Practical Use and the Validity of Inclinometer in Measuring Student's Real-Time Body Balance Control through One Leg Standing Test

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***Abstract*—This study aims to determine the level of validity of using real-time inclinometer sensors to measure the balance abilities of young children. A total of 10 lower elementary school students were the samples for this research (5 males and 5 females ± 7–9 years old). The samples were given the opportunity to carry out four variations of the One Leg Standing Test (OLST), namely Opened Eyes-Step, Closed Eyes-Step, Opened Eyes-Tip, and Closed Eyes-Tip, using an inclinometer sensor in the middle of the chest to then the data conveyed by the sensor is recorded in the software on the tester laptop. From the 10 participants' data, 1000 records were obtained which were then processed statistically to obtain valid results from the use of these sensors in this test. The results show a high level of validity demonstrated by this sensor for almost all variations of the test, and the inclinometer sensor is suitable for use as an instrument to measure body balance accurately.**

***Keywords*—sensor inclinometer, balance, instrument test measurement, physical *education*, sports technology**

I. Literature Review

Balance in the human body is a complex and intricate physiological process that involves the coordination of various sensory systems and motor skills. It is important to carry out daily activities, maintain body posture, and prevent falls or accidents. The success of the movement carried out by a person is strongly influenced by several aspects including balance [1]. Balance means A skill-related component of physical fitness that relates to the maintenance of equilibrium while either stationary or in motion [2]. The acceleration of the center of mass of an object is zero when the object is at rest or in steady motion. Therefore, the resultant force acting on the body must be zero: $\sum F = 0$. This equation is called the force balance condition. The balance of external forces acting on a body in certain cases may be sufficient to guarantee static balance. The center of mass is defined as the fulcrum (axis, fulcrum) around which an object will be in equilibrium under the influence of gravity [3]. If you look at the definition of balance itself, it is the act of keeping your center of gravity over your base of support, and the closer the center of gravity is to your base of support, the more stability. Posture attempts to balance the forces in the body so their sum equals zero [4]. If we refer to this definition, time is not an important variable in determining whether a person has good balance, but rather how a person tries to keep his body weight centered on the center of gravity of his body, and as much as possible not to change his position accordingly to the three-dimensional corners of his body.

A proper functional core routine consists of dynamic movements, challenging the center of gravity, and isometric exercises. To fully train the core, you must also include dynamic stabilization, isometric and proprioceptive movements not only for the core but the entire torso. Medicine balls, balance boards, foam rollers, and physio balls are great tools for core training and should be integrated into every program. The fact is that exercises with a physio ball (a challenging environment) are superior to traditional floor exercises. As we age, balance and stability become impaired. If balance and stability are not addressed, both will continue to be degraded [4]. Core stability, flexibility, and balance are key factors when designing a functional exercise routine. It becomes clear that to maintain balance, a person needs optimal work, proprioceptive, vestibular, and visual mechanisms of interaction with external the world, integrated by the nervous system [5]. A weak core contributes to poor stability, and hinders proper limb movement, causing muscle imbalances in the kinetic chain [4].

Several methods that can be used to assess an athlete's balance are Single Leg Stand [6], Balance Error Scoring System (BESS), Star Excursion Balance Test (SEBT) [7], Balance Test on The Force Plate [8, 9], and Flamingo Balance Test [10]. The Star Excursion Balance Test is one example of a relatively inexpensive and simple way to assess balance in athletes. All that is needed is athletic tape as the floor must be marked with a star pattern consisting of eight directions spaced forty-five degrees apart. The athlete should be instructed to place one foot in the center of the star. Then he should be instructed to reach as far as possible sequentially (clockwise or counterclockwise) in eight directions. The athlete must tap the floor while maintaining his balance, and the distance from the center of the star to the top spot is measured [11], Y-Balance Test [12]. The use of sensors in measuring body balance is still limited to several previous studies such as comparing body sway and trunk kinematic data calculated based on our sensors with data from force platforms [13], gait-force model to extract bio-mechanics information in both the dynamic state as in the gait analyzer and the steady state as in the balance scale [14], the determination of postural sway quantified by tracking the trajectory of the Center Of Pressure (COP) [15], CQ-Stab 2P two-platform posturographic [16], Center Of Pressure (CoP)-related parameters and surface electromyography [17], Three-Dimensional (3D) motion-capture system [18] as well as a single lumbar Inertial Measurement Unit (IMU) to discriminate between the three Y-Balance Test reach directions [19], even using an iPhone [20].

