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Comparison of Baby Walkers Against Toddler Walking Ability Using Biomechanics Through Kinect Sensor and Force Sensing Resistor Measurements

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ABSTRAK

Penyelidikan menstimulasi balita belajar berjalan menggunakan baby walker (BW), memungkinkan telapak kaki balita menapak di permukaan lantai. Tujuan penelitian ini adalah membandingkan efektifitas penggunaan BWstandar dan Redesign dalam menstimulasi balita belajar berjalan dengan perangkat Kinect Sensor dan Force Sensing Resistor (FSR) menggunakan biomekanika berbasis video. Penelitian ini melibatkan 9 balita, usia minimal balita 9 bulan, panjang tubuh 70-80cm, dan panjang telapak kaki 10-12cm. Biomekanika balita pada gaya kompresi kaki melalui video secara real time menggunakan Kinect Sensor dengan analisis gerakan dikembangkan melalui Software Microsoft Visual Studio, dan Software Vitruvius. Pengukuran tekanan telapak kaki menggunakan FSR terhubung dengan sistem Arduino IDE yang ditempatkan di kaos kaki prewalker melalui 5 titik pembacaan. Uji statistik menggunakan paired sample t-test. Gaya kompresi kaki balita menggunakan BWstandar (Redesign), phase heel-strike 218,98 N (447,66 N), phase midstance 273,08 N (462,61 N), phase toe-off 181,94 N (371,99 N), dan tekanan telapak kaki 248 N (339 N). Hasil Pair sample t-test diperoleh ada perbedaan penggunaan antara BWstandar dan Redesign. Disimpulkan Stimulasi balita belajar berjalan dicapai lebih efektif menggunakan BWredesign dan lebih direkomendasikan.

ABSTRACT

The investigation stimulates toddlers to learn to walk using a baby walker (BW), allowing the toddler's soles to land on the floor surface. This research compares the effectiveness of using BWstandard and Redesign in stimulating toddlers to learn to walk with Kinect Sensor and Force Sensing Resistor (FSR) devices using video-based biomechanics. This research involved 9 toddlers; the minimum age of toddlers was 9 months, body length 70-80cm, and foot length 10-12cm. The biomechanics of toddlers on leg compression are performed via video in real-time using Kinect Sensor with movement analysis developed through Microsoft Visual Studio Software and Vitruvius Software. Measuring foot pressure using FSR is connected to the Arduino IDE system and placed in the prewalker sock via 5 reading points. Statistical tests use paired sample t-tests. Toddler foot compression force using BWstandard (Redesign), heel-strike phase 218.98 N (447.66 N), midstance phase 273.08 N (462.61 N), toe-off phase 181.94 N (371.99 N), and foot pressure 248 N (339 N). The results of the Pair sample t-test showed that there was a difference in use between BWstandard and Redesign. It was concluded that stimulation of toddlers learning to walk was achieved more effectively using BWredesign and was more recommended.

1. INTRODUCTION

Toddler development is linked in their first year of life to motor and sensory experiences. Gross motor development is prioritized through the provision of stimulation in early childhood. It needs to be a concern, but the limited knowledge of parents to choose a way of stimulation is an obstacle. Central Bureau of Statistics in 2021 reports that in Indonesia, the number of early childhood children is 30.83 million, consisting of 13.56% babies (age < 1 year), 57.16% toddlers (1-4 years), and 29.28% preschoolers (5-6 years). The Indonesian Ministry of Health in 2014 stated that the results of research in Indonesia in Bandung district, West Java, found that 20-30% of toddlers experience developmental disorders, experience delays in gross motor aspects and language or speech due to lack of stimulation. The Indonesian Ministry of Health in 2014 stated that the in Indonesia, the percentage of toddlers experiencing balance disorders and muscle weakness due to motor delays at the age of 15-18 months is 11.5%. Gross motor development, which helps toddlers, refers to control over environmental actions, such as crawling, standing, and walking (Adolph & Franchak, 2017; Hadders-Algra, 2018; Mendonça et al.,

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2016). This is an important stage in a child's development that allows them to interact with their surroundings and increase their independence. Furthermore, at the age of 9-12 months, toddlers usually begin to learn to walk, which becomes an important milestone in their motor development (Cole et al., 2016; Lee et al., 2018). However, according to previous research, in Indonesia, the average toddler only starts walking at the age of 9-15 months (Mulyani & Budiarti, 2022; Sadiman et al., 2023). It shows the variation in children's development and the importance of understanding individual differences in the developmental process. Generally, toddlers will start learning to walk at 9 to 12 months. Babies will usually start walking independently without holding hands under 15 months. Many parents want their children to walk independently and quickly, using a BW as a walking aid. BWs consist of a wheeled base supported by a rigid frame, a seat with leg openings, and usually a plastic tray (Grivna et al., 2015; Sims et al., 2018). This walking aid supports pre-ambulatory toddlers with their feet on the floor and allows mobility as they learn to walk. Another function of a BW, which supports walking in toddlers, is to train the lower extremity muscles (Janusz et al., 2023; Krivova & Sharov, 2018). However, according to previous research, using a BW for too long in toddlers harms gross motor development and causes injury due to falls (Badihian et al., 2017; Melike et al., 2017). The accuracy of BWs in stimulating toddlers' gross motor skills is a concern. Using the suitable BW can stimulate toddler motor skills according to age. The advantage of using a BW is that it functions apart from being a facilitator of learning to walk during this period, where it helps toddlers who cannot get around and explore the environment in a standing position.

People have widely used the modern BW-designed toddler walker, and many patented enhancements of similar devices have emerged. Summarizing several studies, the level of use of BW in all countries in the world is relatively high, ranging from 42% to 95% (Kaddis et al., 2016; Sharov et al., 2018). Families report various logical reasons, although many parents believe that BW helps toddler learn to walk, evidence not support this. Research on infant injury related to BW use was introduced in 1982 by Fazen & Felizberto. BW mediation can encourage a toddler to walk on the toes, even on the soles of the feet, causing the heel and toe muscles to tighten. Sitting on BW often does not see toddlers using their feet and how their feet move when walking. When a toddler hangs on the BW, the toes stretch to reach the ground and tiptoe. This condition causes toddlers to walk on tiptoe when they get out of the BW; many toddlers who show a tiptoe walking pattern with a history of using BWs when they were small. It was observed in this study that toddlers using BW tended to take shorter strides compared to those who did not. This habit continues to develop into a routine for toddlers to walk based on a narrow gait and increased cadence. Having wheels attached to the BW allows the toddler to take more steps per minute. However, a toddler's balance may not be sufficiently developed to keep up with speed, and toddlers can easily fall over when walking alone without BW support. This paper examines the standard BW type 136 commonly available on the market with a slider-crank component with a maximum height of 50 cm. The BW redesign as an improvement to the standard BW, designed according to the anthropometry of toddler body length with a thread bar component as a thread bar that connects the two upper and lower rings. The BW study was measured using a Kinect sensor supported by Microsoft visual studio and Vitruvius software and a force sensing resistor (FSR) supported by Arduino IDE software, connected to the PLX-DAQ software system with a laptop installed.

