ORIGINAL ARTICLE

Validity and Repeatability of Inertial Measurement Unit for Measuring Walking Gait Parameter of Patients with Non-specific Low Back Pain

Norazebah Hamidon[1], Aizreena Azaman[1,2], Siti Ruzita Mahmod[2], Nur Hidayah Ong Abdullah[3]

[1] School of Biomedical Engineering and Health Sciences, Faculty of Engineering, Universiti Teknologi Malaysia, Skudai 81310, Johor, Malaysia
[2] Sport Innovation and Technology Center (SITC), Institute of Human Centered Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[3] Physiotherapy Department, Hospital Sultanah Aminah Jalan Persiaran Abu Bakar Sultan, 80100 Johor Bahru, Johor Malaysia

ABSTRACT

Introduction: The Inertial Measurement Unit (IMU) is electronic device that enabled us to record joint angles, gait event and spatiotemporal parameter using accelerometers. IMU contain sensors known as inertial sensor which measures its movement by using the inertia principle. This study aimed to determine validity and reliability of spatio-temporal gait parameter using the IMU sensor. **Methods:** This study are prospective cross-sectional recruited thirteen convenience subjects (four men, nine women; 50.0 +/-15.0 years) diagnosed with chronic Non-Specific Lower Back Pain (LBP) from Physiotherapy Department, upon an Orthopedic Specialist's referral, at Hospital Sultanah Aminah Johor Bahru. Spatiotemporal parameters interested: left and right velocity, cadence, stride/step time and stride/step length recorded by Vicon system and IMU sensors synchronously. **Results:** Higher validity was indicated at the Trial 2 detected by the IMU sensors comparing Vicon system, with significant correlation $p \leq 0.05$ except stride time left shank ($r = 0.539$, $p = 0.06$) , left foot ($r = 0.495$, $p = 0.11$) and step length left shank ($r = 0.532$, $p = 0.06$). The result of study also indicated that the reliability of the IMU sensors based on ICCs ≥ 0.75 and 95% CI 0.180 – 0.993, $p \leq 0.01$ in Non-specific LBP patients for spatiotemporal gait parameters comparing Trial 1 and Trial 2. **Conclusion:** The IMU system performs to be valid and reliable for determine spatiotemporal gait parameters in Non-specific LBP patients. IMU provides a possible solution to measure spatiotemporal gait in a clinical setting without requiring specific working area and professional technician.

Keywords: Low Back Pain, Gait analysis, Spatiotemporal gait parameter

Corresponding Author:
Norazebah Hamidon, PhD
Email: norazebah@graduate.utm.my
Tel: +60173124803

INTRODUCTION

Walking is a complex dynamic task that needs an individual to produce and resist a multidirectional forces the joint. Spatiotemporal gait parameters are useful for recognizing the main phases of the gait cycle and identifying large changes in gait patterns (1). Abnormality in walking pattern or also referred to as gait abnormality are commonly observed in patients with severe musculoskeletal disorder such as low back pain. According to National Medical Care (Malaysia) statistics from 11,649 cases diagnosed with musculoskeletal in primary care clinics, up to 2,779 cases diagnosed with Low Back Pain (LBP) reported in August to November 2012 (2). It is expected that increase in back pain cases reported in the year.

The most common of LBP cases (85%) occur are Non-specific LBP (3). Non-specific LBP is define as unknown pathophysiological causes (4). The stage of LBP episode can be categorized as acute when it persists for less than six weeks (0-6 weeks), sub-acute between six weeks until three months (7-12 weeks), and chronic when it lasts longer than three months or up to six months (longer than 12 weeks) (5). Walking impairment can cause social limitation, disability, and increase pain among Non-specific LBP patients (6).

Non-specific LBP patients often report altered spatiotemporal gait parameters such as reduced gait velocity (7,8), shorter step length (7,8), reduced cadence and influenced higher vertical ground reaction forces (9) during walking. These spatiotemporal gait parameters are essential for physiotherapists to analyze the progression treatment of Non-specific LBP (10). However, the comprehensive spatiotemporal gait analysis not obtained by observation of walking performance. Meanwhile,

recently functional outcome measures such as timed-up and go test, timed stair test, and a 10-meters walk test (11) cannot provide spatiotemporal gait parameters such as velocity, stride length and stride time (12).

