Journal of Current Science and Technology, September-December 2023 Vol. 13 No. 3, pp. 610-619
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Cite this article: Rakpongsiri, K., Srisurak, K., & Rakpongsiri, P. (2023). Predicting elderly falls using the roll factor in the "Smart Walk Trainer" equipment for body weight-balance analysis. *Journal of Current Science and Technology*, *13*(3), 609-618. https://doi.org/10.59796/jcst.V13N3.2023.978

Journal of Current Science and Technology

Journal homepage: https://jcst.rsu.ac.th

Predicting Elderly Falls Using The Roll Factor in The "Smart Walk Trainer" Equipment for Body Weight-Balance Analysis

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Received 10 April, 2023; Revised 25 May, 2023; Accepted 9 June, 2023;
Published online 30 August 2023

Abstract

The imbalanced posture of the body is a potential risk of accidents in all ages that can be caused by a variety of reasons, including muscle weakness, aging-related deterioration in balance, or neurological problems, possibly see more problem for the elderly. Knowing the weight-bearing condition would be helpful to improve balance of the body to prevent the risk. The "Smart Walk Trainer" equipment has been developed for analyzing the imbalance weight-bearing conditions of both standing and walking manner. It consists of "Force Sensitive Resistor" (FSR) sensors to measure the weight-bearing of the foot, the controlling and processing system of the NI USB-6009 multifunction I/O hardware, and LabVIEW software. The study using this equipment aims to examine the differences between young and elderly subjects in terms of weight-bearing and balance assessment. The result showed the roll_factor of the elderly deviated greatly from the balance point (Right: Mean = -0.72, SD = 1.4; Left: Mean=0.78, SD=1.41) when compared to the young subjects (Right: Mean = 0.01, SD = 0.56; Left: Mean=-0.19, SD = 0.49) which corresponded to the risk of falling in the elderly. The equipment also provides specialists with enhanced clarity regarding weight distribution patterns, enabling them to identify any abnormalities and then provide targeted exercise recommendations to strengthen specific muscles and promote improved balance for fall prevention.

Keywords*: *fall; smart walk; sole; standing; walking; weight bearing; balance assessment; fall prevention

1. Introduction

Standing and walking are complex actions that require balance and awareness of the body's spatial orientation, as well as the interrelated functions of systems such as the visual system, joint perception system sensory nervous system, and vestibular system. In addition, there are processing and integration of information from the sensory and motor systems, along with the perception of direction from the environment that can be processed as balance in the postural and in the movement of the whole-body system (Pirker & Katzenschlager, 2017). Balance is the body's ability to control and maintain the center of gravity (COG) on the base of support (BOS), thus keeping the body in balance condition (Shumway-Cook & Woollacott, 2007). Maintaining balance involves the interplay of multiple systems within the body, including the vestibular system, proprioception, muscle coordination, and feedback mechanisms. The feedback mechanisms play a vital role in balance control. These mechanisms involve continuous monitoring and adjustments based on sensory information received from various systems. For instance, if a person starts to lean to one side, sensory receptors in the feet and ankles detect the shift in weight distribution and send signals to the brain. The brain then activates appropriate muscles to counteract the imbalance and maintain an upright posture. The integration of information from the vestibular system, proprioception, and muscle coordination allows the body to make real-time adjustments to maintain balance. Balance can be divided into two types: static and dynamic. Static balance is the balance while the body is not moving, such as standing, sitting, etc. Dynamic balance is the balance while the body is moving, such as walking, sitting down, standing up, bending over, lifting things, etc. (Shumway-Cook & Woollacott, 2007; Pirker & Katzenschlager, 2017). Balance and posture of the body while standing and walking are essential to perform activities in daily life to prevent and minimize the risk of accidents that result in injury for all ages, possibly more for the older (Heglund, 1981; Beckham et al., 2014; Sung & Park, 2021; Shahabpoor & Pavic, 2017). Balance and the ability to bear weight play crucial roles in the well-being and quality of life of the elderly population. As individuals age, they may experience a decline in strength, flexibility, and sensory perception, which can significantly affect their ability to maintain balance and engage in weight-bearing activities. Falls pose a significant risk to older adults, leading to injuries and other negative outcomes. According to the World Health Organization (WHO), falls are the second leading cause of accidental or unintentional injury deaths worldwide. In the United States, falls are the leading cause of fatal and non-fatal injuries among older adults. Each year, one in four Americans aged 65 and older experiences a fall. The Centers for Disease Control and Prevention (CDC) reports that approximately 3 million older adults are treated in emergency departments for fall-related injuries in the United States each year. In Canada, falls are the leading cause of injury-related hospitalizations among seniors, accounting for 85% of injury-related hospitalizations in adults aged 65 and older. Falls can have significant consequences for the elderly population, impacting both their physical and psychological well-being. These consequences can include fractures, psychological impacts, increased mortality, and reduced mobility. To promote balance and weight-bearing conditions, exercise programs, consultation with healthcare professionals, and fall prevention strategies are essential. The risk of falls can be related to many factors, such as the physical environment (slippery floors, slopes, and floor roughness) or the quality of footwear. However, people who have better weight-bearing conditions tend to have a better deal the uncomfortable conditions than those with poor weight-bearing conditions in the same environment. Also, the consequences of falling can potentially lead to a significant decrease in health due to permanent injury. Knowing the weight-bearing condition would be helpful to understand the risk for accidents due to imbalance movement manner, and possibly be developed a way to a better weight-bearing pattern to prevent the risk (Muñoz-Organero et al., 2017; Piau et al., 2015; Truong et al., 2016; Sazonov et al., 2013).