The Kinect sensor is used as a 3D motion measurement tool to calculate toddler biomechanics against the toddler's leg compression force when using BW. The Kinect was initially designed to capture body movement for video games. Microsoft Kinect v1 can calculate the 3D positions of twenty body joints using a depth map retrieved from the depth sensor without placing additional sensors or markers on the object's body (do Carmo Vilas-Boas et al., 2019; Mentiplay et al., 2015). Breakthroughs in deep sensing and machine learning technologies, a portable, inexpensive, and easy-to-use alternative to 3D motion analysis, have become commercially available (Van der Kruk & Reijne, 2018; Van Hooren et al., 2023). The Kinect sensor is a color camera and depth sensor, including an infrared projector and a camera for capturing 3D motion (Dolatabadi et al., 2016; Springer & Yogev Seligmann, 2016). Microsoft designed Kinect for XBOX ONE video games and PCs with the windows operating system (Bijalwan et al., 2021; Mentiplay et al., 2018; Pfister et al., 2014). The Kinect Sensor system can be applied to several algorithms: motion tracking, motion capture, depth image, skeleton tracking, human object tracking, head-pose tracking, and facial expression tracking (do Carmo Vilas-Boas et al., 2019; Yeung et al., 2021). The Kinect sensor to measure the performance of CP children when pedaling a united cerebral palsy (UCP) wheelchair on an inclined plane. Many researchers have used these affordable and portable depth sensors for clinical assessment, gait analysis, and rehabilitation (Clark et al., 2019; Knippenberg et al., 2017; Yagi et al., 2020). Clinical assessment using Microsoft Kinect is perfect for postural control and standing balance (Liu et al., 2020; Yang et al., 2014). Kinect reproducibility when analyzing planar motion is functionally similar to conventional marker-based stereophotogrammetry systems (Di Marco et al., 2016; Leardini et al., 2021). However, using Microsoft Kinect shows increased studies involving markerless motion capture systems in neurological rehabilitation (Liu et al., 2020; Yang et al., 2014).

Microsoft Kinect knowledge and evidence for content measurement of biomechanics in toddlers and the efficacy of evaluating other markerless motion capture systems are scarce (D. Chen et al., 2019; Savoie et al., 2019). At the same time, the biomechanics of the toddler's body was measured using the Kinect sensor, and the load distribution of the toddler's feet was also measured using the FSR-402 sensor. Interlink electronics provides electronic measurement applications that require hand-held user input, menu navigation, cursor control, and intuitive interface technologies. The Interlink electronics application is a guide that overviews the solutions, applications, and benefits. FSR is designed to detect and determine pressure distribution on the soles of toddlers' feet when learning to walk using BW. Some researchers designed this tool to save costs on purchasing equipment (Naderi et al., 2019; Taş & Çetin, 2019). FSR is a component of a measurement tool that allows static and dynamic force measurements to be applied to surface contact (Castellanos-Ramos et al., 2019; Gan et al., 2022). FSR is made from thin polymers that resist dropping when the surface is subjected to a load. The FR's sensor is placed in a prewalker toddler's sock with five pressure reading points adjusted to the dimensions and size of the baby's feet. The circuit in this system allows maximum mobility for toddlers because the sensor is attached wirelessly to a computer that collects data and data related to several physiological parameters (Han et al., 2019; Negi et al., 2021). Wearability in device design aims to take measurements unobtrusive but reliable way. Measurement accuracy and reliability play an essential role as a companion to outdoor laboratory equipment. This measurement method is ideal for measuring plantar forces' distribution. Electronic module and data acquisition for measuring baby's foot pressure is made through electronic instrumentation. A load linearity test against pressure is realized and calibrated to verify the system's feasibility using standardized weights of 0.5 kg, 1 kg, 2 kg, and 3 kg. Calibrate by placing the weights on the FSR sensor so that the resulting pressure value is obtained. The resulting data is an analog value in bit units (Baserga et al., 2021; Sifuentes et al., 2019). Although many techniques are available to detect gait walking analysis for plantar force, more research is needed in measuring toddler foot pressure when using BW while learning to walk. The novelty of this study lies in the proposed approach to understanding the effectiveness of using Baby Walkers (BW) in toddlers through the use of biomechanical parameters, such as compressive forces on the feet and pressure distribution on the feet. Based on the information presented, it is necessary to study toddlers using biomechanical parameters, including compression forces on the feet and pressure distribution on the feet, to determine the effectiveness of using BW for toddlers. The purpose of this study was to compare the effectiveness of using BW in toddlers between the standard BW already available on the market and the redesigned BW on the ability of the baby's feet to rest on the floor when walking using biomechanics through Kinect and FSR sensor measurements.

2. METHOD

All subjects and parents of toddlers involved in this study were left in Mojosongo Village, Surakarta City. Nine toddlers were selected as research subjects aged between 9-18 months and a maximum body weight of 20 kg without a history of injury in the past year or musculoskeletal, neurological, or cardiovascular disorders. The sex toddlers involved were six boys and three were girls. Body mass index (BMI) subjects with normal weight status in the range of 15.52-18.44. Anthropometric toddlers have a body length of 70-78 cm, and the sole length between the heel and the toe is 10-12 cm. Observations on toddlers showed that five toddlers could walk fast, and four toddlers could ramble. The length of a toddler's feet is used as a reference for choosing the size of prewalker socks to place the FSR sensor. The Research Ethics Committee of Sebelas Maret University Surakarta approved this research. All parents of toddlers participating gave written consent on the informed consent forms.

