned in place correctly, both gait and jump parameters were evaluated in the same session. The participants were informed to wear their own comfortable and non-restricting clothing during the tests.

Evaluation of gait parameters

The gait assessments began with the participant standing still in an orthostatic standing position. The position had to be maintained for a few seconds until the end of the stabilization of the G-Walk device. The participants were instructed to walk on a 7-meter track. The boundaries of the track were marked to ensure a correct analysis. The participants walked at their natural speed along an absolutely straight path. A successful trial was characterized by the participant completing the 7-meter track and returning to the starting point. The parameters that were evaluated using the G-Walk were; speed (meter/seconds), cadence (steps/minute), stride length (meters), stride duration (seconds), stance duration (% of gait cycle), swing duration (% of gait cycle), double support (% of gait cycle), single support (% of gait cycle) and pelvic angles during gait (degrees).

Evaluation of jump parameters

The jump tests protocols included; counter movement jump (CMJ), static squat jump (SSJ) and counter movement jump with arms thrust (CMJAT). At the end of the jump tests, all kinematic parameters concerning the evaluated jump were provided by the software. The following variables were assessed via the G-Walk device for jump performance; height (cm), peak speed (m/s), take off speed (m/s), take off force (kN), impact force (kN) and maximum concentric power (kN). Each participant performed a session of three trials for each of the assessed jumps. The jump with the maximum height was accepted for analysis.

Test execution

Countermovement jump

The subjects began the test in upright position with their feet placed shoulder width apart and hands on their hips. Once the evaluator gave the command to start, the participants made an initial downward movement via flexion of their hips and knees, then immediately extended their hips and knees again to jump off the ground vertically. During the entire test, the participants were instructed to maintain the upright position of the trunk with their hands on their hips. The stages of CMJ can be seen in Figure 1.

Static Squat Jump

In the evaluation of this test, the participants began the test in upright position with their feet positioned shoulder width apart and the hands on their hips. Once the evaluator gave the command to start, the participants performed a squat by flexing their knees 90 degrees and maintained this position for a second. From this position of static squat, the participant performs a vertical jump without any countermovement towards down to maintain the elasticity. If the participant was to perform a countermovement, the test was considered invalid and thus repeated. During the entire test, the participants were instructed to maintain the upright position of the trunk with their hands on their hips. The stages of SSJ can be seen in Figure 2.

Countermovement Jump with Arms Thrust

The subjects began the test in upright position with the feet shoulder width apart and arms by their sides. Once the evaluator gave the command to start, the participants made an initial downward movement via flexion of their hips and knees, then immediately extended their hips and knees to jump up, vertically off the ground, with the help of their arms. During the entire test, the participants were instructed to maintain the upright position of the trunk. The stages of CMJAT can be seen in Figure 3.

Statistical analysis

Statistical analysis was conducted using the SPSS 22 computer software system. The variables were analyzed using visual (histograms, probability plots) and analytical methods (Kolmogorov-Simirnov/Shapiro-Wilk's test) to determine whether or not they were normally distributed. Descriptive analyses were presented using means and standard deviations (SD) for the normally distributed variables. For the reliability, test-retest analysis intra-class correlation coefficient (ICC) with absolute agreement and 95% confidence interval (CI) were determined between the first and second assessment. The minimal detectable change (MDC), is a certain measure of reliability, which accounts for many sources of variability in defining a confidence interval in units of the measure. MDC is the smallest change you can measure above this systematic error. It is important to calculate MDC because, The MDC is the minimum amount of change in a subject's score that ensures the change is not the result of an error in measurement. MDC was calculated by multiplying the SD of the difference with 1.96. When evaluating interventions, the pre-post difference must be larger than the MDC to express real improvement. The standard error of measurement (SEM) provides a measure of variability but was mainly used for calculating the MDC. The SEM gives information regarding systematic measurement error. SEM values were calculated using the following formula: $SEM=SD\times\sqrt{(1-ICC)}$, with SD representing the standard deviation of the measure .[15] The ICC values were defined as; higher than 0.81 was excellent, 0.61-0.80 was high, 0.41-0.60 was moderate, 0.21-0.40 was fair.[16] Systematic differences were identified using a paired T-test. Statistical significance was set as $p<0.05$ level for this study.