2. Objectives

The study aims to analyze weight-bearing conditions during standing and walking and their impact on balance and fall risk by using the "Smart Walk Trainer" equipment which has been developed for measuring important parameters of the study.

3. Materials and methods

3.1 Hardware design

In this work, to measure the body weigh pressure on the feet, we need a sensor that is capable of transforming mechanical force into an electrical signal for further computerized analysis. The sensor is called "Force Sensitive Resistor", (FSR). The FSR is composed of two membranes separated by a thin air gap. One of the membranes has two sets of conductive lines which are isolated, each set connects to one trace on the tail. The other membrane is coated with FSR ink (carbon base ink) (Figure 1).

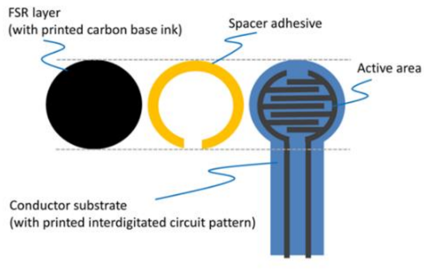

Figure 1 Force Sensitive Resistor, (FSR) structure (Adapted from Malvade et al., 2017)

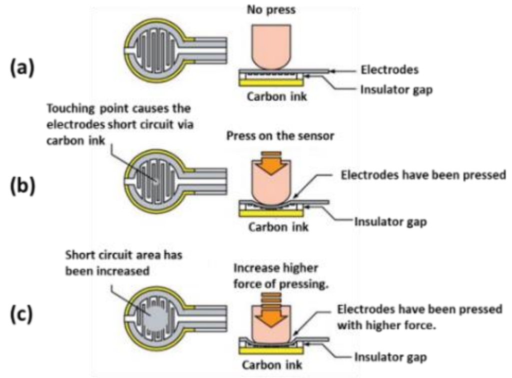

Figure 2 FSR sensor functional structure in (a) no press, (b) press on sensor and (c) increase to higher force of pressing.

When the two layers are pressed together, the two isolated electrodes create a short circuit via the conductive carbon ink, resulting in reduced resistance in the sensor. This FSR will vary its resistance depending on how much pressure is being applied to the sensing area. The harder the force, the lower the resistance. When no pressure is being applied to the FSR, its resistance will be larger than 1MΩ (Figure 2, a-c).

In the force sensing measurement module, a voltage potential divider circuit has been applied to the FSR sensor (Figure 3). The applied power voltage (Vcc) is 5 Vdc and the resistance is 10 k-ohms. The measurement out voltage will vary according to the change of resistance of the FSR sensor during the force applied. The circuit is connected to the input channel of a computer interface I/O unit. The output voltage is an analog signal, then it has been amplified and digitized by a 14-bit-digitizer for the computerize data reading process. Both analog output and power supply have been controlled and operated by the interface kit NI USB-6009 multifunction I/O unit and LabVIEW software from National Instrument (11500 N Mopac Expy, Austin, TX 78759, USA) (Figure 4). The NI USB-6009 box has a built-in management system. It communicates to the computer via a USB interface. The measurement data from the sensors are read by the "DAQ assistance" module in the LabVIEW programming. The data are then collected in a buffer using a "Collector" module for further display in the "Graphical" module (Figure 5).