Two Kinect XBOX ONEs are equipped with 1080p high-definition camera resolution as an evaluation tool. The Kinect sensor is connected to the laptop using the Kinect adapter. Laptop specifications have 64-bit (x64 processor), dual-core 301 GHz, and 4GB RAM. The Kinect camera, as a high-speed 3D motion capture, is placed in the center of the track; the camera is installed in a frontal position facing the subject at a distance of 150 mm; it is installed in a sagittal position facing the subject at a track length of 200 mm. The height of the camera to the subject is 50 mm. The subject's movement begins to be recorded when it moves from a backward to a forward position toward the direction the camera is installed. The position of Kinect sensor has a zero-degree tilt angle and is mounted on a tripod. As the manufacturer recommended, these adjustments ensure that the subject's entire body is within the Kinect's range. Before the gait experiment begins, parents of toddlers are given directions in using standard and redesigned BW. Toddlers are directed to push BW while walking at a slow speed of 0.83 m/s for 60 seconds until they get used to the trial trajectory (Moe-Nilssen & Helbostad, 2020; Roche et al., 2021). This walking speed was selected according to the reference gait dataset (Moe-Nilssen & Helbostad, 2020; Roche et al., 2021). On toddler clothing, fourteen retro-reflective markers (9.5 mm diameter) left and suitable were placed bilaterally on anatomical landmarks to track foot movement to a marker accuracy of within 0.3 mm (J. P. Chen et al., 2015; Gimunová et al., 2022). Experimental data retrieval of walking toddlers for five minutes randomly with five repetitions of the test to record gait patterns in video images using the Kinect. The Kinect sensor is connected to the laptop and is energized. The Kinect has been detected on the computer system and appears on the laptop screen. The next step is to run Microsoft visual studio software with output on the Vitruvius system. Toddlers were given two minutes to rest in the BW harness between trials. This biomechanical test to determine the compression force of a toddler's leg can be explained in the schematic drawing of the protocol in this test described in Figure 1.

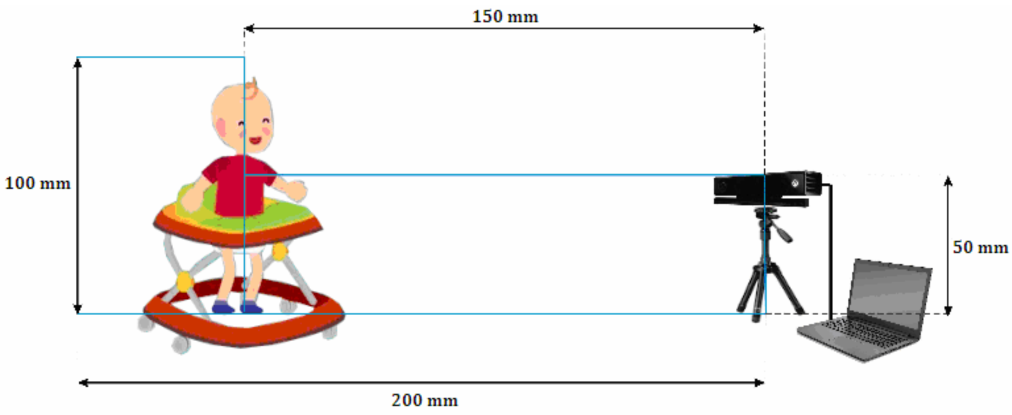

Figure 1. Biomechanics Testing Protocol Using Kinect Sensors When Toddlers Push BW

The foot pressure data recording for toddlers uses the FSR-402 sensor. The data is generated by the FSR-402 sensor pressure, which is placed on the surface of the prewalker sock with five pressure reading points attached to the right and left feet of the toddler. This FSR circuit module is installed on a toddler's leg and connected to a laptop. Pressure data collection was carried out for 5 minutes for five repetitions. Toddlers were given two minutes to rest in the BW harness between trials. This biomechanical test to determine the pressure on the soles of toddlers' feet can be explained in the schematic drawing of the protocol in this test described in Figure 2.

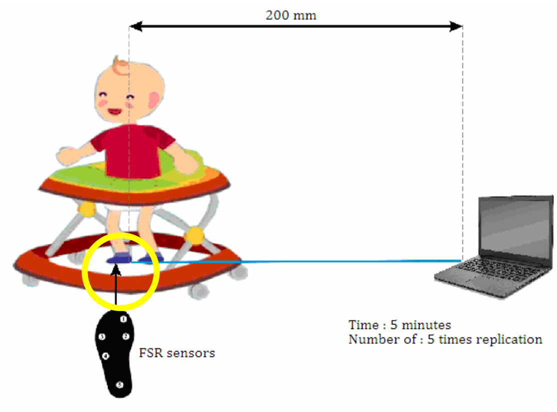

Figure 2. Biomechanics Testing Protocol Using The FSR-402 Sensor When Toddlers Push BW

The toddler's walking cycle includes heel strike, midstance, and toe-off. Each gait cycle calculates the forces and moments in the toddler's body: the palms, forearms, upper arms, shoulder, thighs, shank, and ankles. Kinematic measurements on toddler body segments consist of palm sagittal flexion/extension, forearm sagittal flexion/extension, upper arm sagittal flexion/extension, shoulder sagittal flexion/extension, thigh sagittal flexion/extension, thigh frontal abduction/adduction, shank sagittal flexion/extension, shank frontal abduction/adduction, ankle sagittal dorsiflexion/plantarflexion, is calculated from the sensor data at the reflector position in terms of the angle at each joint at the marker point. Biomechanical calculations based on a simple hinge joint were applied to determine the sagittal segment consisting of the thigh, shank, and ankle treated. Joint angles are calculated assuming relative angles between two adjacent vectors, each angle representing that of the palm and forearm; forearm and upper arm; thighs and shank; shank and ankles. The shoulder is treated as a 3D joint, and the flexion/extension and abduction/adduction angles are calculated for the sagittal and frontal planes of the hip segments, respectively (Ma et al., 2019; Uchida & Delp, 2021). The coding for determining the joint angle in the vector is presented in Table 1.

