Developing and Validating a New Wireless Wearable Device for Balance Measurement in Sport and Clinical Setting

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ABSTRACT

One of the new clinical techniques to assess the lower body parameters is the wearable ultrasonic sensors. The device which can measure the static and dynamic balance abilities in sport and clinical setting by the traveled signals of ultrasonic transmitter and receiver between two feet was developed and validated. The new device consisted of a pressure gauge and a digital centimeter indicator and examined the tests in two balanced states of Stork and Y dynamic. First, 210 participants were selected based on convenience sampling. Then, using the new ultrasonic balance device, all samples took each test conducted by the Stork and Y dynamic tests for 3 times. The results showed high reliability between the data of static and dynamic balances obtained from the ultrasonic device and through the methods of Stork and Y (the SEBT modified version) (r=0.90; r=0.92). The inter-rater reliabilities of the three-time conduction of the stork and Y dynamic tests were found to be very high (ICC=0.92; ICC=0.91). The ultrasonic balance device was both valid and reliable in measuring the Stork and Y dynamic balance tests. The new device could solve that defects associated with traditional stork and Y dynamic tests.

Key Words: Static Balance, Dynamic Balance, Reliability.

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INTRODUCTION

Balance is a key component in daily activity and sport performance (1, 2). It also plays a decisive role in an athlete's sport performance. A matter of fact, maintaining the proper posture (balance) allows an athlete to fully focus on the required movement task (3). This position requires a complex conflict between the musculoskeletal and nervous systems together with an interaction between static (ability to maintain the center of gravity at the surface) and dynamic balance aspects (active motion of the center of pressure during standing, walking or any other activities) (4). Posture control is a complex coordination between sensory and biomechanical information and muscular activities against external forces, and the loss of any of these factors can increase postural sway and reduce the ability to maintain control over a part or the whole body during movement (5). Then, muscle weakness, loss of proprioception, and reduction of the range of motion are among the factors which affect human postural stability (6).

The primary purposes of clinical balance assessments are to identify whether or not a balance problem exists and also to determine the underlying cause of this problem. The determination of the existence of a balance problem is of great help in predicting the risk of falls and to determine the effectiveness of intervention. Quantitative and norm-referenced tools used to assess postural control in the clinic should include measures which are reflective of both the functional capabilities and quality of postural strategies, sensitive and selective for postural control abnormalities, reliable and valid, easy to use and inexpensive (7). However, the results obtained are subjective, show ceiling effects and scoring errors, and are usually not responsive enough to measure progress or deterioration in a subject's ability to balance (8).

The most prevalent approach is to use balance task functional-based tests. The advantage of these tests is their ability to be used in different situations with low cost, low complexity, an in short time (9). The Stork balance test (10) has been used to measure static balance and may be a useful test for clinical evaluation of a subject's ability to stabilize intrapelvic motion (11). In the Stork test, subjects are asked to stand on a flat surface on one foot and place the other foot on the inner side of the relying foot's knee while their hands are located next to their bodies. Then, the time required for an individual to maintain his/her position for the maximum possible duration is recorded by a stopwatch in seconds (10 to 50 sec.). If the relying foot of the subject spins or moves or the other leg is removed from the knee of the relying foot or his/her hands are open and generally in case of any movement by the subject, the stopwatch will be stopped by the experimenter (12).

In literature, two related tests have been used to assess the performance during dynamic single-leg balance tasks, they are: the Star Excursion Balance Test (SEBT) and the Y Balance Test (YBT). The SEBT was originally described as a series of single-leg squats on the stance limb with the contra lateral limb reaching a line in one of eight directions. In an effort to reduce redundancy and improve efficiency, the SEBT was modified from the eight original directions to the three anterior, posteromedial, and posterolateral reach directions (13, 14). In two investigations, a comparison of the differences between SEBT and YBT (15, 16) tests were found for each distance achieved and kinematics. This led the authors to conclude that the two tests may involve different motor strategies as a result of the differences in instrumentation, scoring mode and protocol specifics. The Y balance test comprises a network with 3 lines in different directions and an angle of 120 degrees

determined by using glue strips, tape measure, and a conveyer on the ground. The test is carried out in a way that a person stands on one foot in the core of the network and moves the other foot in 3 directions for three times. After each attempt and change of direction, the subject returns to its initial standing position on one foot. Errors in this test occur when too much pressure is exerted with the finger on the ground, when falling, and moving the relying foot (17).

