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Assessment of balance rehabilitation using an IoT force platform

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Abstract
Balance rehabilitation is a form of therapy that focuses on restoring balance and coordination in patients who have experienced a loss or decline in these functions due to a variety of causes, including injuries, illnesses, or age-related changes. In this paper we propose a solution for assessing the degree of balance rehabilitation using an IoT force platform. A force plate has been designed to assess balance by determining the subject's center of pressure (CoP). The force plate use tree strain gauge sensors that are connected to an ESP32 microcontroller who is a popular choice for building IoT projects. The assessment of balance has been achieved in a study involved 40 subjects, both men and women.

Keywords: Balance rehabilitation, Force platform, IoT for health.

1. Introduction

The assessment of balance in rehabilitation involves evaluating an individual's ability to maintain stability and control during various tasks and activities. This evaluation aims to identify any impairments or deficits in balance that may hinder functional performance and increase the risk of falls or injuries. The quality of life is influenced by balance and it has a notable impact on the risk of falling [1]. Performance-based observational rating scales, such as the Berg Balance Scale, are widely employed in neurorehabilitation practice to evaluate balance control. However, the comprehensive score obtained from these scales has a restricted capacity to provide patient-specific information regarding impairments. This is because patients can employ compensatory strategies to attain a higher score on specific items, limiting the scale's ability to accurately reflect individual deficits [2]. Previous research on static balance has commonly utilized force plates [3-11], which have proven effective in evaluating the center-of-pressure (CoP) and, consequently, the performance of balance [12]. An illustration of this is seen in the elderly population who frequently experience diminished lower limb strength, leading to greater CoP displacement. This serves as an indication of compromised balance and the role of muscle weakness in contributing to postural instability and falls [13].

Balance rehabilitation stands as a revolutionary approach to enhancing stability, rooted in cutting-edge understanding of human biomechanics and motor coordination. It's seen as a helpful, gradually progressing, and active technique that can be employed for patients of all ages, with due consideration to each person's capabilities.

A primary obstacle in any physiotherapy rehabilitation program is the lack of tangible, objective feedback to gauge its effectiveness and impact [14]. As such, during the rehabilitation process, the physiotherapist adheres to a pre-determined protocol, modifying it as necessary based on the patient's current condition and medical history. It's crucial to keep track of several key patient parameters throughout the restorative exercises to ensure that the patient's exertion in completing the tasks doesn't heighten the likelihood of another health event [15].

Maintaining balance relies on sensations from the kinesthetic system, visual awareness, and the workings of the vestibular analyzer. The various forms of balance that have been proposed in academic studies can be broadly divided into static and dynamic equilibrium. Static equilibrium is about maintaining a still position, whereas dynamic equilibrium involves keeping balance during movement, such as walking. Numerous techniques are employed to assess issues with balance [13]. These are classified into two primary categories based on their unique characteristics. The extensive range of tests utilized in healthcare can be justified by the intricate processes responsible for maintaining stability

Imbalance can manifest in various scenarios, including different conditions affecting the central and peripheral nervous system [14], disorders related to the musculoskeletal system [15], sensory impairments [16], vision issues, diverse vestibular disorders, or stroke [17,18]. All these factors can disrupt one or more elements responsible for maintaining control over body position, leading to a disturbance in balance.

2. Materials and methods

A force plate has been designed to assess balance by determining the subject's center of pressure (CoP).

The significant advantage of balance test on force platform is that it eliminates the human factor from the measurement chain and, therefore, the source of errors due to assessor subjectivity. In addition, in the diagnosis and treatment process, a real advantage is using modern transducers, which transform the forces occurring on the subject's support surface into electrical signals that can be measured, processed, and compared.

The force plate is made of 2 wooden boards with a size of 400mm x 400mm and a thickness of 22mm. The three force sensors were fixed at the vertices of an equilateral triangle with a side of 300mm. A spacer presses on each sensor attached to the lower plate and supports the upper plate. The design of the platform was done in Fusion 360

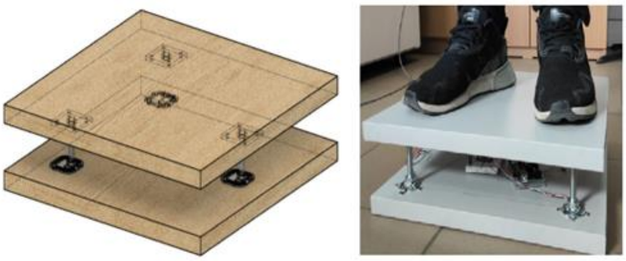


Fig. 1: The experimental force plate.

The force transducers used are of the strain gauge type in a half-bridge structure supporting a maximum mass of 50 kg each. Each sensor is mounted in a Wheatstone bridge and connected to a specialized HX711 weight measurement module. The HX711 amplifier contains a 24-bit precision analog-to-digital converter (ADC) designed for weighing systems and industrial control applications to connect directly to a sensor in the bridge. The input multiplexer selects either the A-channel or the B-channel differential input to the low-noise programmable gain amplifier (PGA). All HX711 amplifiers are connected to an ESP32 microcontroller. The ESP32 offers a powerful dual-core processor, ample memory, and a rich set of peripherals, allowing developers to build complex IoT systems and implement various functionalities. The ESP32's features, such as its low-power consumption, small form factor, and support for various communication protocols, make it a popular choice for building IoT projects. It can be used in a wide range of applications, including home automation, industrial automation, smart agriculture, wearable devices, and many others.