Table 1. Coding in Vitruvius Software in Determining Vector Angles in Gait Cycles

No	Body Segmentation	Joint Angle Against Vector
1	Palm	JointType _start1 = JointType.ElbowRight; JointType _center1 = JointType.ShoulderRight; JointType _end1 = JointType.HipRight;
2	Forearm	JointType _start2 = JointType.WristRight; JointType _center2 = JointType.ElbowRight; JointType _end2 = JointType.ShoulderRight;
3	Upper arm	JointType _start3 = JointType.ThumbRight; JointType _center3 = JointType.WristRight; JointType _end3 = JointType.HandTipRight;
4	Shoulder	JointType _start6 = JointType.SpineShoulder; JointType _center6 = JointType.SpineMid; JointType _end6 = JointType.SpineBase;
5	Thighs and shank	JointType _start5 = JointType.KneeRight; JointType _center5 = JointType.AnkleRight; JointType _end5 = JointType.FootRight;
6	Ankle	JointType _start4 = JointType.AnkleRight; JointType _center4 = JointType.KneeRight; JointType _end4 = JointType.HipRight;

The Kinect sensor device still has a weakness in reading the angles of landmarks on the body when capturing 3D motion. Therefore, the Kinect sensor requires additional software, such as Microsoft Visual Studio and Vitruvius. The purpose of combining the Kinect sensor with these two software is to produce a screenshot of the skeleton tracking and the magnitude of the angle on the measured object. Microsoft visual studio is software used to develop applications in native code and managed code. Microsoft Visual Studio can create a program that displays angles directly on the laptop screen when the Kinect sensor detects the skeleton tracking of the subject. The program display from Microsoft visual studio can be explained in Figure 3.

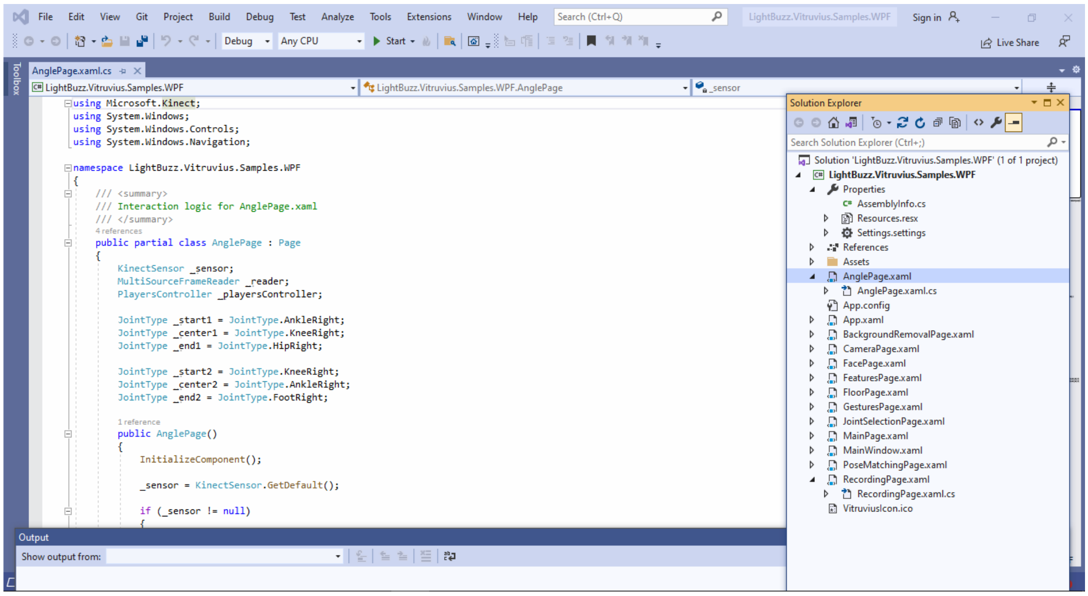

Figure 3. Coding Program from Microsoft Visual Studio

The output program created in Microsoft visual studio is Vitruvius software. Vitruvius software directly displays the corners of specific segments when the Kinect Sensor captures the skeleton tracking on the laptop screen. The output generated by the Vitruvius software can be explained in Figure 4.

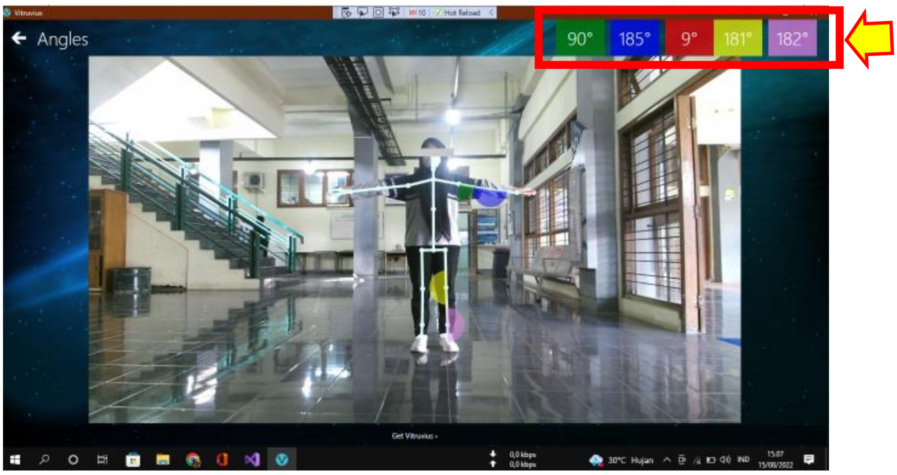

Figure 4. Output Generated by Vitruvius Software

The hardware used to detect pressure on the soles of the feet is an Arduino UNO microcontroller, FSR sensor, 10 kΩ resistor, jumper cable, and laptop. The FSR sensor has several poles: positive, segment 1, segment 2, segment 3, segment 4, segment 5, and negative. The positive pole is connected to the 3.3 V point on the Arduino UNO. The poles of segment 1, segment 2, segment 3, segment 4, and segment 5 are connected to points A1, A2, A3, A4, and A5 on the Arduino UNO. The negative pole is connected to the GND point on the Arduino UNO. The series of foot pressure gauges using the FSR-402 sensor is in Figure 5.