RESULTS

Data analysis was performed with the data obtained from 49 participants. Table 1 demonstrates ICC, 95% CI, SEM, MDC, mean, SD values of test and retest and statistically significance (p) gait measurements. According to the analysis ICC varied from 0.728 to 0.969 in all of the gait parameters except pelvic angles. The statistical analysis showed that all gait parameters' measurements had excellent or high test–retest reliability with the exception of pelvic angles during gait. The test-retest assessment of pelvic angles using the G-Walk device had moderate test–retest reliability (ICC values from 0.463 to 0.659).

Table 2 demonstrates ICC, 95% CI, SEM, MDC, mean, SD values of test and retest and statistically significance (p) jump measurements. According to the analysis ICC varied from 0.900 to 0.986 in all of the jump parameters. The statistical analysis showed that all jump parameters' measurements had excellent test–retest reliability.

No statistically significant difference was found between the mean scores of test and retest according to the paired T-tests of any of the measures, and this indicates the absence of systematic bias ($p>0.05$).

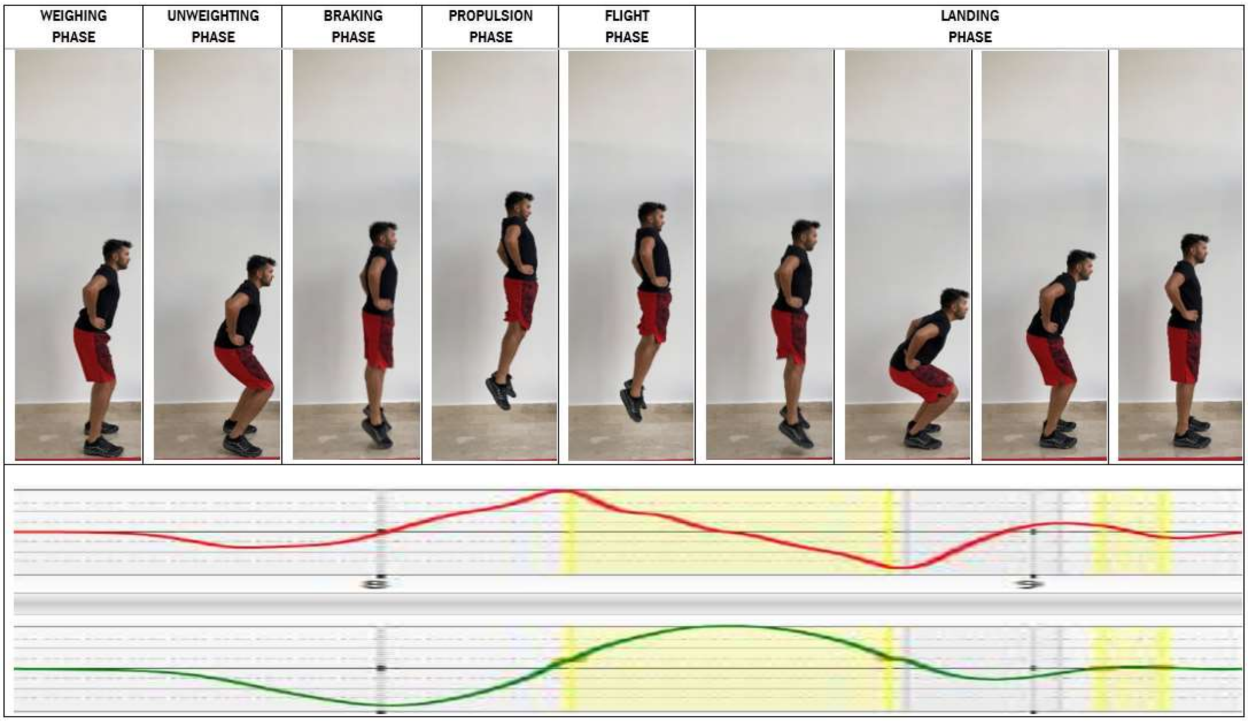

Figure 1. Phases of the countermovement jump (CMJ), red line indicates speed (m/s), green line indicates displacement (m).