One Leg Standing Test (OLST) is a field test that is commonly used to assess body balance. The test is carried out by standing on one leg, the athlete is told that he must stand on one leg as long as possible, keeping the standing leg straight, the other leg bent, and the arm at his side. The individual performing the test should be trained to stop the test when the athlete's arm moves away from his or her side, the supporting leg moves across the floor, or the raised leg touches the floor. The result measured is the length of time the athlete remains balanced on each leg [11]. OLST itself can be done with eyes open [21], and eyes closed [19] depending on the purpose of the activity and the balance situation in the actual world. OLST, when combined with the use of an inclinometer sensor, is predicted to be a very effective tool in measuring the body's static balance ability in real time and with good measurements. In the field of precision measurements and instruments, the inclinometer comes from the Latin words "inclinare" (slant or slant) and "metron" (to measure), the inclinometer functions as a vital tool for determining the angle of tilt, tilt, or slope of an object in relation to the force of gravity. Its diverse applications have not only revolutionized fields such as engineering, construction, and geology but have also found significance in fields such as astronomy, archeology, and sports.

The concept of measuring angles originates from ancient civilizations, where early inclinometers were basic devices consisting of simple weighted strings or plumb bobs. However, significant advances only occurred in the 18th century, with the discovery of sophisticated inclinometer designs. One such milestone was the development of the spirit level by Melchisédech Thévenot, a French scientist, in 1661. This innovation laid the foundation for more complex inclinometer designs and paved the way for modern iterations. Inclinometers operate on the principles of gravity and motion, utilizing various mechanisms to accurately measure angles. One common type is the spirit inclinometer, which uses a tube filled with liquid with air bubbles to indicate the inclination of an object. Another type, accelerometer-based inclinometers, uses accelerometers to measure speed changes and calculate angles. In contrast, gyroscopic inclinometers rely on gyroscopic effects to maintain a stable reference plane, enabling precise angle measurements even in dynamic environments.

II. Materials and Methods

This research aims to reveal the validity of the inclinometer sensor instrument for use as a human balance-measuring device in general purpose. A total of 10 people consisting of 5 male samples and 5 female samples ± 6.5 years old were instructed to carry out the One Leg Standing Test with four variations, namely, standing with one leg fully planted and on tiptoe, as well as conditions with both eyes open and both eyes closed. With this situation, it is expected that there will be differences in conditions, circumstances, and challenges for the participants as well as significant variations in data to be able to test the validity of the sensor in the four varying conditions of the test. The sensor itself consists of two parts, namely the sensor hardware part in the form of a device measuring 42.8 mm long, 36.1 mm wide, and 15 mm thick, which is attached to the test participant's body by attaching it to the bottom of the test participant's sternum using a flexible and adjustable rubber strap. with the test taker's body size so that it fits well and reduces the potential for it to shift out of place during the test. Each testee carries out the test for ± 15 seconds for each variation. Data recording is seen in Fig. 1.

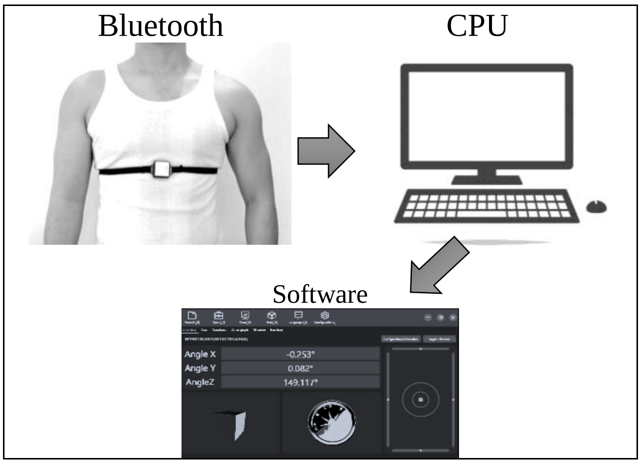

Fig. 1. Diagram of data recording.