In the “Smart Walk Trainer” equipment, the FSR sensors have been designed for data collection of the weight-bearing of the foot for analysis. The sensors have been installed in an insole made of soft and flexible material. Eight sensors have been used and placed at the following locations: the medial border of the left (L1) and right foot (R1), the lateral border of the left (L2) and right foot (R2), the medial border of the left (L3) and right heel (R3), and the lateral border of the left (L4) and right heel (R4) (Figure 6).

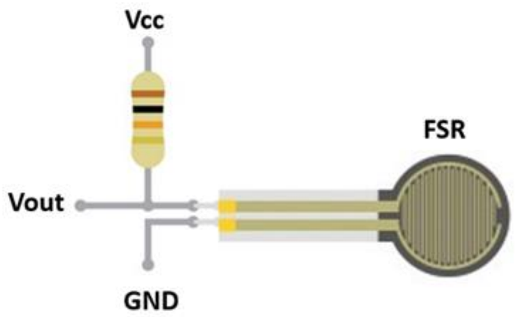

Figure 3 Application circuit of FSR sensor.

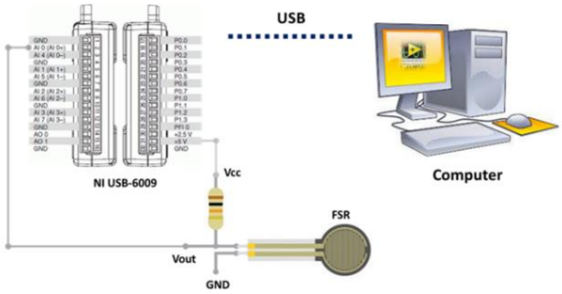

Figure 4 Diagram of interface kit NI USB-6009 multifunction I/O unit, FSR sensor application and computer control.

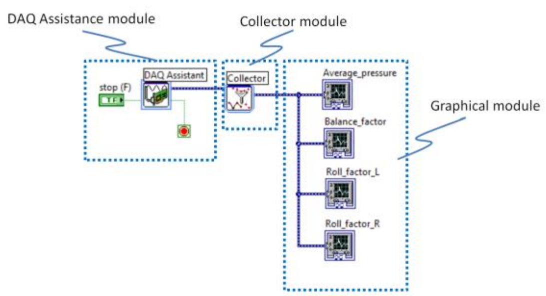

Figure 5 LabVIEW programming for data acquisition and graphical display.

3.2 Measurement parameters design

The reading values in kilogram (Kg) unit of the pressure on the sole from the 8 FSR sensors installed in the soles area are analysed and displayed on the computer screen in real-time. The reading signals have been shown in "Smart Walk Trainer" parameters as details below.

2.2.1 Average_pressure is the average value of the foot pressure measured on the four points for both left (L) and right (R), see equations (1) and (2). Normally this value should be close between both left and right feet in a walking and standing manner. If the values of left and right have a significant difference, it might be considered as a potential of the improper foot weight-bearing imbalance that might induce unpreferred physical pain of muscle. The correct manner could be trained by using this equipment to reduce the deviation of the average values of the left and right feet.

$$\text{Average\_pressure\_L} = [L1+L2+L3+L4]/4 \quad (1)$$

$$\text{Average\_pressure\_R} = [R1+R2+R3+R4]/4 \quad (2)$$

2.2.2 Balance_factor is a parameter calculated from the differentiate value of average_pressure of left and right feet, see equation (3). The ideal value is zero for the good manner of the body for both walking and standing.

$$\text{Balance\_factor} = \left[\text{Average}_{\text{pressure}_L}\right] - [\text{Average\_pressure\_R}] \quad (3)$$

2.2.3 Roll_factor is a calculation value of the pressure sensor on the medial border the lateral border for both left and right feet, see equations (4) and (5). This factor indicates how well the soles of feet are in a good manner. The preferred value is close to zero. However, if the value deviated from the zero-balance point, the improper manner of walking and standing might require improving by using the Smart Walk Trainer equipment.

$$\text{Roll\_factor\_L} = [L1] - [L2] \quad (4)$$

$$\text{Roll\_factor\_R} = [R1] - [R2] \quad (5)$$

The overall graphical concept for the analysis diagram of "Smart Walk Trainer" parameters is shown in Figure 6. In a cycle of walking, the Average weight value of the right foot will be calculated from the four sensors in the right sole (A1), followed by the left foot (A2) (in diagram A). At the same time, the roll_factor is calculated (in diagram C). After completing a walking cycle, the Balace_factor will be calculated from the subtraction between A1 and A2 values (in diagram B). The repeated process of calculation keeps going until stopping the program.