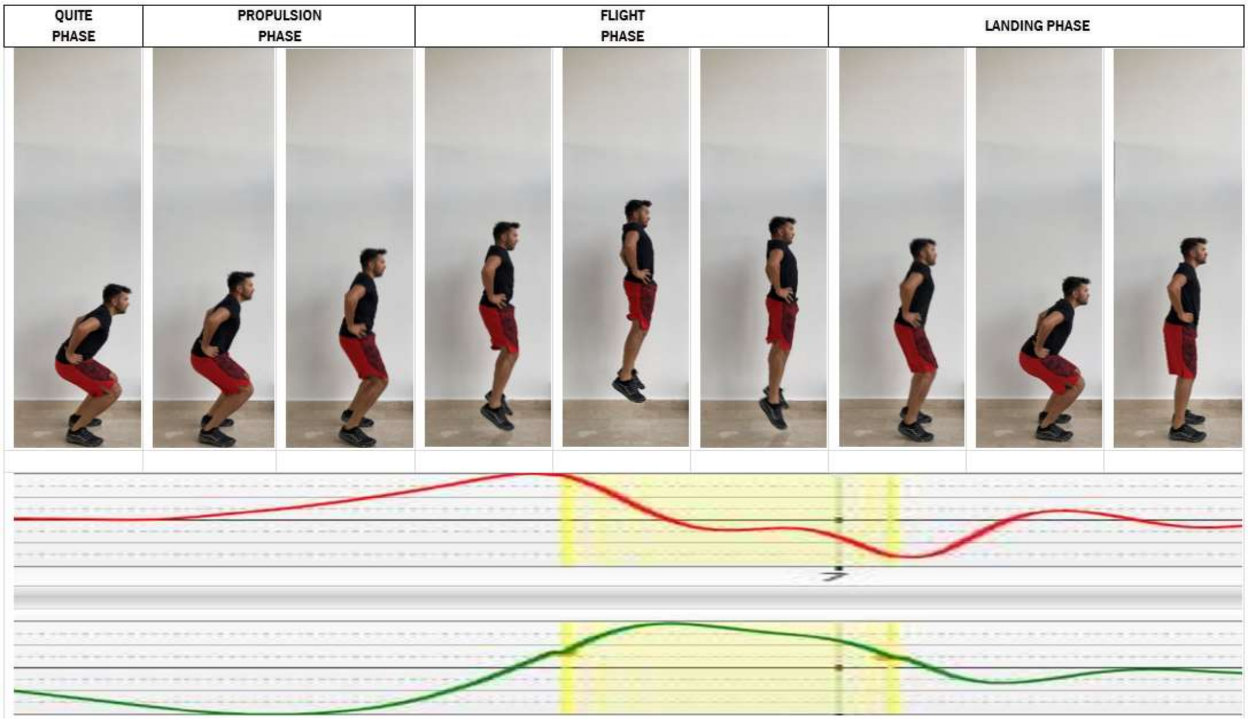

Figure 2. Phases of the static squat jump (SSJ), red line indicates speed (m/s), green line indicates displacement (m).