Having had a good reliability and validity (18), the researchers believe that in evaluating the ability to balance on one and two legs with common means of observation and description, such as the stork and Y balance tests, there is a possibility of errors by the observer due to errors that cannot be seen visually; therefore, the results may be associated with biases (10). The main sources of these errors can be the test duration, poor grading, the use of manual timer to record events, handy ruler, and subject's surface area (18, 19). The disadvantage of these methods is that they give subjective measurements, particularly concerning accuracy and precision, which have a negative effect on the diagnosis, follow-up and treatment of the pathologies. On the other hand, the traditional scales used to measure the postural balance in clinical conditions are semi-subjective, carried out by specialists who observe the quality and ability of a person's standing on one leg. Training balance and evaluating of postural control requires appropriate tracking and feedback of performance. Then, in clinical situations, researchers and experimenters are required to have an instrument to measure the balance with the highest objectivity, in the shortest possible time, and at the lowest cost. To solve this problem, the progress in new technologies has given rise to devices and techniques which allow an objective evaluation of balance parameters, resulting in more efficient measurement and providing specialists with reliable

information on participant's ability of balance (20).

Recently, wearable sensors were developed for the measurement of balance control in clinical tests of balance and mobility (21). These sensors, with wireless data transfer, have the potential to overcome the major drawbacks of cost, size and limited location of computerized testing, as well as enabling the objective measurement of postural sway and movements during task performance. Wearable sensor technology can accurately measure the postural control (22, 23) and may provide a new avenue for motion feedback during balance tests (24). Also, the incorporation of wearable sensors into balance training has been repeatedly suggested in review articles (25, 26). One of the new clinical techniques to measure balance, gait and pathology parameters is the use of ultrasonic sender and receivers. Ultrasonic sensors have been used to measure short step and stride length and the distance between feet (27, 28). With the knowledge of the speed at which sound travels through air, ultrasonic sensors measure the time needed to send and receive the wave produced, as it is reflected on an object. With the knowledge of the time it takes the signal to travel and come back, and the speed, it is possible to obtain the distance between the two points (20). Since the ultrasonic sensors have been used for the measurement of lower limb rehabilitation (29-31), considering the importance of accuracy and speed in measurement of the balance abilities, the current research tries to present a newly-designed smart balance measurement device to which whether these sensors are beneficial and practical to develop and measure the static and dynamic postural balance. Then, the questions Does ultrasonic sensors precisely provide the data on static and dynamic balance positions like other technologies, including pressure and force sensors, inertial sensors, goniometers (20) etc.? Can the new tool, a composite of

functional and wearable tests, fix the defects of mentioned functional balance tests and minimizes the probability of human errors in measurement situations? Will be answered, Also, the reliability and validity of the device will be determined.

MATERIALS AND METHODS

Participants. For this study, 210 participants (105 male and 105 female) were selected based on convenience sampling method. After filling out the consent form, participants commenced the experiments. They were all right-handed and right-footed, with no history of professional sports or damage to the lower parts of their bodies.

Features of the New Device. The Static-Dynamic Ultrasonic Balance (SDUB) device has pressure gauges under the foot and sides of the waist to force a fixed amount of pressure. Therefore, if the pressure is too much or too little, it will be considered as an error. To measure body deviation angle relative to the x and y axis, the two-axis angle sensors (zct260j model) with a range of -60 to +60 degrees were installed on a transmitter board. To measure the distance between strides, theSfr05 ultrasonic distance meter with a maximum measureable distance of 4 m and measurement accuracy of 0.1 cm were used. Sending and receiving information between the sender and receiver circuits were performed with 9600 bit/second speed of information transition.