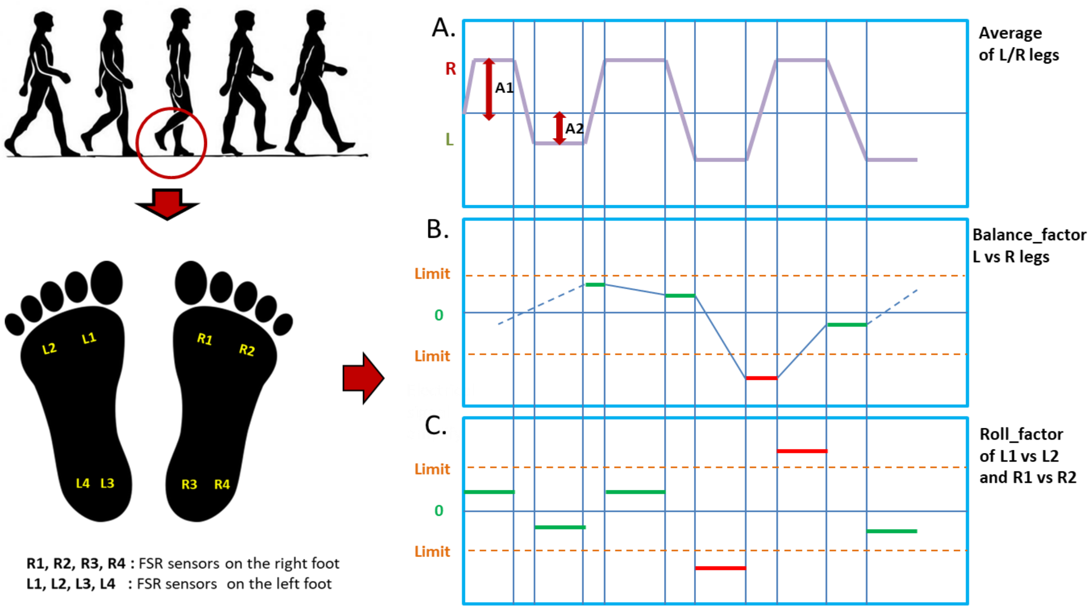

Figure 6 Analysis diagram of "Smart Walk Trainer" parameters; A. Average pressure, B. Balance factor and C. Roll factor.

Figure 7 Graphic user interface (GUI) of "Smart Walk Trainer" program

3.3 Graphic user interface (GUI) design

The "Smart Walk Trainer" equipment has been developed to analyze weight-bearing position balance conditions and is used for training to improve balance. The software is designed for friendly use with a graphical display in real-time and interacts with the user during the training. The overall graphic user interface (GUI) of the "Smart Walk Trainer" software is shown in figure 7.

It is composed of five main portions.

1) Data file management

This portion is for managing the data files both loading and saving via the "LOAD" and "SAVE" commands. The data files could be saved or loaded on the local computer or on the cloud storage on the internet online link.

2) Personal information

This portion is for inputting the personal information of the subject that has been trained with the "Smart Walk Trainer" equipment. The information possibly be helpful for the improvement of activities.

3) Program control

This portion is the main control function of the program. It is composed of "RUN", "STOP" and "EXIT" commands. The "RUN" command is for start training, the "STOP" command is for stopping the training, and the "EXIT" command is for closing the program.

4) Graphical display

This portion shows measurement parameters in real-time both graph and values. There are four parts to this portion.

4.1) The "Average_pressure" parameter shows the average values of the four sensors of each sole on both the left and the right, see equations (1) and (2).

4.2) The "Balance_factor" parameter shows the offset value of the "Average_pressure" between the left and the right feet, see equations (3).

4.3) The "Roll_factor_L" shows the differential value between the pressure sensor on the medial border and the lateral border of the left sole, as shown in equation (4). The green, yellow, and red indicators are Good, Fair and Poor status.

4.4) The "Roll_factor_R" shows the differential value between the pressure sensor on the medial border and the lateral border of the right sole, as shown in equation (5). The green, yellow, and red indicators are Good, Fair and Poor status.