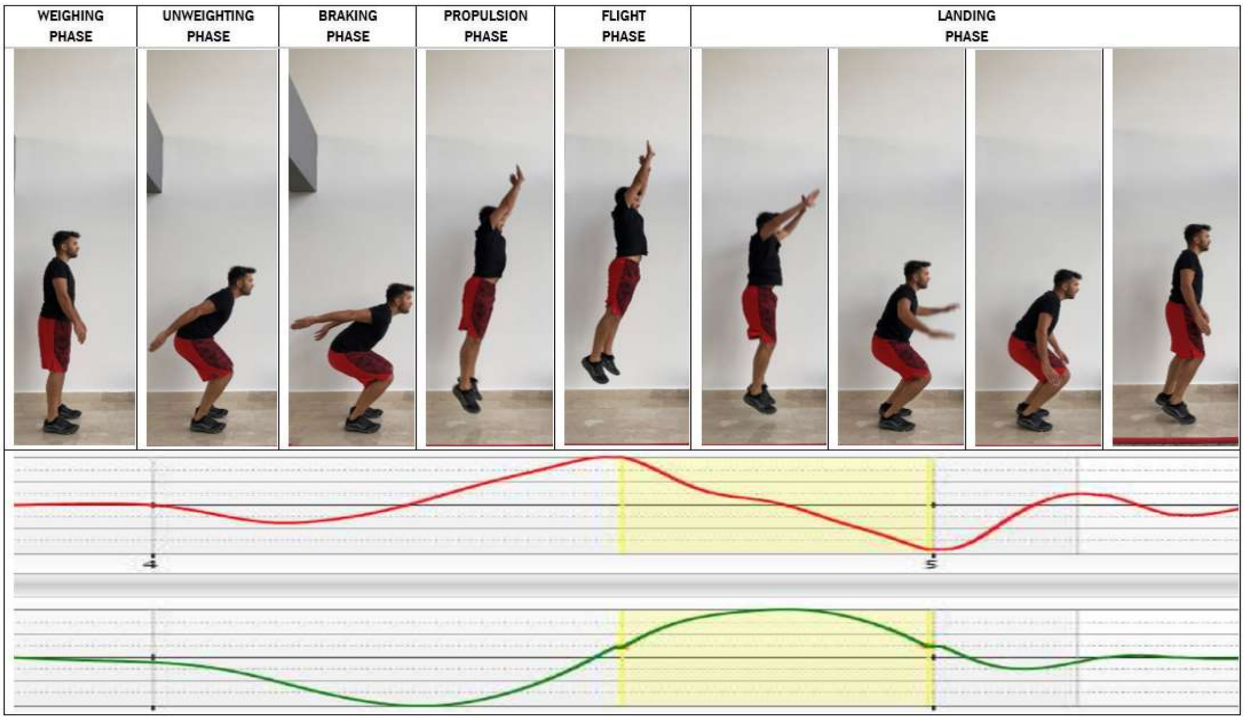

Figure 3. Phases of the countermovement jump with arms thrust (CMJAT), red line indicates speed (m/s), green line indicates displacement (m).

Table 1. Intraclass correlation coefficient, confidence interval, standard error measurements, minimal detectable change, means, standard deviations, and p values of gait parameters.

			95% CI				Test		Retest		
		ICC	LB	UB	SEM	MDC	Mean	SD	Mean	SD	p
Cadence		0.868	0.767	0.925	1.01	2.80	116.4	7.63	115.74	6.38	0.343
Speed		0.898	0.818	0.942	0.33	0.91	1.26	0.20	1.23	0.22	0.205
Gait cycle duration (sec)	DS	0.868	0.770	0.927	0.09	0.25	1.04	0.06	1.04	0.07	0.633
	NDS	0.881	0.788	0.932	0.09	0.25	1.05	0.06	1.04	0.07	0.281
Stride length (m)	DS	0.957	0.923	0.975	0.04	0.11	1.29	0.24	1.31	0.22	0.183
	NDS	0.957	0.923	0.975	0.04	0.11	1.29	0.24	1.31	0.21	0.215
% Stride length (% height)	DS	0.958	0.924	0.976	2.35	6.51	80.43	14.94	81.68	14.63	0.129
	NDS	0.960	0.927	0.977	2.36	6.54	80.46	15.06	81.74	14.79	0.159
Step length (% stride length)	DS	0.790	0.596	0.884	0.29	0.80	50.54	1.56	50.20	1.63	0.783
	NDS	0.789	0.592	0.883	0.29	0.80	49.46	1.56	99.81	1.64	0.805
Stance phase (% cycle)	DS	0.741	0.545	0.856	0.38	1.05	60.22	2.67	60.13	2.33	0.765
	NDS	0.841	0.719	0.910	0.36	1.0	60.52	2.23	60.77	2.51	0.339
Swing phase (% cycle)	DS	0.816	0.677	0.897	0.36	1.0	40.09	2.48	39.87	2.33	0.437
	NDS	0.728	0.516	0.845	0.43	1.19	39.48	2.24	39.01	3.39	0.222
First double support phase (% cycle)	DS	0.782	0.617	0.879	0.30	0.83	10.42	1.95	10.5	2.09	0.740
	NDS	0.864	0.756	0.922	0.36	1.0	10.14	2.21	10.45	2.57	0.192
Single support phase (% cycle)	DS	0.839	0.714	0.908	0.36	1.0	39.53	2.26	39.22	2.51	0.234
	NDS	0.841	0.722	0.912	0.35	0.97	39.98	2.26	39.85	2.38	0.591
Gait Cycle Symmetry Index		0.761	0.570	0.871	0.49	0.14	96.3	2.73	96.39	2.82	0.474
Symmetry Index of Pelvic Angles	Tilt	0.548	0.202	0.749	3.34	9.26	68.29	20.74	67.83	23.54	0.897
	Obliquity	0.659	0.398	0.808	0.16	0.44	98.19	1.16	98.13	1.04	0.359
	Rotation	0.463	0.048	0.685	0.14	0.39	98.16	1.18	98.51	0.92	0.062