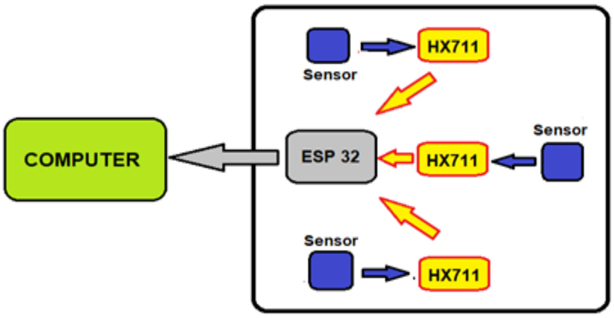


Fig. 2: Structure of the measurement system.

The software application that manages the evaluation using the force plate has been developed in a programming language similar to C ++, which allows the programming of the ESP32 platform. The interface calculates body weight distribution in real-time. To determine the position of the center of pressure (CoP), we establish the origin of the axes in the center of gravity of the equilateral triangle with the three sensors at the vertices and write the following equations:

$$F_z = F_a + F_b + F_c$$
$$M_x = F_z \cdot y_0$$
$$M_y = F_z \cdot x_0$$

where F_z is the z-axis resultant of forces, M_x and M_e are the moments on the x and y-axis, respectively. Depending on the measured values for F_a, F_b and F_c the coordinates x_o and y_o will be calculated determining the position for CoP.

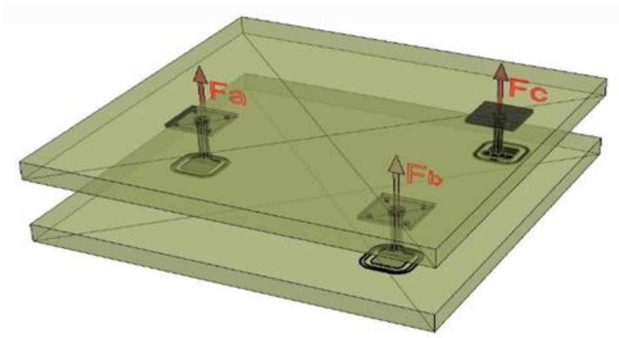


Fig. 3: The force plate.

3. Results & Discussion

The study involved 40 subjects, both men and women. The age range of the study group was 20-41 years, with a mean age of 24.17 years. There was an increased incidence of patients aged 23 years (34%) compared to those aged 26-41 years (4.75%).

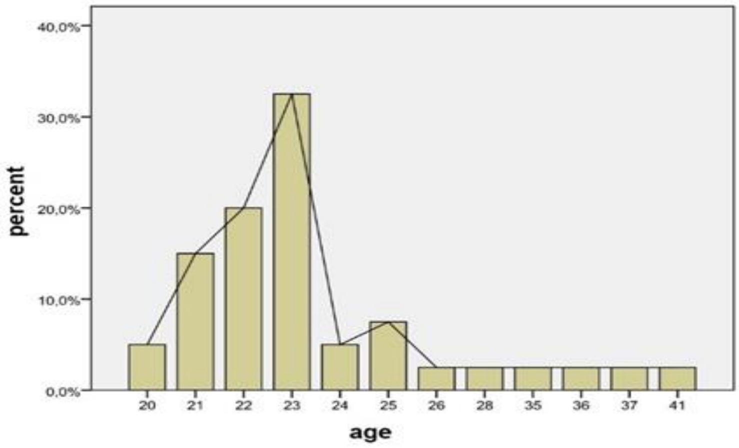
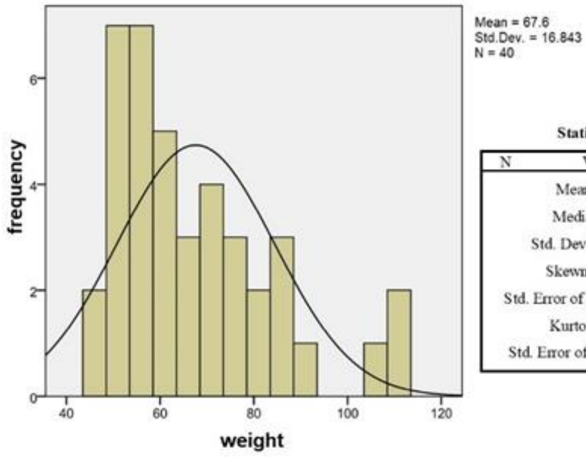


Fig. 4: Age distribution of the studied group.