Although a gold-standard measurement of gait analysis such as Vicon optical motion capture system which enables computerized recording and analysis for spatiotemporal parameters are widely used, it is costly, time and space consuming (13). It is also requires a trained personnel to conduct. Thus, there are major doubts for its practicality in a clinical setting. Alternatively, several low-cost instruments were introduced such as Kinect (14) and webcams (15) but they are limited to a small volume of walking area capture, and only limited step of walking are presented for data analysis (16). Therefore, the Inertial Measurement Unit (IMU) are considered more desirable for measuring the spatiotemporal parameters of gait (16,17) in patients with LBP in clinical setting (18).

Recently, the IMU has been widely used in clinical research as a means of objective assessment of functional performance in clinical conditions (19). The IMU is electronic device that enabled us to record joint angles, gait event and spatiotemporal parameter using accelerometers (20). IMU contain sensors known as inertial sensor which measure their own movement by using the inertia principle. Previous studies were used IMU as one of instrument gait analysis to determine consistency with 'gold-standard measurement' in four gait characteristic, temporal, spatial, spatiotemporal and gait for younger and older people (17).

There are several types of IMU are now established such as Xsens (1), Physilog and APDM have been validated in previous literature with good to excellent agreement and higher validity (16) relative to the gold-standard measurement. However, they have been designed to measure spatiotemporal gait parameters in certain pathological conditions only such as osteoarthritis, Parkinson's disease, vestibular disorder and stroke patient (19). It is also focused only on lumbar kinematic pattern of LBP patients (21), and certain gait parameter such as gait velocity (22). To the best of author's knowledge, there are no studies was conducted to identify the validation of IMU among the Non-specific LBP patients (19,20). Therefore, this study intends to determine validity and reliability of spatiotemporal gait parameters using the IMU sensor comparing with the Vicon optical motion capture system focus on Non-specific LBP patients.

MATERIALS AND METHODS

Subjects

Twenty subjects between 35 – 65 years old, who were diagnosed with chronic Non-specific LBP and can walk independently without assistance or walking aids, were recruited from Physiotherapy Department, upon an Orthopedic Specialist's referral, Hospital Sultanah Aminah Johor Bahru, Johor using purposive (convenience) sampling. Calculation sample sizes are based on power analysis using G*Power Software (Version 3.1.9.4) (23). Statistical analysis correlation (t-test) was used to calculate total sample size of this study with statistical power of 0.95 at an effect size of 0.65 with an alpha level of 0.05 (9).

Inclusion criteria were current or recurrent episodes of Non-specific LBP for up to three to six months (chronic) without unilateral referred leg pain, no numbness or nerve involvement of the lower limb, and complains of lower back pain with a Visual Analogue Scales (VAS) score at least 1 to 7. Subjects were excluded if they are pregnant (24), obesity with body mass index (BMI) above 35 kg/m^2 (7), true length leg discrepancy greater than 5 mm (25) and history of musculoskeletal conditions other than LBP such as scoliosis, spondylolisthesis or ankylosing spondylosis (26). Pregnant, obesity, true length leg discrepancy greater than 5 mm can influence the value of spatiotemporal gait parameter. This study procedures was approved by Medical Review & Ethics Committee (MREC), Ministry of Health Malaysia (NMRR-19-3859-52313).

Materials

Four IMU sensors (Trigno Avanti,Delsys) were placed using Velcro strap on lateral aspect of the shank (above the lateral malleolus) and dorsum of the feet for each leg (16). An IMU sensor (27mm x 37mm x 13 mm in dimension) consists of three digital sensors: a three axis accelerometer (x-axis, y-axis, z-axis), a three axis gyroscope and three axis magnetometer with sampling rate of 128 Hz and at a range of +/- 14g. Sensors were wirelessly synchronized and auto-calibrated. Signal from these sensors were collected by microprocessors with 16-bit resolution and stored at EMGwork 4.5.4 software.

A Vicon optical motion capture system was used as a reference measurement to compare the validity and reliability of IMU (27). This study used Vicon Nexus Plug-in-Gait (Vicon Motion System Ltd, UK) with a sampling rate of 100 Hz consists of six fix infrared cameras to analyze the 3D orientation of body segment of pelvis, thighs, legs, and feet. There are sixteen reflective markers (14 mm) were placed based on the plug-in-gait model anatomical landmarks (9). Anatomical landmarks for plug-in-gait model included both anterior iliac spine (ASIS), posterior iliac spine, midthigh, lateral epicondyle of the femur, lateral side of midshank, lateral malleolus, heel, and distal head of second metatarsals.