A digital centimeter indicator shows the exact distance (cm) of foot movement in the Y test by two TTL ultrasonic micro switches. Using a handheld device which has been designed in 2 rows of 6 characters, the type of test can be selected. On a LED screen, the duration and type of test and the number of errors is displayed wirelessly.
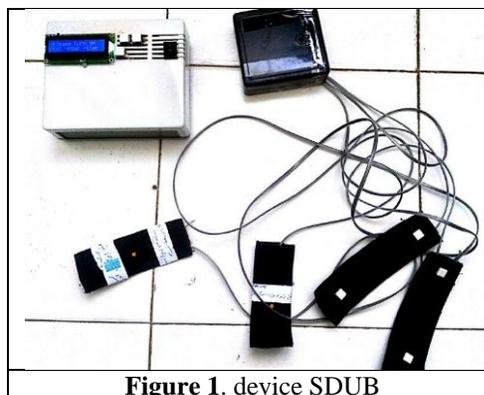
Figure 1. device SDUB

Method of Measurement. Before the tests, the subjects ran and carried out stretching exercises for 10 min to warm up. One of the common locations for placing the sensors is the trunk (32, 33). Hence, the SDUB device was put on their chest during the tests to determine its validity. For each tests of static (Stork test) and dynamic balances (Y test), the subjects performed 6 tries (3 of them was done through the traditional balance measurement method and 3 through the new SDUB device) and the number of errors and the time of first error in the Stork test and the error distance (cm) in the Y test were recorded. In the Stork test, subjects were asked to stand on a flat surface on one foot and place the other foot on the inner side of the relying foot's knee, while their hands were located next to their bodies. Shortly following this, the time required for an individual to maintain position was recorded by a stopwatch in seconds. If the relying foot of the subject span or moved or the other leg was removed from the knee of the relying foot or his/her hands were open and generally in case of any movement by the subject, the stopwatch was stopped by the experimenter. This process was carried out automatically in the new SDUB device. In the dynamic balance test of Y, the subjects were asked to stand at the center of a circle and lift one foot off the ground and move it

to the farthest point possible on the 3 predetermined lines. Then, by using the traditional and SDUB methods, the maximum errorless distance was recorded for each participant. In the traditional administration of the Y test, the experimenter looks at the individual and

visually detects the errors ; however, in the new SDUB device these shortcomings and ambiguities have been removed and just by clicking the start button, the device automatically detects and records all errors (Figures 2 and 3)**.**
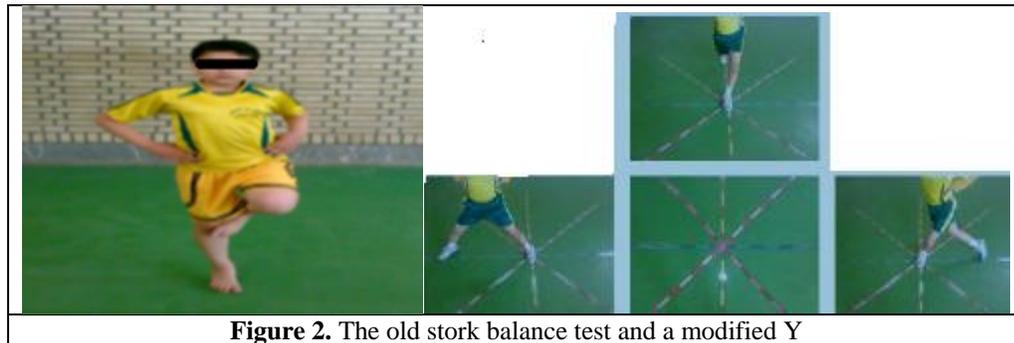
Figure 2. The old stork balance test and a modified Y

Figure 3. the participant when using ultrasonic balance

Statistical Analysis. To examine the normality of the data, the Kolmogorov-Smirnov test and to determine the validity of the SDUB device (to analyze the relationship between the results obtained from the new device and the traditional administration of the Stork and Y tests), the Spearman correlation analysis were used. The validity of the device was also determined by the inter-rater coefficient (ICC) (34). All of these statistical analyses were done using SPSS (version 18) and at the significance level of 0.05 (p<0.05).

RESULTS
The static balance test findings
Table 1 shows the validity of the static balance by two applied methods. As can be seen, there existed a significant relationship between the values of static balance (r=0.92). In addition, according to this table, the standard error of measurement in the SDUB device was smaller (3.20) than that in the traditional Stork test Execution (5.30). Table 2 shows the mean of the 3 Stork balance test tries and the reliability coefficient between them in the SDUB device. As can be seen, there was a high internal consistency between the three trials (ICC=0.92). According to Table3, significant

relationships and high correlation coefficients were found between the recorded data of 3

trials using the SDUB device.

