# Assessing the Balance of an Adult Idiopathic Toe Walker and the Effect of Adding Custom Heel Wedges: Case Report

Submitted by

Olivia Racette

Bioengineering

To

The Honors College

Oakland University

In partial fulfillment of the

requirement to graduate from

The Honors College

Mentor: Tamara Treanore, Director and Instructor of Orthotist and Prosthetist Assistant Studies

Department of Health Sciences

Oakland University

April 7, 2023

## Abstract

Idiopathic toe walkers present with a distinctly different walking pattern that, over a long period of time, can alter the development of the calf muscles and Achilles tendon, as well as decrease the stability one has while standing. While research has been performed on how to prevent toe walking, the focus has been on the pediatric population, who are more responsive to treatments, rather than adults whose bodies have adapted to an abnormal way of walking. This study reveals the benefits of creating custom heel wedges for an adult toe walker. The balance of the subject was first assessed using the BTrackS Balance Plate. Then, custom heel wedges were fabricated and the subject's balance was reevaluated while wearing the heel wedges. The results illustrated an improvement in balance after using the heel wedges, because the subject has more plantigrade support when standing. Due to the successful results, this study offers an alternative solution for toe walkers who cannot or do not want to receive other types of treatment, and potentially decrease the numerous types of injuries they endure due to their lack of stability.

## Introduction

Toe walking is defined as when an individual walks on their toes or the ball of their foot without ground contact from the heel or midfoot. While toe walking can be common in children as they are learning to walk, a child is diagnosed as an idiopathic toe walker (ITW) if they continue to toe walk beyond three years of age. When examining a toe walker's gait, or style of walking, the absence of heel contact, known as heel strike, is clearly noticeable as the heel never touches the ground [1]. Toe walkers typically present with decreased balance and coordination, and over time, additional issues may arise, including a limited range of motion in the ankle, and shortening of the calf muscle or Achilles tendon. A toe walker can also experience back pain from increased lumbar lordosis, or inward curvature of the spine in the lower back, as well as knee pain from greater pressure being put on the front of the knee joint [2]. Several treatment methods exist to stretch the calf muscles and/or Achilles tendon and hopefully put an end to toe walking, but with mixed results. Some of these treatments include physical therapy, orthotics, serial casting, a Botulinum Toxin A injection into the gastrocnemius and soleus muscles, and surgery [3].

This study aims to create a custom heel wedge that will increase the balance of a toe walker due to creating full foot contact of the subject. This will be measured using the BTrackS Balance System that will assess balance before and after using the heel wedge. As a result of better foot contact, this will lead to more plantigrade stability in a toe walker, and could decrease pain from no longer placing the weight load on the ball of the foot. While treatments intended to block toe walking have proven to help in some cases, these treatments are meant for younger children and are significantly less successful. Heel wedges are a noninvasive solution that can instantaneously help the patient by providing balance without inducing pain.

One study treated ITW patients with rigid lower leg orthoses that prevented the patient from plantar flexing and saw an improvement in all patients' gait patterns after one year. At that point, 64% of the patients had discontinued toe walking and 23% of the patients were toe walking half the time or less [4]. However, this study included patients with ages ranging from 2.5 to 13.1 years old. With adult patients, their calf muscles and Achilles tendon are already tight from years of toe walking, and wearing an orthosis to address these established restrictions, would require a high level of time commitment as well as preparation for a successful outcome. A case study was conducted on a 28 year old male toe walker who was diagnosed as an adult idiopathic toe walker. Botulinum toxin-A was injected into his gastrocnemius muscles and he went through 10 days of intense gait training and rehabilitation. At the end of therapy, the patient displayed the ability to heel strike, as well as an increased ankle dorsiflexion range of motion. While the treatment worked for this patient, it was only a case study, and patients undergoing this treatment would need to be willing to get the injection and undergo a rigorous therapy for the treatment to work [5].