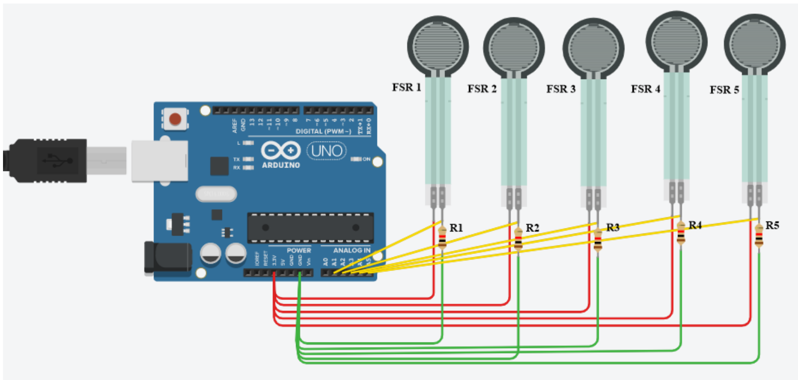

Figure 5. Series of Pressure Gauges on The Soles of The Feet

The FSR sensor circuit is placed on the surface of the sole so that the amount of pressure on the sole is known. Each point has a diameter of 10 mm, is 0.3 mm thick, and reads a maximum weight of 20 kg. The distribution of FSR sensor points can be shown in Figure 6.

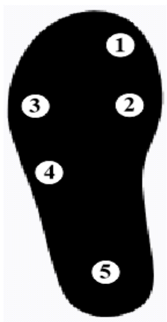

Figure 6. Placement of The FSR-402 Sensor at The Prewalk Sock Points

The placement of the FSR sensor was divided into 5 points: point 1 affixed to the toe, point 2 affixed to the first metatarsal, point 3 affixed to the fifth metatarsal, point 4 affixed to the cuboid, and point 5 affixed to the heel. The software used is Arduino version 1.8.19, and PLX-DAQ functions as a control center in integrating hardware. The programming language in the Arduino software is the C++ language based on the Arduino Integrated Development Environment (IDE). Programming in the Arduino software for reading foot pressure is shown in Figure 7.

Figure 7. C++ Programming with Arduino Software for Reading Foot Pressure

The PLX-DAQ software is connected to Microsoft excel to record and store readings on the Arduino software. The PLX-DAQ software aims to facilitate data recording from the Arduino microcontroller. The display of the PLX-DAQ software is shown in Figure 8.

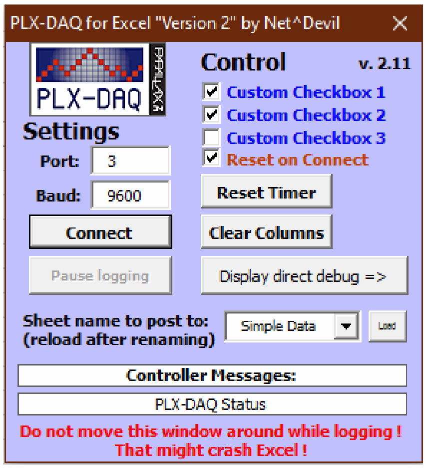

Figure 8. Display of PLX-DAQ Software

Port settings use the port connected to the Arduino UNO Microcontroller. Baud is the data transfer rate in bits per second or bits per second (bps). Filling in the baud setting according to the program in the Arduino software is 9600 bps. The connect menu starts connecting the PLX-DAQ to the Arduino UNO microcontroller device. After connecting, the connect menu automatically replaces the disconnect menu, which disconnects the PLX-DAQ and the Arduino UNO device. This study uses biomechanics to determine the effectiveness of using BW on toddlers' ability to tread on the floor using video-based biomechanics by comparing standard BW with a slider-crank and redesigning it with a thread bar. Standard and redesigned BW specifications can be shown in Table 2.

Table 2. Standard and Redesigned BW Specifications

Specification	Standard BW	Redesign BW
Wheel	6 pieces	4 pieces
Table	There is	There are not any
Seat or Harness	Made of fabric covered with foam and connected to the upper frame	Harness-type BW moonwalk, made of fabric that can be removed and attached to the frame and equipped with a buckle
Product Dimensions	L-50 x W-53 x H-50 cm	L-67 x W-65 x H-90 cm
Feature	Slider-crank	Thread Bar
Picture		

Sock specifications for the placement of the FSR-402 sensor. The socks used to measure the pressure of the soles of the feet are prewalker baby socks. The specifications for prewalker baby socks are described in Table 3.

Table 3. Specifications for Prewalker Socks

Material	Flexible rubber
Feature	Breathable, Prominent, Anti-slip, Warm, Durable, Following the shape of a toddler's foot
Size	Size 11 (insole 11 cm, maximum foot size 11 cm) Size 12 (insole 12 cm, maximum foot size 12 cm) Size 13 (insole 13 cm, maximum foot size 13 cm)
Color	Yellow, Pink, Grey, White, and Blue
Picture	

Statistical data testing used the paired sample t-test to find differences in measuring body biomechanics parameters, including testing the compression force of the feet and pressure when toddlers used standard and redesigned BW. The Shapiro-Wilks test initially tested the normality of all biomechanical parameters ($p > 0.05$). Differences using standard and redesigned BW with a p-value of 0.0001 ($p < 0.05$) using paired sample t-tests include thigh and shank segment forces, thigh and shank segment moments, foot compression forces, and foot pressure.

3. RESULT AND DISCUSSION

Result

BW should provide pre-ambulatory toddler postural support and opportunities to experience bipedal motion. BW functions to simulate independent walking by encouraging and even accelerating the initial acquisition of this skill. BW devices provide toddlers with entertainment during use, allowing parents and toddlers a level of previously unavailable independence. BW designs vary; most have a perineal seat or strap suspended from a rigid or folding frame. Several wheels or casters support the frame. Some designs provide a small table surface for food and toys. The standard BW design is designed for toddlers nesting into a compact form in the frame. BW should have a height adjustment mechanism between the upper and lower frame rings to control the length of the toddler's body according to his age so that BW can provide stimulation for learning to walk. The standard BW available on the market generally has a slider-crank facility to adjust the toddler's body length height. The slider-crank mechanism is a four-bar mechanism with several custom-made configurations by making one or more links of unlimited length. Meanwhile, BW redesigned it with moonwalk model harnesses to help toddlers develop coordination, balance, and motor skills. Redesigned BW with a thread bar component to adjust the height suitability of the toddler's body length has the facility of a threaded rod, referred to as a pole, which is a rod of varying lengths woven in a helical structure. The threaded rod combines linear and rotational motion to create strong resistance to pressure. The advantages and disadvantages of the standard and the redesigned BW for the toddler's body length can be explained in Table 4.