Procedures

Procedures of data collection was divided into two phase; before testing and during testing. Before testing was performed at Physiotherapy Department, Hospital

Sultanah Aminah Johor Bahru. During testing involved measuring spatiotemporal gait parameter using the IMU system and Vicon motion capture system at Motion Analysis Lab, School of Biomedical Engineering and Health Sciences, Faculty of Engineering, Universiti Teknologi Malaysia, Johor.

The study is a non-invasive and passive study. Inclusion and exclusion criteria were screened at Electrotherapy room of Physiotherapy Department. Physiotherapy assessments were evaluating before testing to ensure that non-specific LBP group are suitable to undergo the study. It includes history taking, previous physiotherapy treatment, observation, range motion, muscle power, and neurological test. Non-specific LBP patients were required to mark their pain intensity scale using the Visual Analogue Scale (VAS) with "no pain" (0) to "more pain" (10). VAS was used to record pain intensity experienced by the non-specific LBP group based on a scale of 1 to 10 which 1 representing little pain and 10 representing more pain (28). Investigator was giving the appointment date for data recording. The appointment date was set within one week after the assessment. The data recording process took almost two hours for each subject.

All subjects were required to fill up an informed consent and demographic data such as age, gender, history of injuries, and past surgical history prior the data recording process. Physical evaluation were assessed includes height (express in meters) and body weight (express in kg) for body mass index (BMI) calculation. The other anthropometric measurements of each leg were taken by hand using a tape measure and caliper for the Vicon motion capture system (Plug-In Gait) requirement. Before data recording, all subjects have explained the purpose, safety issues, and complete procedures during the safety briefing. Non-specific LBP groups are informed to provide feedback regarding any increase in pain during the data recording process and allowed to discontinue if they are uncomfortable or investigators deem that testing detrimental or risky for the subject to continue.

After placement of the sensors and markers, subjects stand with the shank vertical (longitudinal axis perpendicular to the floor) for Vicon motion capture system calibration and static capture before performing the test. Subjects were allowed to do warm-up for five minutes (29) and walking trial with looking straight ahead for adaptation (24). After familiarization, subjects walked at a self-selected preferred speed along a 6.5-m walkway (30). Walking trial was repeated for twice to guarantee reproducibility of the result (25). At the start, the IMU sensors and Vicon system switched on together. After a 15 – 20 minute break to prevent fatigue, the second set of walking trials with the same protocol were repeated (27). Refer to Fig.1 for flowchart procedures of data collection. The Vicon system measurements

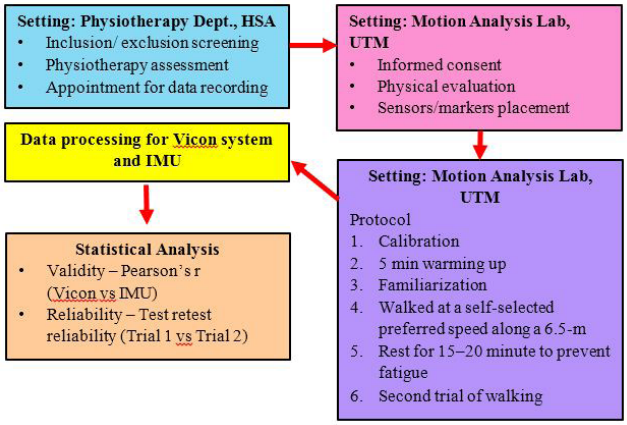

Figure 1: Flowchart procedures of data collection

were repeated to control for variations in spatiotemporal parameters between the first set and second set (31).

Offline data processing

There are six spatiotemporal parameters were analyzed included left and right cadence (steps/minute), stride time (second), step time (second), stride length (meter), step length (meter and velocity (meters/second) recorded by Vicon system and IMU. Reconstruction of trajectory and marker labelling of Vicon system measurement were done using Nexus version 1.8.5 and analyzed using Polygon 4.3.3 software. The Auto Correlate Event was used to detect the pattern of the tracked marker and define the events for the rest of the trial. Each Auto Correlate Event was checked manually. If incorrect, manual entered on the time bar using 3D marker trajectories. Spatiotemporal gait parameters value using the Vicon system were generated automatically from Vicon Polygon 4.3.3.