A study published in 2022 compared two ITW treatments for children: carbon fiber solid ankle-foot orthoses (AFOs) and serial casting. Although serial casting, or putting a new cast on a patient over a period of several weeks to lengthen a muscle, has proven its effectiveness in increasing dorsiflexion range of motion, it is not optimal for all patients due to the time commitment and the interference with daily activities. The study revealed that using the carbon-fiber AFOs produced a similar effect as serial casting, making it a suitable replacement [6]. However, as this study was only tested on children under nine years old, it likely does not pose a solution for older ITW patients who may not be able to tolerate the orthoses or commit to the lifestyle restrictions and time commitments.

## Materials


**Figure 1.** The Balance Tracking System is composed of a balance plate that connects to a computer via a USB cord. The computer runs the BTrackS software to perform the balance tests.

The testing was conducted with the Balance Tracking System (BTrackS), depicted in Figure 1, which is a portable force plate that measures the center of pressure and postural sway, or movement of the center of mass, of an individual while they are standing. The BTrackS is an FDA class 1 registered device that consists of a 14.5-pound portable force plate (BTrackS™ Balance Plate) and the software package called BTrackS Assess Balance [7]. The board has a USB cord to connect to the computer that runs the software. Once a patient profile is entered in the software, different balance tests can be used depending on the study.

The heel wedges were made with a polyethylene foam called Plastazote®, a P-Cell® EVA foam middle layer, and a cork middle layer and base. Plastazote® is heat moldable so it can provide a close, custom fit to the subject's heels. Along with P-Cell® EVA foam, Plastazote® is easy to clean and disinfect, due to being a closed cell foam, which is essential for a material that will be confined in a shoe [8]. Cork is well known for its antimicrobial properties against bacteria such as *E. coli*, which will prevent the wedge from becoming contaminated by sweat or other substances [9]. In addition, cork has many other positive characteristics, such as being shock absorptive, odor resistant, durable, and grindable, so it can be easily modified while withstanding everyday wear [10]. Together, these materials will create durable, shock absorbing, and supportive heel wedges that will widen the subject's base of support.

## Methods

First, measurements at the ankle and foot were taken. The first measurement was the ankle joint range of motion. The range of dorsiflexion and plantar flexion, or flexion and extension at the ankle, was measured, along with calcaneal inversion and eversion, which is when the sole of the foot tilts toward and away from the midline, respectively [11]. This helped determine the subject's limitations as well as how the subject typically stands. Based on the data, appropriate cushioning was provided in areas with higher pressure. Since the subject is a toe walker, they presented with plantar flexion, calcaneal inversion, and supination, meaning that the highest pressure is on the lateral borders and the balls of the feet [12]. The subtalar joint neutral position of the hindfoot was also measured, which contributed in establishing the correct hindfoot alignment for the heel wedge.

Afterwards, a subjective assessment was performed to discover a relative ideal height for the heel wedge. A ⅛ inch layer of firm foam will be placed under the subject's heels and layers were continually added to create a makeshift wedge until the subject feels the most steady and comfortable. The height of the layers was measured to provide the finished height of the heel wedge.

The next task was to create Harris Mat impressions, which consist of an ink infused screen suspended over a paper. The subject was directed to stand normally on the Harris mat. This created a plantar pressure distribution map of the contact areas of the foot, which determined the parts of the feet that require support to increase the weight-bearing surface area. The ink impression on the paper have areas of light and dark shades of ink, with the darker spots indicating a higher amount of pressure in that area of the foot.