Table 1. Balance stork validity between the two measuring device

	Mean±SD	The coefficient of variation (CV)	SE (Time)	r	P
Traditional balancing test stork	110.11±6.57	10.57	5.3	0.92	0.001**
SDUB	112.58±7.21	12.45	3.2		

**: Significant at p<0.01.

Table 2. Results of the reliability test in SDUB in 3 tries

	The standard error of measurement (Time)	Amplitude	ICC
trial 1	112.52±12.33	25.5	
Trial 2	109.12±9.29	26	0.92
Trial 3	110.25±10.85	25	(0.91-0.93)
Total trials	111.58±11.85	27	

Table 3. Matrix of correlation coefficients (r) between 3 tries to measure the balance of stork with an electronic balance

	Trial 1	Trial 2	Trial 3
Trial 1	-		
Trial 2	0.91	-	
Trial 3	0.87	0.88	-

The dynamic balance test findings

Table 4 shows the validity of the dynamic balance by two applied methods. As can be seen, there existed a significant relationship between the values of dynamic balance (r=0.90).According to this table, the standard error of measurement in the SDUB device was smaller (4.30) than that in the traditional Y test Execution (5.70). Table 5 shows the mean of the 3 Y balance test tries and the reliability coefficient between them in the SDUB device. As can be seen, there exited a high internal consistency between the three trials (ICC=0.91).

According to Table 6, significant relationships and high correlation coefficients were found between the recorded data of 3 trials using the SDUB device.

Table 4. Validity of dynamic balance Y is measured by two methods

The balance Y	Mean ± SD	The coefficient of variation (CV)	SE(Time)	r	P
traditional Y test	181.19±11.69	12.66	5.7	0.9	0.002
SDUB	185.15±10.65	13.34	4.3		

Table 5. Balance ultrasonic device reliability test results in 3 tries using Y

	SE (Time)	Amplitude	ICC
trial 1	189.52±11.87	25	
Trial 2	186.12±10.76	24.5	0.91
Trial 3	184.52±10.56	24	(0.90-0.92)
Total trials	185.85±10.34	26	

Table 6. The matrix of correlation coefficients (r) between 3 tries to measure Y balance with SDUB

	Trial 1	Trial 2	Trial 3
Trial 1	-		
Trial 2	0.90	-	
Trial 3	0.87	0.89	-

DISCUSSION

Given the existence of errors, such as errors hidden from the eyes of the observer, poor grading, and the use of a ruler or a manual timer in the execution of static and dynamic balance tests, the present study aimed to introduce a newly designed ultrasonic system to debug previous balance measurement tools. In the measurement of balance tests of Stork and Y, the Pearson correlation test results showed significant relationships between the recorded data using the SDUB device and the recorded data using the traditional tests. Balance tests, known as the single-leg stance tests, are widely used for the diagnosis and monitoring of patients in research and clinical settings, due to its simplicity, high-reliability and low cost (35). However, the main result of this test is greatly enriched if it is supplemented with the devices for precise recording. Based on these results, it can be said that the SDUB device has the ability to measure errors, time, and distance, with accuracy better than the traditional tools.

The average time and distance of the Stork and Y balances measured by the SDUB were, respectively 5 seconds and 4 cm less than those measured by the traditional tools. These differences can be related to the differences in the measurement process of these two tools. The SDUB device measures the static and dynamic balances and records their patterns through sending signals and signals returning from the different parts of the body, whereas these actions are carried out through the eyes of the experimenter in the traditional methods. Moreover, in a traditional Stork test, the experimenter waits until an error occurs

and then stops the stopwatch; but the SDUB device automatically calculates the time when the first error occurs. These situations can be justified by the standard error of measurement in the two methods (17, 36, 37). The standard error of measurement of the Stork and Y balance tests in the traditional method were 5.3 and 5.7, respectively whereas they were, respectively 3.2 and 4.3 in the SDUB method, indicating less measurement error in the newly designed device in comparison with the traditional methods. Consequently, the differences between the data recorded by the two measurement tools could be due to the different processes applied in data collection. Our results are consistent with that study of Qi *et al.* (2014) on extracting the spatial-temporal gait parameters (38), and Maki et al. (2012) study on measurement of stride length (27). They both applied wireless ultrasonic sensors and showed that the ultrasonic sensors possessed high and good reliability for assessing the lower body parameters in sport and clinical standing position.