During the test, the sensor hardware installed on the testee's body provides real-time data on the testee's movements from three-dimensional angles of the body axis during the test, which are recorded every 0.1 seconds via Bluetooth access to be recorded on the software installed on the computer and become test results that have been done. The sensor consists of two main parts that have different functions, namely the hardware and software parts. The hardware part consists of electronic components that are installed on the sample's body when carrying out the test, and the software part is installed on a PC or laptop which functions to see in real-time how the sensor moves according to the sample's body movements and records this into raw data in a TXT file, and then processed using Microsoft Excel tools to make it easier to process statistically. The statistical data processing itself uses JAMOVI 2.4.5 software which examines descriptive and inferential statistical data to determine the level of validity of the sensor instrument for use as a balance sensor in general sports measurement activities. Interface software data inclinometer recorder is shown in Fig. 2.

Fig. 2. Interface software data inclinometer recorder.

III. Result

The number of records obtained for each test participant consists of 500 records (N-records) for each gender, male, and female. The data obtained through the sensor consists of data records from 3 angles. All data obtained results of $p < 0.001$ based on the Shapiro-Wilk data normality test.

Table 1. Descriptive of OLST step

	Gender	X OE Step	Y OE Step	Z OE Step	X CE Step	Y CE Step	Z CE Step
N-records	Male	500	500	500	500	500	500
	Female	500	500	500	500	500	500
Mean	Male	9.1	3.45	−3.64	91.8	1.33	−9.56
	Female	91.7	7.96	42.6	91.5	4.42	17.4
SD	Male	4.53	2.05	43.8	6.48	5.4	4.6
	Female	4.82	3.81	57.1	8.37	5.48	55
Shapiro-Wilk *p*	Male	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Female	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

The results of the OLST test data on the tiptoe leg variations are attached in the table below which explains the data obtained from the test results using the tiptoe position using the inclinometer sensor. The number of notes obtained for each test participant consists of 500 notes (N-records) for each gender, male and female. The data obtained through the sensor consists of data records from 3 angles X, Y, and Z, where every time a movement is made by the testee, the data from these three axes tends to change according to the body movement. This data is data on the degree of movement carried out by the samples, where the average position of the 3 corners of Female and Male is Table 2, and the SD comparison is shown in Fig. 3. All data obtained results of p <0.001 based on the Shapiro-Wilk data normality test.

Table 2. Descriptive of OLST tip

	Gender	X OE Tip	Y OE Tip	Z OE Tip	X CE Tip	Y CE Tip	Z CE Tip
N	Male	500	500	500	500	500	500
	Female	500	500	500	500	500	500
Mean	Male	100	3.2	−0.252	102	1.23	−9.06
	Female	96.1	3.64	34.2	101	4.17	3.4
SD	Male	3.5	1.7	43.1	42.5	9.78	46.7
	Female	7.31	8.31	6.1	6.48	8.57	59.7
Shapiro-Wilk *p*	Male	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Female	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

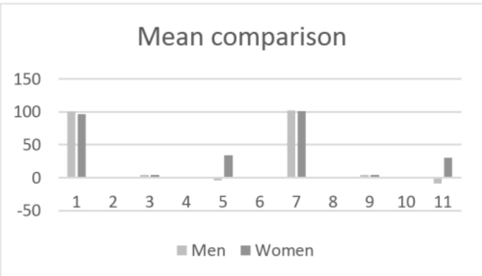

Fig. 3. Comparison of the average balance positions from 3 angles X, Y, and Z when standing on tiptoes.

Table 3 is a table of correlation test results between variables using the Pearson correlation test which shows a very significant relationship ($p < 0.001$) for the test variation variables tested for almost all angles of movement measurement in the test in the OLST position with the foot planted. Different and insignificant results can be seen in the correlation data between X CE Step–and Z OE Step and This will be a concern in future research regarding this instrument.

Table 3. Correlation Matrix XYZ axis tread position

AXIS	Sig	X OE Step	Y OE Step	Z OE Step	X CE Step	Y CE Step	Z CE Step
X OE Step	Kendall's Tau B	—					
	p-value	—					
Y OE Step	Kendall's Tau B	0.045	—				
	p-value	0.033	—				
Z OE Step	Kendall's Tau B	−0.101***	0.594***	—			
	p-value	< 0.001	< 0.001	—			
X CE Step	Kendall's Tau B	0.205***	0.002	−0.042	—		
	p-value	< 0.001	0.918	0.047	—		
Y CE Step	Kendall's Tau B	−0.013	0.308***	0.349***	0.011	—	
	p-value	0.523	< 0.001	< 0.001	0.592	—	
Z CE Step	Kendall's Tau B	−0.094***	0.397***	0.52***	−0.251***	0.244***	—
	p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	—

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 4 is a table of correlation test results between variables using the Pearson correlation test which shows a very significant relationship ($p < 0.001$) for the test variation variables tested for almost all angles of movement measurement in the test in the OLST position with the feet on tiptoes. Different and insignificant test results were seen only in the X CE Tip–Z OE Tip correlation.