Meanwhile, the signal processing from four IMU sensors was converted to an algorithm using EMGwork. The procedure of gait event detection and algorithm analysis was applied manually to the sampled raw data. Signal x and z-axis from the accelerometer were analyzed because found to be the most revealing to estimate the spatiotemporal gait parameters for IMU (32,33). The gait event detection procedures were synchronized with video recording to ensure the process is precise. The entire algorithm from each accelerometer signals was divided into stride/gait segmentation (Fig.2). Stride segmentation is the process of determine each gait cycle in the algorithms (34). It is important to reduce the drift error of IMU (35).

Gait cycles occur when two consecutive steps during walking of the individual. A gait cycle calculate when one foot touches the ground and ends with same foot touches the ground again. Stride segmentation was derived from algorithms developed by Lee et al. (2010) (36), as shown in Fig. 3. Stride segmentation was determined using Fig. 3 by identifying the steepest positive slope when the foot hits the ground, known

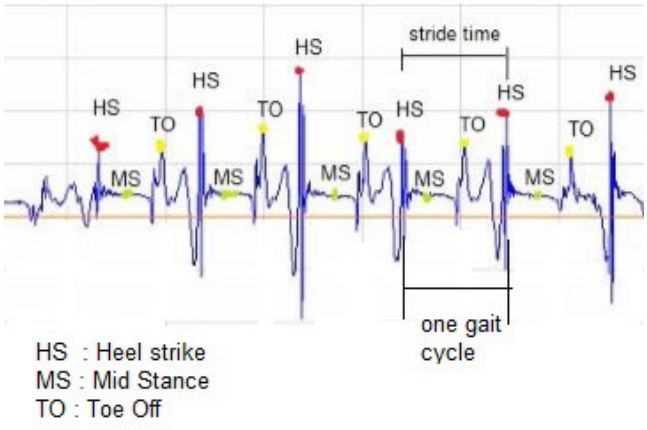

Figure 2: One gait cycle start when one foot touches the ground and ends when that same foot touches the ground again

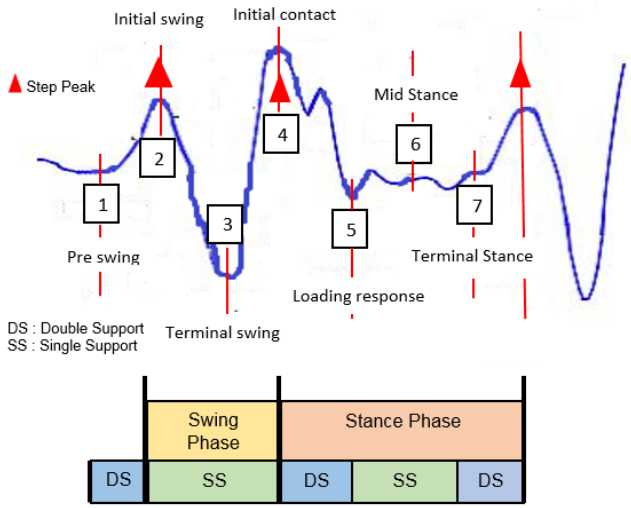

Figure 3: The relationship between ankle acceleration and time during each gait cycle

as a heel strike (HS) (no.4) (37). With this segment, stride time (ST) (s) was identified from the first steepest positive slope to the second steepest positive slope. ST was identified as the time between successive HS for the ipsilateral foot. ST was calculated as second heel strike time minus first heel strike time (Eq.1). One stride time is equal to two step time (SPT) (Eq.2). Terminal swing (no.2) occurs when the ipsilateral foot decelerates abruptly when foot away from the ground. The steepest negative slope (deceleration) is indicated as the terminal swing. At mid stance (no.6), the lowest velocity nearly to 0 m/s^2 occur at foot. Toe off (no.7) when the ankle joint movement changes from plantar flexion to dorsal flexion in sagittal plane (37).

Velocity (V) (m/s^2) defined as walking speed for each stride (35) and calculated as distance of walkway (6.5 meter) divided by time taken for each walking trial (identify using algorithm) (38) (Eq.3). Cadence (C) is a number of steps per minute. Cadence calculated with stride time divided into two to get step time parameter after that 60 second divided by step time (38) (Eq.4). Afterwards, stride length (SL) (m) was formulated using cadence multiply velocity divide by cadence (38) (Eq.5). SL is a distance between successive HS for ipsilateral foot. SL was divided by two to formulate step length (STL) (Eq.6).