5) Limit control setup

This portion is for setting up the limit of the training for the "Balance_factor", the "Roll_ factor_L" and the "Roll_factor_R" parameters. The limit values are defined at two levels, referred to as the "Good limit" and the "Poor limit. Ideally, these three parameters shall be zero. However, in humans, these parameters may deviate from zero depending on individual daily behavior.

Table 1 Characteristics and parameters in standing and walking of young and elderly volunteers.

	Young (n=10)				Elderly (n=10)			
	Mean	**SD**	**Max**	**Min**	**Mean**	**SD**	**Max**	**Min**
Age (years)	21.1	1.62	25	20	61.8	1.62	65	60
Weight (kg.)	71.8	6.91	81	63	63.4	1.96	66	60
Height (cm.)	172.3	7.04	182	164	164.9	1.97	168	162
BMI (kg/m$^{2)}$	24.19	0.57	24.68	22.86	23.32	0.87	24.01	21.77
Standing								
Average_pressure R.(kg.)	8.9	0.83	10.14	7.93	7.78	0.49	8.51	7.13
Average_pressure L.(kg.)	8.94	0.88	10.28	7.85	7.69	0.36	8.13	7.1
Balance_factor	-0.04	0.12	0.08	-0.23	0.09	0.24	0.53	-0.23
Walking								
Average_pressure R.(kg.)	13.72	1.37	15.45	12.18	13.82	0.53	14.77	12.83
Average_pressure L.(kg.)	13.9	1.71	16.3	11.87	13.31	0.77	14.48	12.45
Balance_factor	0.18	0.61	0.32	-1.4	0.51	0.94	1.86	-1.36
Roll_factor R.	0.01	0.56	1.08	-0.9	-0.72	1.4	1.1	-3.88
Roll_factor L.	-0.19	0.49	0.18	-0.92	0.78	1.41	3.07	-0.93

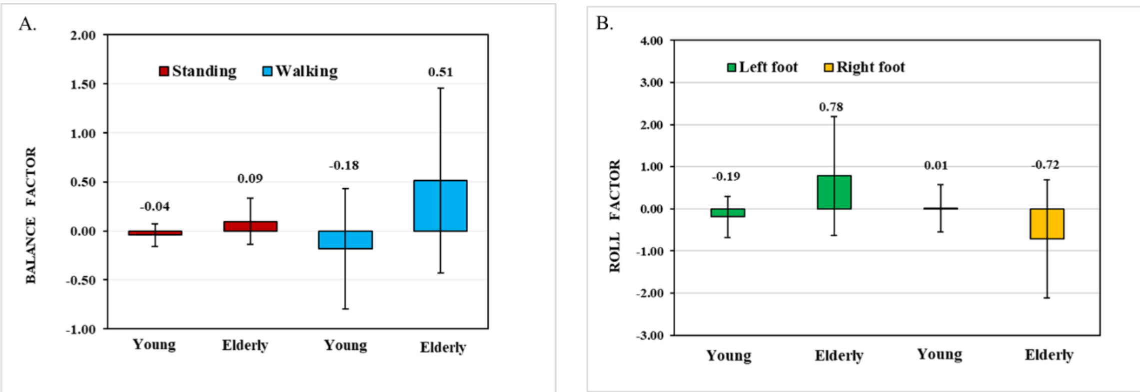

Figure 8 (A) Balance factor (Mean±SD) of young and elderly while standing and walking and (B) Roll factor (Mean±SD) of both feet of young and elderly while walking.

If the value is within the "Good limit", the indicator will show green (Good), if the value is out of the "Poor limit", the indicator will show red (Poor), and if the value is in between the "Good limit" and the "Poor limit", the indicator will show yellow (Fair)

4. Results and discussion

4.1 Results

In the study using the Smart Walk Trainer equipment, 20 male and female volunteers were evaluated, including both young and elderly individuals. All participants had a normal body mass index (BMI), with the young group having a mean BMI of 24.19±0.57 kg/m^2 and the elderly group having a mean BMI of 23.32±0.87 kg/m2 (Table 1).

Regarding the standing posture, the young group exhibited an average pressure of 8.90±0.83 kg on the right foot and 8.94±0.88 kg on the left foot. The mean balance factor was -0.04±0.12 kg, indicating a slight deviation from balance In comparison, the elderly group had a mean Average pressure of 7.78±0.49 kg on the right foot and 7.69±0.36 kg on the left foot. The balance factor had a mean of 0.09±0.24 kg.