Lastly, a series of tests were conducted on the subject using the BTrackS. The first test was the Weight Distribution Test, where the subject's standing posture was assessed. The subject stood still and their center of mass location was calculated. The Balance and Fall Risk Test was completed next. The subject was directed to stand on the BTrackS balance board with a relaxed stance, hands on their hips, and with their feet shoulder width apart. Once they were situated, the subject was told to stand as still as possible for twenty seconds. A trial run was done, followed by two actual runs. Based on the path length, or how much the subject moved, they were placed in a percentile according to their age and sex that displays the risk they have of falling. Then, the modified Clinical Test of Sensory Interaction on Balance (mCTSIB) was performed. This assessment consisted of four rounds, with the subject positioned as described in the Balance and Fall Risk Test. In the first round, the subject stood still for thirty seconds with their eyes open. The second round was the same but with their eyes closed. For the third round, a foam pad was placed on the balance board. The subject stood for thirty seconds with their eyes opened and then for the fourth round, with their eyes closed. The BTrackS system analyzed the movement of the center of balance, then displayed the percentile the subject was in based on their path length in each round. The final test to perform was the Single Leg Stance Test, where the subject was told to stand as still as possible again, but on one leg at a time, with the other leg bent holding the foot at least six inches off the ground.

After collecting and recording the data, the heel wedges were fabricated. When the heel wedges were complete, the subject used them to perform the four BTrackS balance tests again. The new results were compared to the original results to see if the balance improved, and if so, by how much. The expected result was that the subject's balance improved while using the heel wedge. This was proven if the subject's percentile for the BTrackS tests increases from the original tests. The subject has a larger base of support as they have increased plantigrade contact with the ground.

**Safety/ ISO Standards**

The project contained low-level safety risks. The subject in this study agreed to participate and were aware they can decide if they no longer want to be involved. There was no major risk of harm to the subject since there was little movement involved in the testing of the heel raises. When taking the measurements, the subject had the choice to stop at any time if they felt any sort of discomfort or pain. The Harris Mat impressions posed minimal risk of falling because the impressions were captured while the subject walked as they typically would. The subject had the highest potential for falling during the test that requires standing on foam and the single-leg standing balance test. To alleviate the possibility of falling with the use of the BTrackS, there were two people who stood close to the subject throughout the entire testing phase to ensure that they did not lose their balance and fall.

Before collecting data from the subject, the International Organization for Standardization (ISO) standards were studied to establish proper handling of personal identifying data. By referencing these standards, it was ensured that the data taken before and after the implementation of the heel wedges was managed professionally and appropriately. The first standard referenced was ISO 20691, which describes the biotechnology requirements for data formatting and description in the life sciences. This standard was developed for the biotechnology, diagnostic, and pharmaceutical industries because they rely on data obtained from a wide range of functional and biological studies, assays, field measurements, and process descriptions. Data from these life science fields must be accessible, interpretable, and reusable [13]. The standard states that data is only useful if it is accessible and stored in well-structured, consistent formats. It also discusses data sets, which was important for this study as it involves data from two rounds of four different tests with the BTrackS. It is critical to note how and where the resulting data is stored to portray an accurate representation of the heel wedges' effectiveness. The standard also acknowledges long-term data storage, which was not as critical for this study as it is taking place over a single semester. However, it is important that this data is not lost because it could be valuable for future research projects.

Another relevant standard is ISO 27799, which was developed for hospitals and other facilities that regularly collect patient information. It includes many different types of health information that need to be protected, such as personal health information (PHI), statistics and research data, and information related to public health surveillance. The standard mandates that all healthcare organizations have strict controls in place to protect the health information entrusted to them, which is fulfilled by maintaining the best-established privacy and security practices in health informatics while using technology in a secure and well-managed manner [14]. Although this project handled the data of a single patient, it was of utmost importance that the data was kept safe and that the identity of the individual was not compromised.

To keep patient information secure, HIPAA laws have been developed to be used in healthcare settings. The Health Insurance Portability and Accountability Act of 1996 (HIPAA) is a federal law that ensures the privacy and protection of a patient's sensitive health information. This decreases the risk of abuse of PHI and fraud. The patient also has more control over their PHI and the ability to decide who or where the information gets sent to [15]. The subject's PHI was protected by not using identifying names or descriptions when saving data on any device for measurements or BTrackS testing. To protect the privacy and prevent disclosure of the subject's identity while performing tests, they were conducted in a closed lab without video cameras, and paper was put over the windows located on the door of the testing room.