Equation:

(i) Stride time (s) calculate as the time between successive HS for ipsilateral foot.
$ST = t(HS^k) - t(HS^{k-1})$ (39) (Eq.1)

(ii) Step time (s) calculate as the stride time divided two
$SPT = ST/2$ (Eq.2)

(iii) Velocity (m/s^2) calculate as walking speed for each stride
$V = distance / time$ (38) (Eq.3)

(iv) Cadence (step/min) calculate as number of steps per minute.
$C = 60s / step\ time$ (38) (Eq.4)

(v) Stride length (m) calculate as the distance between successive HS for ipsilateral foot.
$SL = (120 \times velocity)/ cadence$ (38) (Eq.5)

(vi) Step length (m) calculate as the distance between successive HS for contralateral foot to toe off (TS) for ipsilateral foot. One stride equal to two step.
$STL = SL / 2$ (38) (Eq.6)

Statistical Analysis

Data of the first and second trials of each instrument were analyzed. To examine the validity between Vicon system and the IMU, Pearson correlation coefficient or Pearson's r were used to analyzed the correlation between Vicon system according to two placement of IMU sensor (16). Significance was assumed for a p value smaller than 0.05. The intraclass correlation coefficient (ICC) were used to estimate the consistency of the two measurements. Test-retest reliability was calculated via two-way random effect (model 2.1,absolute agreement, average measure) (27). ICC estimates based on the 95% confident intervals with an agreement was rated poor, moderate, good or excellent agreement (40). All computations were done with IBM SPSS (statistics 25) software.

RESULTS

Subjects

About thirteen out of twenty subjects were statistically analyzed. Data from seven subjects were rejected due to technical issues: three subjects due to technical issues regarding missing marker of 3D perspective Vicon system, two subjects due to synchronized raw data from Vicon Nexus to Vicon Polygon for gait parameter analyzed and two subjects due synchronization IMU sensor to EMGworks software failed. The analyzed subjects (four men, nine women; 50.0 +/-15.0 years; 66.0+/- 21.1 kg; 1.68+/-0.2 m; 27.0+/-7.1 kg/m^2) in this study had a pain scale ranged 3.00 to 6.00. Subjects had a low level of pain, able to walk without increased pain

at low back. Most subjects are right dominant leg.

Validity spatiotemporal gait parameter of IMU sensor compared with the Vicon system

Table I showed the majority spatiotemporal gait parameter detected by the IMU sensors comparing Vicon system at Trial 2 have higher significant correlation with the p value below 0.05 except stride time left shank (r = 0.539, p = 0.06) , left foot (r = 0.495, p = 0.11) and step length left shank (r = 0.532, p = 0.06). There are significant correlation with the p value below 0.05 between IMU sensors and Vicon system at Trial 1 except cadence left shank (r = 0.516, p = 0.07) and right shank (r = 0.446, p = 0.13), stride time left shank (r = 0.408, p = 0.17 and right shank (r = 0.391, p = 0.19). It is shows the cadence and stride time value can incluence the significant correlation at step time, stride length, step length, and velocity. In overall, this study indicated that the IMU is a validated tool in determining spatiotemporal gait parameter in patients with non-specific LBP. Foot placement of IMU sensor is suitable placement for patients with non-specific LBP because it presented more significant correlation with the p value below 0.05 at most of spatiotemporal gait parameters when compared with shank placement of sensors in both trial.

Reliability spatiotemporal gait parameter of IMU sensors based on Trial 1 and Trial 2

The reliability test is important to ensure the spatiotemporal gait parameter value measured by IMU lack of human error and operation devices error (41). Test-retest reliability was calculated based on the 95% confidence intervals of the ICC estimates, the agreement was rated poorly if less than 0.5, moderate between 0.5 to 0.75, good between 0.75 to 0.9, or excellent if greater than 0.90 (40). Table II and Table III presented the reliability of spatiotemporal gait parameters using

Table II: Test retest reliability of spatiotemporal gait parameter using IMU for shank placement sensor