Regarding the walking posture, the young group exhibited an average pressure of 13.72±1.37 kg on the right foot and 13.90±1.71 kg on the left foot. The balance factor had a mean of 0.18±0.61

kg. However, the roll factor deviated slightly from balance, with a mean of 0.01±0.56 kg on the right foot and -0.19±0.49 kg on the left foot. For the elderly group during walking, the mean Average pressure was 13.82±0.53 kg on the right foot and 13.31±0.77 kg on the left foot. The balance factor had a mean of 0.51±0.94 kg. However, the Roll factor showed a more significant deviation from balance, with a mean of -0.72±1.40 kg on the right foot and 0.78±1.41 kg on the left foot.

4.2 Discussion

Strength, endurance, and flexibility of muscles not only affect physical fitness, but also posture while standing and walking, as well as body alignment along the vertebral column. The head and neck were slightly bent forward. The legs are apart properly and supported the full weight of both feet (Ohlendorf et al., 2020). A review of the literature found that in a standing position, the body weight is evenly distributed over both feet, each 50% of the load (Comerford & Mottram, 2001). The percentage weight on the forefoot was about 60-66 when on the heel was about 33-40 (Scharnweber et al., 2017). And found a little more weight on the right foot than the left foot (Ohlendorf et al., 2019). Not putting a full load on both feet or standing with extra weight on one foot may be a result of habituation, aptitude (Lalande et al., 2016) or weakness of the muscles that support the balance due to perception disorder (Moon et al., 2014) or a disease related to the Musculoskeletal system (Walsh et al., 2017; Butterworth et al., 2015; Menz et al., 2013; Mickle & Steele, 2015). If everyone could analyze and know the weight-bearing of their feet, they will be able to adjust their weight-bearing and balance to the proper conditions that help in standing and correct posture to reduce problems which may be caused by muscles not working properly. It has an overall effect on standing correct and dignified. This prepares the body for proper walking, maintaining stability during movement, and continues to promote personal health (Ohlendorf et al., 2019). The results of the experiment on 20 young and elderly volunteers (both male and female) found that while standing, the average pressure on the left foot was slightly more than on the right in the young group (8.94±0.88 kg and 8.90±0.83 kg, respectively). The difference in average_pressure value is 0.04, and the balance_factor was between -0.23 to 0.08. It is possibly due to the study being conducted on young volunteers without foot weight-bearing problems. Therefore, there was not much difference in the weight of both feet since the balance factor was approached zero, which was consistent with research that found that healthy or young people who did not have problems with foot weights would be able to put full weight on the soles of the feet while standing (Lalande et al., 2016). Conversely, in the elderly found an Average pressure on the right foot slightly more than on the left in elderly (7.78±0.49 kg. and 7.69±0.36 kg., respectively). However, the standing Balance_factor of the elderly was like that of the young (-0.23 to 0.53) (Figure 8A)

When the volunteers were asked to walk at a normal speed for 10 steps, it was found that the average_pressure of the right and left foot while walking were higher than standing conditions in young (13.72±1.37 kg. and 13.90±1.71 kg, respectively) and in elderly (13.82±0.53 kg. and 13.31±0.77 kg, respectively). Similarly, the balance factor of walking was higher than the standing condition in young (0.18±0.61) and in the elderly (0.51±0.94) (Figure 8A). It shows that starting a walk from a calm stand is a complex task that requires building momentum or producing more forceful weight shifting while stabilizing posture (Lalande et al, 2011; Marsk, 1958). Interestingly, the mean roll_factor of the right foot and the left foot in the elderly deviated greatly from the balance point when compared to young subjects (Figure 8B). The roll_factor in this study refers to the difference in weight-pressure on the inside and outside of the plantar foot. If the foot roll_factor is close to 0, this means that there is no difference in weight applied to the insole area. This means that you can put your full weight on the soles of your feet. In our study found that the imbalance in weight-bearing can affect more in the elderly while walking. Previous study on foot weight-bearing explained that the imbalance in weight-bearing can affect the instability of balance and may increase the risk of falling (Taube et al., 2006). Additionally, in the elderly, carrying weight on the lateral side of the foot between heel and forefoot contact may affect balance during walking. It is according to the falling history of our elderly subjects that they fell more than 2-3 times in the year before joining this research.