In the study group, scoliosis predominated in females (57.50%), while for the rest of the spinal and thoracic disorders the proportion of cases according to the sex of the patients did not differ significantly (42.50% male). The risk of developing pathological spinal deviations is significantly higher in females, represented by a risk ratio of 2.02 (OR=2.02; p=0.00086; 95%CI), compared to the risk in males. Analysis of the frequency of spinal deformities in patients of the study group according to their sex was carried out according to the control group. The results of the Chi-square test based on the contingency table revealed that there was no significant association between the sex of the subjects and the occurrence of spinal deformities ($\chi 2=6.58$; p=0.0096; 95%CI). There is a certain prevalence of disorders in the female sex in both the study and control groups. The parameters measured were: weight, height, leg length. According to these, values were obtained for the three pressure points inside the platform (pa, pb, pc), x_{med} (deviation on the Ox axis), y_{med} (deviation on the Oy axis) considered as secondary parameters. A study of the weight of the subjects in the study group leads us to an average value of 67.60 kg. Of these, 8 have weights between 50-55 kg respectively 55-60kg, a low incidence being found in patients weighing more than 100Kg.



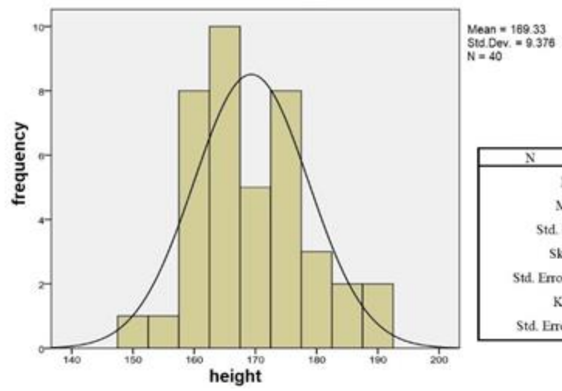
Statistics

N	Valid	40
	Mean	67.60
	Median	63.00
	Std. Deviation	16.843
	Skewness	1.129
	Std. Error of Skewness	0.374
	Kurtosis	0.875
	Std. Error of Kurtosis	0.733

Fig. 5: Weight distribution of the studied group.

The Skewness Coefficient (describing the slope of the frequency distribution curve) obtained is 1.129. This value indicates a leftward slope of the frequency distribution curve. The Kurtosis coefficient 0.875 indicates a leptokurtic, flattened distribution which confirms the inhomogeneity of the distribution of the studied batch. The average height was 169.33cm, a high incidence was observed for the value of 163 cm (12% of patients), a low value was found for patients with height between 150-159cm (2% of patients). The skewness coefficient 0.505 indicates a normal distribution of the frequency distribution. Kurtosis coefficient -0.174 indicates a flattened distribution, slightly flattened compared to the normal distribution of the studied batch. The force plate is provided with three sensors arranged in the form of an equilateral triangle, generically denoted pa, pb, pc. The statistical study of these parameters returns values between 10-50 i.u. The mean values for each sensor were 19.82 for pa, 16.30 for pb and 15.82 for pc.

A significant difference is observed between the posterior sensors (pb, pc) and pa, which is a composite of them. Pearson coefficient analysis of the sensor pairs shows a medium relationship between the pa-pb and pa-pc pairs respectively (r=0.353, p=0.025 respectively 0.347, p=0.28, 95%CI) and a strong one for the pb-pc pair (r=0.783, p=0.0001, 95%CI). This leads us to a comparison of the body weight of the studied group with the way it is distributed among the three sensors.



Statistics

N	Valid	40
Mean		169.33
Median		167.50
Std. Deviation		9.376
Skewness		0.505
Std. Error of Skewness		0.374
Kurtosis		-0.174
Std. Error of Kurtosis		0.733

Fig. 6: Distribution by height of the studied group.

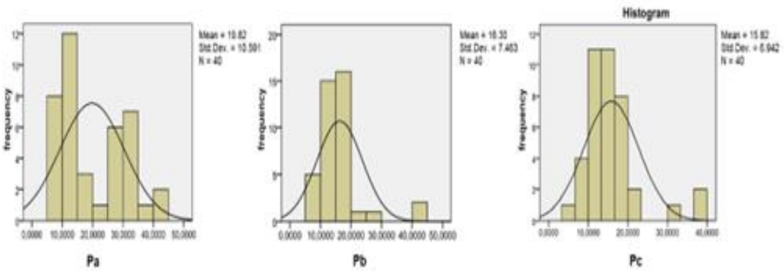


Fig. 7: Distribution of the pa, pb, pc sensor values.

4. Conclusions

Advanced technologies and equipment, such as force plates, motion capture systems, or wearable sensors, may be used to obtain more precise and objective measurements of balance. These assessments can provide detailed information about parameters like center of pressure, sway patterns, weight shifts, and biomechanical factors. IoT integration in rehabilitation offers opportunities for remote monitoring, personalized interventions, and improved patient engagement [22]. Some studies revealed that IoT technology has a beneficial influence on the rehabilitation process. In particular, IoT serves as a valuable tool in overcoming physical obstacles associated with extended treatment and offers advantages in the context of home care. A comprehensive balance assessment helps healthcare professionals tailor interventions and design targeted rehabilitation strategies to improve balance, reduce fall risk, and enhance overall functional abilities.

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