Placement	Parameter	ICC	95% confidence interval	p value
Shank				
Left	Cadence (step/min)	0.947	0.740 - 0.986	0.00
	Stride Time (sec)	0.942	0.723 - 0.984	0.00
	Step Time (sec)	0.938	0.757 - 0.982	0.00
	Stride Length (m)	0.914	0.720 - 0.974	0.00
	Step Length (m)	0.911	0.709 - 0.973	0.00
	Velocity	0.894	0.653 - 0.968	0.00
Right	Cadence (step/min)	0.930	0.747 - 0.979	0.00
	Stride Time (sec)	0.917	0.705 - 0.975	0.00
	Step Time (sec)	0.920	0.700 - 0.976	0.00
	Stride Length (m)	0.866	0.563 - 0.959	0.00
	Step Length (m)	0.861	0.547 - 0.958	0.00
	Velocity	0.934	0.770 - 0.980	0.00

* ICC = intraclass correlation coefficient

Table III: Test retest reliability of spatiotemporal gait parameter using IMU for foot placement sensor

Placement	Parameter	ICC	95% confidence interval	p value
Shank				
Left	Cadence (step/min)	0.885	0.370 - 0.970	0.00
	Stride Time (sec)	0.890	0.365 - 0.972	0.00
	Step Time (sec)	0.878	0.295 - 0.969	0.00
	Stride Length (m)	0.770	0.213 - 0.931	0.01
	Step Length (m)	0.760	0.180 - 0.928	0.01
	Velocity	0.823	0.443 - 0.945	0.00
Right	Cadence (step/min)	0.814	0.400 - 0.943	0.00
	Stride Time (sec)	0.804	0.375 - 0.940	0.00
	Step Time (sec)	0.800	0.365 - 0.938	0.00
	Stride Length (m)	0.929	0.767 - 0.978	0.00
	Step Length (m)	0.933	0.780 - 0.980	0.00
	Velocity	0.977	0.919 - 0.993	0.00

* ICC = intraclass correlation coefficient

Table I: Validity of spatiotemporal gait parameter using IMU sensors compared with Vicon system

	Trial 1				Trial 2			
	Shank		Foot		Shank		Foot	
	Left	Right	Left	Right	Left	Right	Left	Right
Cadence (step/min)	0.516	0.446	**0.656**	**0.631**	**0.612**	**0.825**	**0.547**	**0.837**
	(p = 0.07)	(p = 0.13)	**(p = 0.01)**	**(p = 0.02)**	**(p = 0.03)**	**(p = 0.00)**	**(p = 0.05)**	**(p = 0.00)**
Stride Time (sec)	0.408	0.391	**0.549**	**0.594**	0.539	**0.809**	0.495	**0.807**
	(p = 0.17)	(p = 0.19)	**(p = 0.05)**	**(p = 0.03)**	(p = 0.06)	**(p = 0.00)**	(p = 0.11)	**(p = 0.00)**
Step Time (sec)	0.282	0.544	0.400	**0.564**	**0.561**	**0.701**	**0.547**	**0.655**
	(p = 0.35)	(p = 0.06)	(p = 0.18)	**(p = 0.04)**	**(p = 0.05)**	**(p = 0.01)**	**(p = 0.05)**	**(p = 0.02)**
Stride Length (m)	0.540	**0.694**	**0.561**	**0.604**	**0.554**	**0.708**	**0.675**	**0.797**
	(p = 0.06)	**(p = 0.01)**	**(p = 0.05)**	**(p = 0.03)**	**(p = 0.05)**	**(p = 0.01)**	**(p = 0.01)**	**(p = 0.00)**
Step Length (m)	**0.554**	0.496	**0.605**	0.495	0.532	**0.693**	**0.626**	**0.796**
	(p = 0.05)	(p = 0.08)	**(p = 0.03)**	(p = 0.11)	(p = 0.06)	**(p = 0.01)**	**(p = 0.02)**	**(p = 0.00)**
Velocity	0.460	**0.687**	0.489	**0.680**	**0.700**	**0.914**	**0.732**	**0.901**
	(p = 0.11)	**(p = 0.01)**	(p = 0.09)	**(p = 0.01)**	**(p = 0.01)**	**(p = 0.00)**	**(p = 0.04)**	**(p = 0.00)**

* bold number indicate correlation is significant at the p ≤ 0.05 (2-tailed)

IMU sensors comparing the Trial 1 and Trial 2. Overall results were showed IMU sensors are reliable in term of measuring spatiotemporal gait parameters for Non-specific LBP patients with p value < 0.05.