Table 4. The Advantages and Disadvantages of the BW Standard and the Redesign

Type	Standard BW	Redesign BW
Picture		
Advantages	Dimensions BWs against circumference body toddler have suitability	Harnesses on BW is a standing model
Deficiency	Harnesses on BW model seat or multi harness	Dimensions BWs against circumference body toddler to a width

The advantage of the BW standard is that the dimensions of the baby walker are compatible with the length and circumference of the toddler's body. Disadvantages BW standard has a model seat or multi-harness harness so that toddlers sit more and their feet do not plant properly. The advantage of the BW redesign is that it has a harness model stand so toddlers can stand straight and their feet tread correctly. BW redesign has a drawback where the BW dimension to the toddler's body circumference is too broad. The advantages and disadvantages between the standard BW and the redesign are evidenced by the toddler's foot pressure results in Figure 9. The use of standard BW by toddlers where the sole pressure is above the average is subject 2 and subject 5. Subjects with foot pressure below the average are subject 1, subject 3, subject 4, subject 6, subject 7, subject 8, and subject 9. All subjects in the redesigned BW had foot pressure above the average, including subject 1, subject 2, subject 3, subject 4, subject 5, subject 6, subject 7, subject 8, and subject 9. Measurements differed in the pressure on the soles of toddlers' feet when using standard and redesigned BW. That means the testing results on toddler foot pressure using the standard BW are smaller than the redesigned BW.

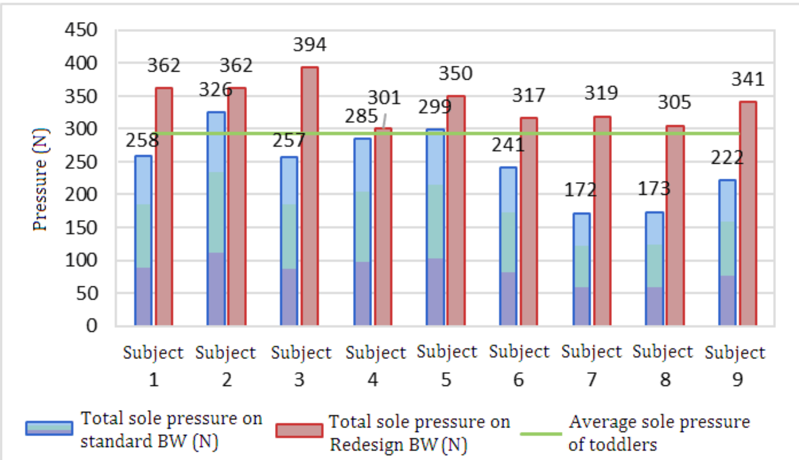

Figure 9. Under-five-foot pressure between standard and redesigned BW

Comparison of the results of biomechanics testing of toddler body segments between standard and redesigned BW conducted on nine toddlers aged 9-15 months with a body length of 70-78 cm. Video capture was conducted during testing using a Kinect sensor connected to Microsoft visual studio and Vitruvius software. Before testing, ensure that the Kinect sensor and supporting software have been calibrated by comparing the results of angle measurements using the Kinect sensor and angle level. This calibration ensures that the resulting angle is accurate and per the specifications of the Kinect sensor manufacturer. Observation video was taken at a distance of 150 mm between toddlers and the Kinect sensor. The results of measuring the biomechanics of the toddler's body on the compression force of the foot when the toddler used the standard and redesigned BW can be explained in Table 5 and Figure 10.

Table 5. Biomechanical Testing of Toddler's Foot Compression Force (N) when Using Standard BW and Redesigned

Subject	Heel-strike		Midstances		Toe-off	
	Standard BW	Redesign BW	Standard BW	Redesign BW	Standard BW	Redesign BW
Subject 1	-251.25	-483.55	-288.85	-512.75	-199.40	-378.15
Subject 2	-206.14	-401.00	-263.10	-421.38	-183.59	-329.55
Subject 3	-224.24	-484.53	-298.48	-516.45	-199.43	-401.45
Subject 4	-190.84	-428.79	-241.21	-424.59	-147.47	-360.64
Subject 5	-204.26	-440.74	-255.59	-432.09	-173.97	-353.94
Subject 6	-188.39	-402.21	-259.43	-427.52	-181.09	-340.76
Subject 7	-258.56	-472.26	-282.23	-462.24	-180.62	-412.74
Subject 8	-189.90	-423.06	-250.44	-450.75	-155.80	-330.20
Subject 9	-257.20	-492.76	-318.43	-515.69	-216.12	-440.46

*negative values are due to the downward direction of the force

The biomechanics of a toddler's body on the compression force of the foot when using BW is the result of the heel-strike, midstance, and toe-off phases. Heel-strike phase, foot compression force (largest and smallest) when using standard BW (258.56 N in subject 7 and 189.90 N in subject 8); redesigned BW (492.76 N in subject 9 and 401.00 N in subject 2). Midstance phase, foot compression force when using standard BW (318.43 N in subject 9 and 241.21 N in subject 4); redesigned BW (516.45 N in subject 3 and 421.38 N in subject 2). Toe-off phase, foot compression force is when using standard BW (216.12 N in subject 9 and 147.47 N in subject 4); redesigned BW (440.46 N in subject 9 and 329.55 N in subject 2). The redesigned BW shows that the compression force of a toddler's foot makes it possible to support the learning to walk and train the muscles of the lower extremities. The soles of the toddler's feet can touch directly with the floor surface to increase the toddler's interest in being able to walk immediately. This stimulation method can improve gross motor development in learning to walk. Selection of an effective BW is needed to stimulate gross motor development in training the lower extremity muscles to become stronger and support body weight. This tool is considered a safe walking aid but continues to guard and supervise toddlers so that injuries do not occur. Biomechanical results show that the foot compression force when toddlers use standard BW averages 218.98 N in the heel-strike phase, 273.08 N in the midstance phase, and 181.94 N toe-off phase. Toddlers using the redesigned BW have an average heel-strike phase of 447.66 N, a midstance phase of 462.61 N, and a toe-off phase of 371.99 N. The standard BW foot compression force is smaller than the BW redesign; low forces and moments on the shank and sole segments are possible that the BW redesign provides walking stimulation for toddlers with greater leg compression force. Biomechanical measurements of toddler foot pressure readings from the FSR-402 sensor were compared between standard and redesigned BW. The FSR sensor placement point installed on the prewalker sock is divided into 5 points on the sole surface: the toe, first metatarsal, fifth metatarsal, cuboid, and heel. Biomechanics testing on nine toddlers had a foot length of 10-12 cm. The results of toddler foot pressure when using standard and redesigned BW can be shown in Figure 11.