ICC: Intraclass correlation coefficient. CI: Confidence interval. SEM: Standard error measurements. MDC: Minimal detectable change.
DS: Dominant side, NDS: Non-dominant side. LB: Lower bound. UB: Upper bound.

Table 2. Intraclass correlation coefficient, confidence interval, standard error measurements, minimal detectable change, means, standard deviations, and p values of jump parameters.

	ICC	95% CI		SEM	MDC	Test		Retest		p
		LB	UB			Mean	SD	Mean	SD	
CMJ										
Height (cm)	0.986	0.975	0.992	1.23	3.41	24.47	8.35	24.34	8.05	0.657
Peak speed (m/sec)	0.957	0.925	0.976	0.065	0.18	2.60	0.42	2.59	0.43	0.674
Take off speed (m/sec)	0.958	0.926	0.976	0.066	0.18	2.58	0.43	2.58	0.44	0.776
Take off force (kN)	0.928	0.863	0.958	0.056	0.16	0.81	0.37	0.76	0.34	0.205
Impact force (kN)	0.966	0.938	0.980	0.11	0.30	1.47	0.74	1.53	0.69	0.098
MCP (kN)	0.970	0.945	0.983	0.22	0.61	3.34	1.14	3.25	1.4	0.188
CMJ with arms thrust										
Height (cm)	0.981	0.966	0.989	1.49	4.13	28.56	9.72	28.19	9.78	0.344
Peak speed (m/sec)	0.955	0.919	0.974	0.076	0.21	2.89	0.5	2.85	0.5	0.205
Take off speed (m/sec)	0.950	0.911	0.972	0.076	0.21	2.88	0.5	2.84	0.5	0.219
Take off force (kN)	0.966	0.933	0.980	0.074	0.21	1.02	0.49	0.96	0.47	0.273
Impact force (kN)	0.960	0.929	0.977	0.11	0.30	1.62	0.70	1.59	0.65	0.418
MCP (kN)	0.973	0.950	0.984	0.29	0.80	4.14	1.95	3.98	1.84	0.089
Squat jump										
Height (cm)	0.964	0.936	0.979	1.25	3.46	24.17	8.60	23.61	7.91	0.208
Peak speed (m/sec)	0.931	0.879	0.961	0.063	0.17	2.59	0.42	2.56	0.42	0.387
Take off speed (m/sec)	0.900	0.822	0.943	0.067	0.19	2.57	0.43	2.52	0.47	0.232
Take off force (kN)	0.969	0.946	0.983	0.056	0.16	0.83	0.36	0.84	0.36	0.446
Impact force (kN)	0.939	0.894	0.966	0.11	0.30	1.53	0.77	1.54	0.62	0.797
MCP (kN)	0.976	0.959	0.987	0.22	0.61	3.35	1.53	3.33	1.40	0.725

ICC: Intraclass correlation coefficient, CI: Confidence interval, SEM: Standard error measurements. MDC: Minimal detectable change. kN: Kilo Newton. CMJ: Counter movement jump. MCP: Maximum concentric power.