Table II showed there are moderate agreement of most spatiotemporal gait parameter using IMU sensors located at both shank with ICCs ≥ 0.85, 95% CI 0.5 to 0.75. Good agreement presented at left step time, right cadence and right velocity with ICCs ≥ 0.90 with 95% CI 0.757 to 0.982, 95% CI 0.747 to 0.979 and 95% CI 0.770 to 0.980, respectively. Table III showed poor agreement between Trial 1 and Trial 2 at majority spatiotemporal gait parameter value for foot placement sensor with ICCs ≤ 0.90 with 95% CI less than 0.50. Excellent agreement was indicated at right velocity with ICCs 0.977 with 95% CI 0.919-0.993 while good agreement at right stride length (ICCs 0.929, 95% CI 0.767 to 0.978) and right step length (ICCs 0.933, 95% CI 0.780 to 0.980).

DISCUSSION

The validity and reliability study of inertial measurement units (IMU) is becoming an important issue due to the increasing demand for these technologies (42). There are 624 algorithms from IMU sensors were analyzed in this study. The result of this study demonstrated IMU sensors are valid and reliable tool in measuring spatiotemporal gait parameter for patient with Non-specific LBP. Indirectly, this result also proposed that the stride segmentation identified by Lee et al. (2010) (36) and equation formula used to calculate spatiotemporal gait parameter for IMU sensors are appropriate.

This study indicated that the IMU is a validated tool in determining cadence and velocity in patients with Non-specific LBP. It was supported by Laudanski et al. 2012 (43) was proved the IMU sensor had a great benefit in accurately assessing velocity and cadence in healthy adults. Dobkin et al. (2011) (44) found that bilateral ankle accelerometers were higher validated compared with stopwatch-timed for velocity after hemiparetic stroke in indoor and outdoor walking speeds. IMU also has a significant correlation in certain spatiotemporal gait parameter such as stride time, step time, stride and step length. This result was similar to previous literature (17), step length parameter measured by tri-axial accelerometer-based movement sensor showed good to moderate correlation with GaitRite instrumented walkway in two different groups of healthy adults aged, younger (20 to 40 years old) and older (50 to 70 years old). Previous studies showed IMU has excellent validity in measuring stride length in healthy adults (16) and patients with total hip or knee arthroplasty (45).

Overall test-retest reliability results showed that IMU sensors have higher consistency in measuring spatiotemporal gait parameters for Non-specific LBP patients. This study findings agree with the literature (16,27,46) that have examined the reliability of spatiotemporal gait parameters using IMU for gait analysis. Lefeber and colleagues (2019) (27) found IMU showed good to excellent test-retest reliability for gait cycle duration, cadence, and stride velocity for patients in the subacute stage of stroke. This result also corresponds with (47,48) who evaluated the accuracy, sensitivity and robustness in measuring gait parameter using single IMU's mounted on the lower lumbar for healthy adults. The results of the study showed an acceptable accuracy of single IMU's in measuring speed, cadence, stride length, and stride duration.

When comparing parameters at two different placements, our findings showed that the IMU demonstrated higher validity with p ≤ 0.05 at most spatiotemporal gait parameter of foot placement compared to shank placement. However, both placement verified reliable with p value < 0.05. Washabaugh et al. (2017) (16) and Caldas et al. (2017) (20) have showed foot placement of the IMU sensor performed to better measure gait parameter and good repeatability with minimally detectable change although on a different day and different types of walking surface. Gait event detection was improved as the sensor placed closer to the ground (49). From the study, we can suggest that placement of IMU sensors at the foot are suitable for non-specific LBP. This setting will allow patient to feel more comfortable while performing the walking test because only two sensors will place at both feet comparing to four sensors before this.

However, some of procedures must be considered or changed to ensure the measurement is more precise and valuable. Previous studies have reported that 10-meter walk test using IMU method demonstrated excellent agreement with stopwatch method in clinical used (50). Walkway testing must consider above to 10 meter to allow complete acceleration and deceleration (22). Complete acceleration and deceleration algorithm were for more accurate stride value, such as cadence, stride length, step length, and velocity parameter. Warm-up walking and two or more walking trials are needed to guarantee result reproducibility (25). It has proven by this study when most of spatiotemporal gait parameters have significant correlation in the Trial 2.

CONCLUSION

IMU sensors are one of the valid and reliable gait analysis instrument for measuring cadence, velocity, stride/step time and stride/step length for patient with Non-specific Low Back Pain. IMU provides a possible solution to measure spatiotemporal gait in a clinical setting without requiring specific working area and professional technician. This study represents the first step in developing a new understanding of prognosis and rehabilitation management for LBP patients in Malaysia.

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