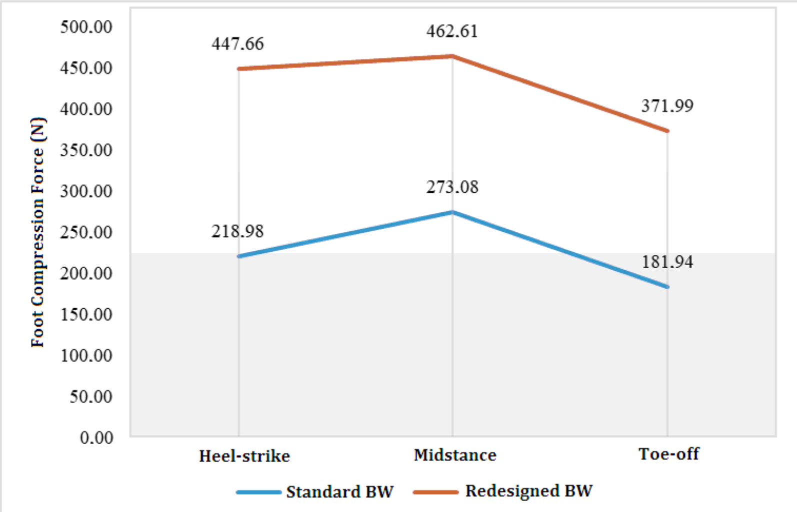

Figure 10. Average Foot Compression Force when Using Standard and Redesigned BW

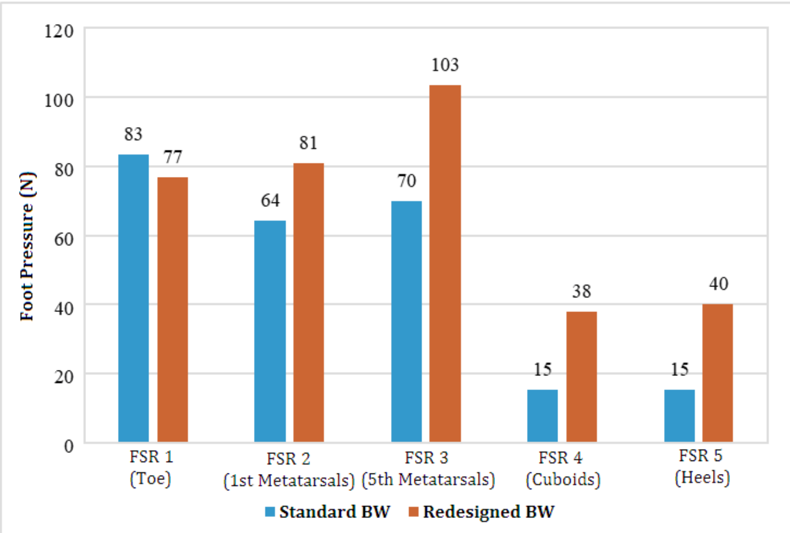

Figure 11. Average Sole Pressure of Toddlers at each Measurement Point between Standard and Redesigned BW

The total pressure on the soles of toddlers' feet when using standard BW was 248 N, and redesigned BW was 339 N. Meanwhile, the average toddler foot pressure was measured using FRS-402 when toddlers used standard and redesigned BW where the point FSR 1 was in the toe area (83 N and 77 N), FSR 2 point in the first metatarsal area (64 N and 81 N), FSR 3 point in the fifth metatarsal area (70 N and 103 N), FSR 4 point in the cuboid area (15 N and 38 N), and the FSR5 point in the heel area (15 N and 40 N). Foot pressure from biomechanics testing on redesigned BW is higher than standard BW. There may be differences in product dimensions that cause toddlers' feet not to touch the floor properly. When using the standard BW, where the pressure on the soles of the toddler's feet is lower, it is shown in the toe, first metatarsal, and fifth metatarsal areas, meaning that the position of the toddler's feet using BW is on tiptoe. The pressure on the soles of the toddler's feet when using the redesigned BW is more significant and evenly distributed in all areas of the measurement point; the soles of the toddler's feet can touch the floor surface properly. That means redesigned BW is better as a device for stimulating learning to walk in toddlers, indicated by more significant pressure on the soles of the feet. The use of a BW did not change the gait gain. Development of gait in toddlers using standard and redesigned BW at around six weeks, although it does not confirm the clinical assumption that use of BW delays the acquisition of independent gait parameters, nor does it support the belief of parents who expect that use of these devices can accelerate the emergence and development of gait (Chagas et al., 2020; Cranage et al., 2021; Price et al., 2018). In this study, gait testing where toddlers wear pre-walk socks had minimal impact on spatiotemporal gait parameters. When wearing pre-walk socks feel soft, and toddlers walk as if they were not wearing footwear. Small kinematic changes are identified when toddlers walk in pre-walk socks, especially in the knees and soles of the feet. The kinematic changes when toddlers walk on bare feet, however small, may be intrinsically related. The results of the comparative analysis between standard and redesigned BW were processed statistically by paired samples t-test, comparing the dependent groups in which the variables had a normal distribution. The accepted critical significance level is α = 0.05. The associated null hypothesis is rejected when the p-value is less than 0.05. The results of the paired samples t-test on standard and redesigned BW are shown in Table 6.