**Troubleshooting**

If the initial design of the heel wedges did not yield the hypothesized results, it could result in the subject's balance ability remaining the same or even declining. This could have been corrected by altering the design of the heel rise. The subject's balance would likely not improve if the heel wedges did not provide enough height to increase the weight-bearing surface area. This would be easily resolved by laminating additional layers of cork to the bottom of the heel wedges with rubber cement. The heel wedges would then be sanded to have smooth edges as layers are added. The heel wedges would continue to have layers added until the optimal height is found. If the addition caused the heel raise to be too tall and the numbers got worse, the extra layer of the heel raise could be removed with no destruction to the heel wedges, due to the properties of rubber cement. Conversely, if the heel wedges were too tall, they could have led to discomfort and caused the subject to put further pressure on their forefoot. This would be resolved by grinding material from the bottom of the heel raise to adjust the height.

## Results

A visual analysis of the subject standing was performed first. It was noted that the subject significantly leaned forward while standing, as seen in Figure 2. The red dashed line indicates the approximate mid-coronal plane, or where the subject would be divided into equal anterior and posterior halves, if they had a completely straight posture while the solid yellow line is the subject's actual mid-coronal plane. As shown, almost the entire body is anterior to the red line.

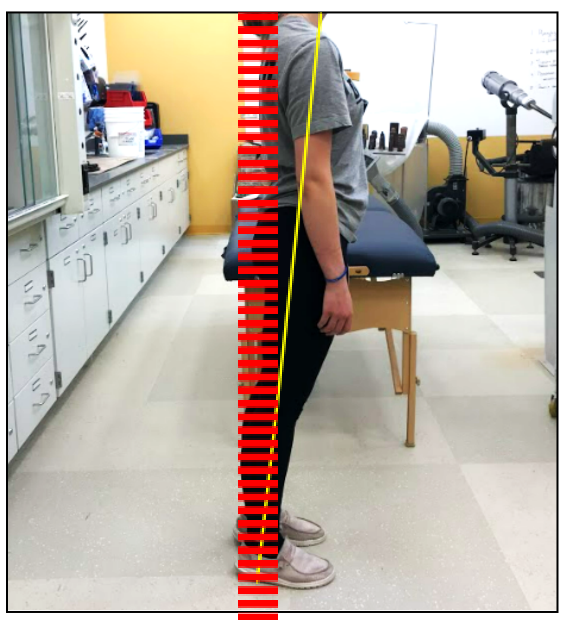

**Figure 2.** The subject's posture while standing reveals a considerable forward lean.


(a) (b)

**Figure 3.** (a) A lateral view of the subject shows the body weight entirely placed on the forefeet with no heel contact. (b) A posterior view of the subject that illustrates the subject's supination.

Examining the feet from the side illustrated the characteristics of a toe walker. As depicted in Figure 3(a), the subject places the body weight on the forefeet and a visible gap is evident between the heels and the ground. The subject has a tendency to supinate, shown in the right foot in Figure 3(b), however the left foot presents with calcaneal eversion, commonly associated with pronation, but this is likely due to compensating for balance. The subject confirmed that they felt more comfortable in supination and resting their body weight on the lateral borders of their feet.

The range of motion of the subject's ankle joints were measured using manual manipulation and a goniometer. The left foot presented with a range of motion of 30 degrees of calcaneal inversion, 4 degrees of calcaneal eversion, and 15 degrees of dorsiflexion. The right foot had 28 degrees of calcaneal inversion, 6 degrees of calcaneal eversion, and 15 degrees of dorsiflexion. Using these measurements, the subtalar neutral angle was calculated using Equation [1]. For both the left and right foot, the result was 11.3 degrees of inversion from maximum eversion.

$$Subtalar\ Neutral\ Position\ = \frac{Inversion\ Range\ of\ Motion + Eversion\ Range\ of\ Motion}{3} \qquad (1)$$

**Figure 4.** Custom heel wedges fabricated for the subject. The wedges are composed of four layers of shock absorbing and antibacterial materials designed to support the subject's heels.