Apart from validity, reliability is also of great importance. Reliability is an important property of an instrument to ensure its measurement stability and reproducibility. With increased reliability, the measurement error of the instrument decreases. Applying the new technologies used for the single-leg test, including accelerometers (39), inertial (33) and ultrasonic sensors (27, 29-31, 38) have been accompanied with good intra and inter observer reliability. They are valid and sensitive instruments used for precise measurements during postural balance testing. In the present study, due to the high reliability of the static (Stork) and dynamic

balances (Y) (0.92 and 0.91, respectively), it can be said that when the subjects performed the tests appropriately, the recorded time and distance by the SDUB device demonstrated similar results in different measurements. The high reliability of the SDUB device makes it a secure and authentic device when it is to be used in research studies with a large sample size. It can also be used repeatedly to measure the balance of individuals at different times and with high reliability.

CONCLUSION

Overcoming the biases accompanied with the experimenter during the static and dynamic balance tests has always been one of the objectives of research in the field of health and sports. Like other wearable wireless systems, the high validity and reliability of the SDUB device, in addition to lower standard error of measurement in comparison with the traditional methods, are indicative of its accuracy in the measurement of the Stork and Y balances and is a good reproducibility of its test results which is very important in balance tests. Therefore, with regard to high validity

and reliability of the device, together with its special advantages over other instruments in the measurement and analysis of balance tests of Stork and Y, researchers in the field of sports and clinical setting are recommended to use this device in their investigations and evaluation of balance tests.

APPLICABLE REMARKS

- In examining past research, it was found that observations of the eyes were associated with large errors which influenced the results and their applicability. Therefore, in this study a device was designed which could measure balance with high reliability, and did not require human intervention to perform. This can be a good alternative for measuring with the human eyes.

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طراحی و روایی سنجی دستگاه بی‌سیم برای اندازه‌گیری تعادل موقعیت‌های ورزشی و بالینی

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چکیده

تعادل یکی از اجزای کلیدی و جدایی‌ناپذیر در فعالیت‌های روزانه و عملکردهای ورزشی می‌باشد. تعادل در عملکرد رشته‌های ورزشی نقش مهمی را ایفا می‌کند. هدف از تحقیق حاضر معرفی دستگاه جدید طراحی و ساخته شده برای تعادل ایستا و پویا به همراه تعیین روایی و پایایی آن می‌باشد. دستگاه جدید ساخته شده شامل فشارسنج و سانتیمترشمار الکترونیکی بوده که انجام آزمون‌ها را در دو وضعیت تعادل ایستای لک‌لک و پویای Y محاسبه می‌کند. بدین منظور تعداد ۲۱۰ نفر بصورت نمونه‌های در دسترس انتخاب شدند. تمامی نمونه‌ها ۳ بار هر آزمون را با روش آزمون لک‌لک و SEBT یا اصلاح شده Y و دستگاه تعادل اولتراسونیک انجام دادند. برای تعیین روایی دستگاه تعادل اولتراسونیک از ضریب همبستگی پیرسون و برای بررسی پایایی دستگاه تعادل ایستا و پویای اولتراسونیک از ضریب همسانی درونی (ICC) استفاده گردید. نتایج نشان دادند بین داده‌های تعادل ایستا و پویای حاصل از دستگاه تعادل اولتراسونیک و روش تعادل لک‌لک و Y اصلاح شده (SEBT) روایی بالایی به ترتیب وجود دارد (r=0.90، r=0.92). همچنین پایایی درون آزمونگر بین ۳ بار انجام آزمون تعادل ایستا (لک لک) و پویا (Y اصلاح شده آزمون ستاره) به ترتیب بسیار بالا به دست آمد (ICC=0.91) (ICC=0.92). دستگاه تعادل اولتراسونیک در سنجش میزان تعادل لک‌لک و Y وسیله‌ای معتبر و قابل اطمینانی می‌باشد؛ لذا استفاده از این وسیله برای اندازه‌گیری دقیق و سریع میزان تعادل ایستا و پویا (تعادل لک‌لک و Y) توصیه می‌شود.

واژگان کلیدی: تعادل ایستا، تعادل پویا، پایایی.

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