Table 6. Paired Samples t-test Results on Standard and Redesigned BW on Foot Compression Force and Foot Pressure

Parameter	Standard BW (Mean ± SD)	Redesigned BW (Mean ± SD)	*t-value*	*p-value*	Conclusion
Forces					
Shank segment	104.44 ± 7.73	124.55 ± 8.62	-57.237	0.0001	Significant Difference
Foot segment	105.55 ± 7.92	125.66 ± 8.80	-57.237	0.0001	Significant Difference
Shank Moments					
Heel-strike	-10.48 ± 3.10	-20.65 ± 3.56	21.043	0.0001	Significant Difference
Midstance	-1.31 ± 2.67	-19.93 ± 2.91	17.434	0.0001	Significant Difference
Toe-off	3.93 ± 2.67	-13.42 ± 2.32	19.766	0.0001	Significant Difference
Foot Moments					
Heel-strike	1.361 ± 2.08	-6.58 ± 2.29	16.824	0.0001	Significant Difference
Midstance	10.538 ± 2.97	-5.873 ± 1.62	15.569	0.0001	Significant Difference
Toe-off	15.768 ± 2.84	0.641 ± 1.80	17.426	0.0001	Significant Difference
Foot Compression Forces					
Heel-strike	-218.98 ± 29.69	-447.66 ± 36.3	36.569	0.0001	Significant Difference
Midstance	-273.08 ± 25.38	-462.61 ± 41.4	25.749	0.0001	Significant Difference
Toe-off	-181.94 ± 21.56	-371.99 ± 39.1	19.323	0.0001	Significant Difference
Foot pressure	248.16 ± 52.82	338.95 ± 31.20	-5.675	0.0001	Significant Difference

The first study compares the gait parameters of pre-walk and lower extremity sock walking in toddlers. Spatiotemporal gait sizes in toddlers are slightly different from one toddler to another. Although the results showed a difference in walking gait parameters between the use of BW, the walking speed of toddlers in this experiment was ignored. However, toddler walking in pre-walk socks does not reduce the range of motion of the knee's frontal shoulder and sagittal plane and increases the eversion of the hind leg. Given that there are differences in use between standard and redesigned BW, statistically, there appear to be generally slight experimental differences in variability between experimental conditions, and the clinical importance of these findings may be uncertain.

Discussion

The advantage of the standard BW is that the product dimensions match the toddler's body circumference. Standard BW facilities have an adjustable cushion seat height that is more comfortable, and this causes toddlers to sit more, and their feet rarely touch the floor. Biomechanical measurements of BW in toddlers do not change gait acquisition but instead emphasize how to provide active walking stimulation. The use of the two BW tools explains that gait development in several studies approaches around 12 months, as expected by parents for toddlers where leg motor muscles continue to develop according to age (Kepenek-Varol et al., 2020; LeBarton & Iverson, 2016). Another possible cause is that toddlers aged nine months cannot stand and balance their bodies; the maximum standard BW height is 50 cm, causing a discrepancy in the seat height between the soles of the feet and the toddler's waist, where toddlers in this study are generally shorter. The advantage of the redesigned BW is that it has a stand-type moonwalk harness. Even though toddlers look shorter when using standard BW, when using redesigned BW, they can stand upright, and the soles of their feet can touch the floor when walking. Allows redesigned BW to provide better stimulation of learning to walk in toddlers. Clinical assumptions recognize that the gait pattern of walking using BW is known based on the pressure of the toddler's feet, which leads to a shift in the body's center of gravity, causing wrong foot contact on the floor (Schopf & Santos, 2015; Sharov et al., 2018). The results of this study do not confirm the clinical assumption that the use of BW delays the acquisition of independent gait in toddlers, nor does it support the belief that the use of this device can accelerate the emergence and development of gait (Adolph & Franchak, 2017; Grivna et al., 2015). The biomechanical alignment of the lower limbs and the toddler's body is altered, allowing for increased stimulation of learning to walk.

The foot compression force from toddler biomechanics during the standard BW test is smaller than the redesigned BW. That means using redesigned BW is better for supporting stimulation in toddlers learning to walk. Thus, the results of this study are not corroborated by previously published research, that the use of BW is still believed to contribute to learning to walk in toddlers and provide autonomy (Chagas et al., 2020; Janusz et al., 2023). After the acquisition of the biomechanics phase in toddlers includes heel-strike, midstance, and toe-off phases, defined as toddlers' ability to do three phases of steps with BW support, emphasizing that BW has been used by the public in more significant numbers than shown in research, despite conflicting recommendations of toddler and child health experts, it is estimated that 60-90% of children between six and fifteen months use it (Schopf & Santos, 2015; Sharov et al., 2018). Toddler motor development is a process that changes following different phases of instability and stability. This development is influenced by motor and sensory experiences and increases in the neural complexity and biomechanical points of toddlers to adapt to different tasks, then achieve a period of adjustment and improvement of motor skills. In order to know the pressure on the soles of toddlers' feet, where the FSR-402 sensor is connected to the Arduino UNO, the circuit is attached to prewalker socks. The FSR circuit and the Arduino UNO module are connected to the Arduino IDE software installed with the PLX-DAQ software. The Arduino UNO microcontroller controls the entire system, containing a 16-bit analog-to-digital converter (ADC) for measuring foot pressure on the pre-walk sock insole. In that order, the measured ADC values are converted to voltage, resistor, force value, and kilograms. The converted values are sent from the smart device to the laptop via Bluetooth LE. The pressure distribution on the sole of the toddler's foot to both feet was studied and recorded simultaneously. The sole pressure value is influenced by many factors, such as the anatomical structure of the foot, the separation of joint movements, and gender (Naderi et al., 2019; Taş & Çetin, 2019). However, the load on the right and left legs are similar because we record images of both feet simultaneously while walking and pushing BW. This study found no significant difference between the BMI values of boys and girls who were almost the same age. This study also found no significant difference or correlation between toddler height and weight and the average FSR value for all areas on both boys' and girls' feet soles. It can be considered in interpreting the results of this study against some limitations during the experiment. Time duration improves when toddlers walk by pushing their weight, even though it changes several gait parameters, including stride length, foot distance, and foot placement (Chagas et al., 2020; Cranage et al., 2021; Price et al., 2018). The use of soft pre-walk socks had minimal effect on toddler joint kinematics and spatiotemporal gait measures. Even though the time of the experiment cannot control this parameter, the effect of time during the experiment is minimized by grouping the data. Future studies with attention to standardization of toddler arm testing protocols encourage BW. Experimental time grouping is to align toddlers' habit of using pre-walk socks.

4. CONCLUSION

The comparing the use of BW in toddlers against biomechanical parameters regarding gait compression force and foot pressure, there is a significant difference with the use of BW redesign, where the soles of toddlers' feet can rest on the floor surface better than standard BW, allowing it to provide toddler walking stimulation to support motor development foot. When toddlers encourage BW to walk, it starts with holding their body weight and maintaining balance so that they focus on moving. More significant toddler foot pressure indicates a toddler walking on tiptoe. However, the magnitude of the foot pressure effect is relatively small, so the clinical significance of this finding is uncertain. Despite its drawbacks, BW is used by many families, not limited to the economic strata.

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