The subjective height test was then conducted. The subject felt most comfortable with a heel height of 1 inch under both feet. The heel wedges, displayed in Figure 4, were later fabricated with the proper height and angulation. The bottom of the wedges was a ⅜ inch layer of cork. The next layer was a ¼ inch of P-Cell® EVA, followed by a ¼ inch layer of cork. The top layer was composed of a ⅛ inch of Plastazote® foam. These four layers were cut to the appropriate size, glued together, and then skived to the appropriate angulation of the foot.

**Figure 5**. The subject's Harris Mat impressions while standing show that contact is not being placed on the heels. The ink impressions clearly define the forefeet as the only part of the foot in contact with the ground.

The Harris Mat impressions were obtained with the subject when standing. As depicted in Figure 5, the greatest pressure was seen to be on the forefoot and lateral borders of the foot as expected. A visual examination of the subject's feet shows callusing at the first and fifth metatarsal heads, as well as the halluxes, or big toes. This corresponds to the Harris Mat impressions, as the darkest regions are in those areas, revealing those spots to have the greatest pressure while the subject is standing. The Harris Mat impressions also reveal no heel contact, shown by the lack of any ink on the paper from the heel to around the arch of the foot.

The four balance tests with the BTrackS were conducted on the subject with and without the heel wedges. The subject performed both rounds wearing the same shoes, and when the subject used the heel wedges, they were inserted inside the shoes. The subject is placed into a percentile for each test according to their age and sex. The percentile rankings are computed from the BTrackS Normative Database which comprises over 20,000 results from individuals 5 years old to 100 years old.

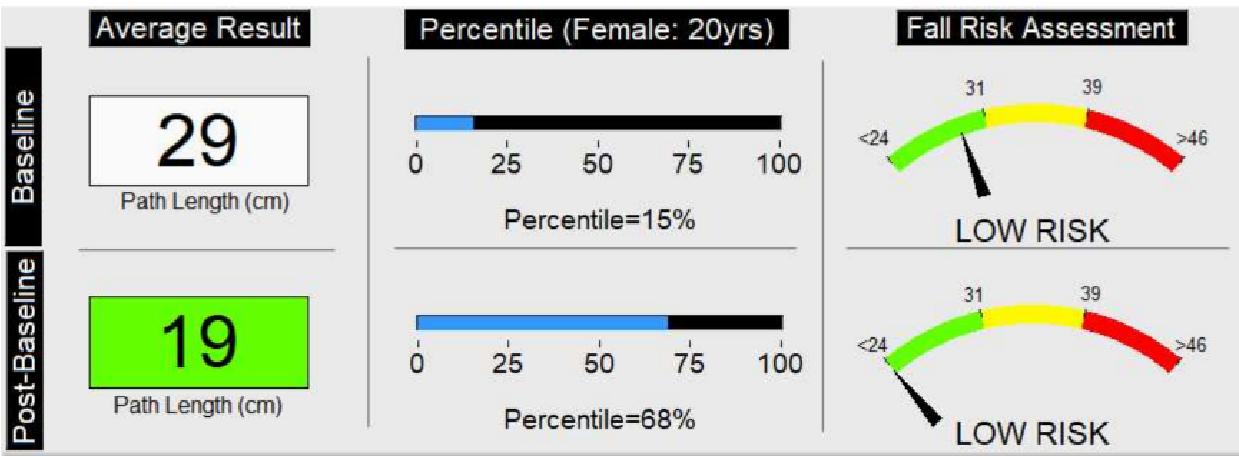


**Figure 6.** The Balance & Fall Risk Test consists of three 20-second trials where the subject stands as still as possible. The baseline represents the test without the heel wedges while the post-baseline is with the use of heel wedges.