Table 4. Correlation Matrix XYZ Axis tread position

		X OE Tip	Y OE Tip	Z OE Tip	X CE Tip	Y CE Tip	Z CE Tip
X OE Tip	Kendall's Tau B	—					
	p-value	—					
Y OE Tip	Kendall's Tau B	0.166***	—				
	p-value	< 0.001	—				
Z OE Tip	Kendall's Tau B	−0.184***	−0.307***	—			
	p-value	< 0.001	< 0.001	—			
X CE Tip	Kendall's Tau B	0.086***	−0.013	−0.008	—		
	p-value	< 0.001	0.546	0.702	—		
Y CE Tip	Kendall's Tau B	0.052*	0.244***	−0.17***	−0.068***	—	
	p-value	0.014	< 0.001	< 0.001	0.001	—	
Z CE Tip	Kendall's Tau B	−0.158***	−0.274***	0.496***	0.041	−0.24***	—
	p-value	< 0.001	< 0.001	< 0.001	0.054	< 0.001	—

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

IV. Discussion

Inclinometers have been used in many studies related to abilities and studies of the human body and joint movement, such as in research on lower locomotor joint movement [22] which is limited to the sagittal axis, the use of an inclinometer to measure ankle joint mobility [23], Range of Motion (ROM) assessment [24], body posture [25], standing and sitting time activities [26], to measure the angle between the tibial shaft and the vertical [27], quadriceps muscle flexibility using maximal knee flexion angle [28], Knee joint angle [29], Upper arm elevation, upper back, head and neck forward flexion postures [30], shoulder flexion and scaption range of motion [31], spending time in standing position [32], and to measure Joint Position Sense (JPS), and the strength ratio of External and Internal Rotators (ER/IR) in handball athletes [33]. Of all the uses of inclinometers, none has specifically recorded a person's balance ability over a certain period, to observe the body's balance condition. This research aims to reveal the usefulness and validity of a time-based inclinometer for measuring body balance in real-time, combined with OLST which has been widely used in various scientific studies. OLST itself has become an instrument that is often used to determine a person's balance ability both while still and in motion [34]. The use of sensors in measuring the body of athletes is an urgent need in accordance with current developments and technology [35]. This is very rational because the components and sensors measuring various variables of the human body's abilities are now sophisticated and starting to be affordable. However, the use of inclinometer sensors to measure balance in real-time is not widely used at present. In various articles published in the last 10 years, personal balance tests are still carried out manually with a specific time or average time as a measure, such as in the One Leg Standing Test (OLST) which aims to indicate both static and dynamic balance. A test to measure the ability to stand on one leg using an innovative tool has also been carried out by [36] by focusing on upper body mass and segment control in maintaining body balance, [37] who performed stability tests using one leg on the Lafayette Stability platform. The use of easy-to-use sensors will be very beneficial for everyday life, wearable balance-improving devices have their potential of serving as balance aids in daily life, which can be used indoors and outdoors [38].

V. Conclusion

By looking at the results of the descriptive statistical explanation and inferential statistical tests above, it can be concluded that this inclinometer sensor is valid and can be used as an instrument to measure body balance. Apart from that, this sensor also provides data that is much more accurate than tests previously carried out using the traditional method, namely using time as the main measurement. Through measurements from three different dimensional angles in real time, we can find out some of the benefits of this tool to record the tendency of the sample's body position regarding the position of trying to maintain their body balance, but to the ability of the body parts to maintain balance and not just record how long it takes for them can keep one of his feet from touching the floor for a certain period. As technology advances, inclinometers will inevitably develop further, revealing new possibilities and applications that will continue to redefine the boundaries of measurement and precision in measuring human balance ability. In a world driven by innovation and accuracy, inclinometers remain an indispensable tool, guiding us down a path of precision with accurate data to guide us in performing better motion analysis over time, and more economically and efficiently.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Firdaus Hendry Prabowo Yudho conducted the research; Fahmy Fachrezzy and Firmansyah Dlis analyzed the data; Firdaus Hendry Prabowo Yudho wrote the paper; all authors had approved the final version.

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