Therefore, it is revealed that the further the deviation of the roll_factor value away from zero, the greater the person's weight imbalance and may be an indicator at risk of falling. From a graphics of weight-bearing, it may be necessary to adjust the weights of the outside and inside feet to be approximately the same. So that the roll_factor value of both feet is not much different to prevent the weight-bearing imbalance and risk of falling. The imbalanced posture of the body is a potential risk of accidents in all ages that can be caused by a variety of reasons, including muscle weakness, aging-related deterioration in balance, or neurological problems.

However, it could be improved by using the "Smart Walk Trainer" Equipment. People often underestimate the experience of bearing weight on their feet. However, by using this tool to analyze foot load, one can visualize a graphical representation of weight-bearing and adjust weight distribution to achieve a balanced posture, ensuring equal weight distribution on both feet and throughout the entire foot. This tool facilitates self-weight training, allowing individuals to practice and improve their balance effectively. Furthermore, it provides physiotherapists with enhanced clarity regarding the patient's weight distribution patterns, enabling them to identify any abnormalities and provide targeted exercise recommendations to strengthen specific muscles and promote improved balance for fall prevention.

The satisfaction of using the Smart Walk Trainer equipment has been evaluated by using the following items; (1) ease of use and safety, (2) useful for real-time graphical visual feedback, (3) data management, and (4) comfortable with portability and mobility. The overall result indicates that 25% of the volunteers were satisfied at the highest level and 75% were at a high level (Table 2).

A poor balance_factor is due to unequal weight distribution on the left or right foot, while a poor roll_factor is due to improper weight distribution on the inner and outer soles. This problem could possibly be caused by improper posture or body alignment from unexpected habits. The Smart Walk Trainer equipment can be used to monitor and provide feedback for improving one's walking habits. By practicing proper weight-bearing conditions, users can aim to achieve the green light indicator. However, if poor balance_factor and roll_factor result from medical conditions, it's important to consult with a healthcare professional, such as a doctor or physical therapist. They may prescribe exercises to strengthen weak muscles, manage pain, improve balance, and promote proper weight distribution. Then the Smart Walk Trainer equipment could be used to support the healing.

The current existing system is a "force plate" used mostly for monitoring and research in Work Physiology. It is composed of a flat plate with weight measurement units underneath. The weight values would be manually read and recorded when the Smart Walk Trainer equipment automatically reads the values and displays them in real-time.

5. Conclusion

Imbalanced posture is a potential risk factor for accidents across all ages, and can be caused by a variety of reasons, including muscle weakness, age-related deterioration in balance, and neurological problems. Such accidents could result in injuries. This research aimed to develop equipment for analysing the weight-bearing conditions of both standing and walking, with a focus on imbalances. The outcome parameters, which include average_pressure, balance_factor, and roll_factor, are crucial for verifying weight-bearing conditions. The results show in real-time the graph, values, and level indicators.

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Table 2 The satisfaction evaluation result

Item	Number of volunteers (Percentage, %)					
	Shoe with sole sensor			Smart walk program		
	moderate	much	most	moderate	much	most
Ease of use and safety.	8(40%)	8(40%)	4(20%)	8(40%)	8(40%)	4(20%)
Useful of real time graphical visual feedback	-	-	-	-	5(25%)	15(75%)
The data management	-	-	-		5(25%)	15(75%)
Comfortable of portability and mobility.	8(40%)	8(40%)	4(20%)	8(40%)	8(40%)	4(20%)
Overall satisfaction	-	15(75%)	5(25%)	-	15(75%)	5(25%)

The indicators, shown in green, yellow, and red, represent good, fair, and poor status, respectively, and can assist users in making effective improvements. Our research using this equipment found the roll_factor of the elderly deviated greatly from the balance point when compared to the young subjects which corresponded to the risk of falling in the elderly. However, under a physician's or physical therapist's consultation, this equipment could help improve the balanced posture and minimize the risk of falling. This equipment could potentially be used more extensively in individuals with diseases or problems that affect their feet or weight distribution while standing and walking, thereby helping them adjust their weight correctly and potentially improving their overall posture.

6. Acknowledgements

We would like to thank our collaborators in Faculty of Allied Health Science, Thammasat university for their support in this project. This study was supported by Thammasat University Research Fund, Thailand, Contact NO. TUFT 041/2020.

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