DISCUSSION

This study has presented evidence regarding the test retest reliability and MDC values of the G-Walk device on gait and jump assessment in 49 healthy adults.

Test-retest reliability expresses the amount which a measure is constant and repeatable. It involves validation of an assessment over multiple points of time. Reliability is the proportion of a true score deviation to an observed score deviation. It is generally presented using a correlation coefficient, ranging from 0 to 1. The closer the coefficient is to 1, the more reliable this test measure is considered to be, suggesting that the true score can be assessed with little error variance.

The results show that the G-Walk had high or excellent test–retest reliability in the assessment of gait parameters with the exception of pelvic angles and excellent test–retest reliability in the assessment of jump performance in healthy adults. This reflects the devices' ability to provide consistent test-retest measurements. The reliability levels were calculated using ICCs. In our reliability analysis, the coefficient of confidence, which is the ICC value, was set at 95%, indicating a very high confidence level. The ICC values ranged from 0.728 to 0.969 between consecutive measurements performed in seven days in terms in all of the gait parameters except pelvic angles and 0.900 to 0.986 for the parameters measuring jump performance. This shows that the G-Walk gait and jump analysis system is reliable for these measured parameters.

MDC values are used in identifying a true change in the variable being measured, that is beyond arbitrary variations.[17] As a derivative of the ICC and the SD of the scores, the MDC value provides knowledge of the psychometrics of the assessed measure. In this study, the MDC value of the G-Walk parameters show that the G-Walk has little measurement error for the spatio-temporal gait parameters and jump performance.

The SEM is a reliability measure that assesses the stability of response. The SEM is used to calculate the standard error in repeated scores. The assessment of gait and jump performance via wearable sensor devices must be applicable in a clinical setting in order for it to be effective. Thus; it needs to be easy to apply in a variety of life situations and it needs to be reliable. In light of the results presented here, the G-Walk system is a reliable method to assess gait and jump performance in healthy adults in a clinical setting.

De Ridder et al have investigated the concurrent validity of the G-Walk on the assessment of gait parameters in healthy subjects. They have concluded that, the G-Walk is reliable for all measured spatiotemporal parameters. They also stated that, for gait parameters such as; stride length, stride duration, speed, and cadence the device had excellent concurrent validity. Alike their findings we have also found the BTS G-Walk to have excellent reliability for measuring these parameters.[3] In addition to the study conducted by De Ridder et al, we have also found that the reliability of the G-Walk on measuring pelvic angles was moderate.

The G-Walk was recently introduced as a multipurpose testing device for the assessment of gait and jump performance. To our best knowledge, the present study is the first study performed with the aim of assessing the reliability of the G-Walk device on jump performance. The variables assessed via the G-Walk device for jump performance were; height (cm), peak speed (m/s), take off speed (m/s), take off force (kN), impact force (kN) and maximum concentric power (kN). According to our results, it was seen that the G-Walk device was reliable in assessing all of the previously mentioned parameters during all of the types of jumps assessed in this study. Previous literature states that the assessment of jump performance using other body-worn inertial sensor devices was also found to be reliable and valid.[18,19] Our findings add to literature that in addition to other body-worn inertial sensor devices, the G-Walk device is also reliable in assessing jump performance in healthy adults.

Limitations

This study has a few limitations. The number of the participants and the age of the participants, may compromise the ability to generalize results to other aged populations for example adolescents and elderly individuals. Furthermore, the reliability of the G-Walk should also be performed in various pathological conditions. The aim of the present study was to put forth the reliability of the G-Walk device. Further investigation should be made regarding the validation process of the G-Walk device.

Conclusion

Alongside being portable, easy to use and affordable at cost, the G-Walk was found to be reliable in the measurement of gait and jump performance in healthy adults.

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Conflicts of Interest: *None*

Ethical Approval: The protocol of the present study was approved by the ethical committee of Gazi University (issue: 2019-345 date: 04.11.2019).

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