The Balance & Fall Risk Test result, presented in Figure 6, is equal to the average Center of Pressure (COP) path length from three 20-second trials. The Fall Risk Assessment is based on the number of standard deviations the subject's results are from an average adult between 20-39 years old. The subject had an initial (baseline) result of 29 centimeters (cm), which placed them in the 15th percentile, meaning that the subject performed better than 14% of females aged 20-39 years. With the heel wedges (post-baseline), the subject's result was 19 cm, which placed them in the 68th percentile.

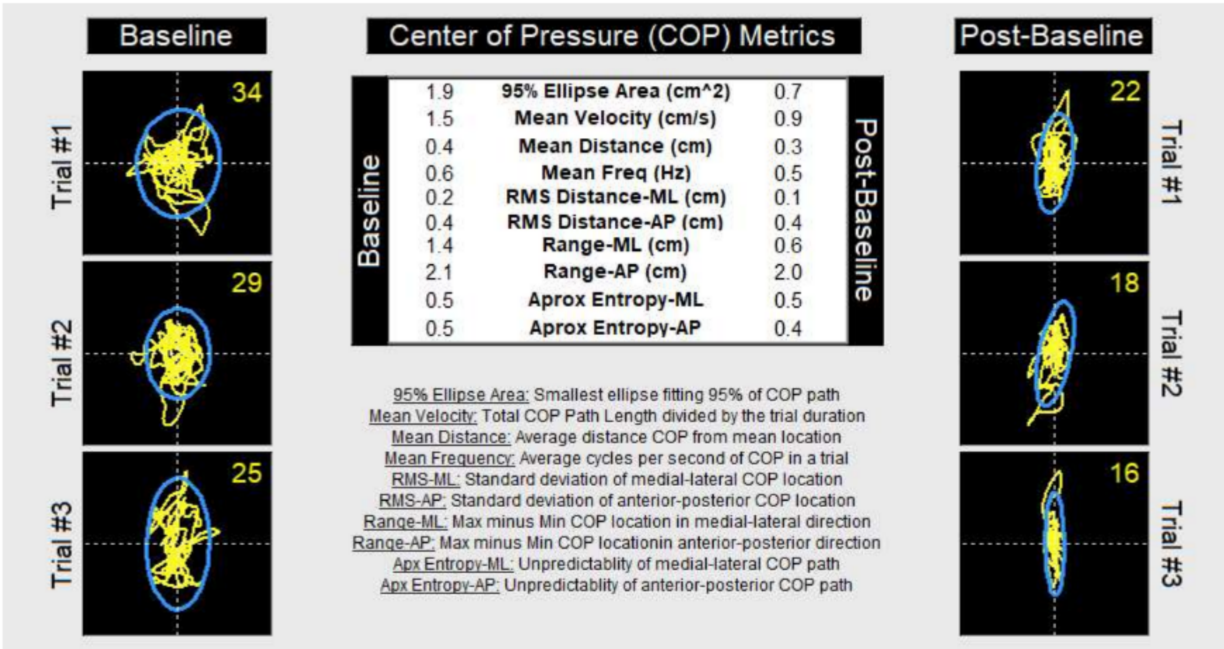


**Figure 7.** A diagram displaying the Balance & Fall Risk COP Path Length and 95% Ellipse visuals.

In addition to decreasing the COP path lengths during the Balance & Fall Risk test with the use of the heel wedges, the subject was also able to keep their COP centered within a smaller area, seen in Figure 7. The point where the two gray dotted lines intersect represents the average COP position. The yellow lines illustrate the movement of the subject's center of pressure when standing while the blue ellipses represent the smallest ellipse that fits 95% of the COP path data. The post-baseline results visibly show a decrease in ellipse size while taking a closer look at the numerical data in the table reveals that the post-baseline measurements are either the same or smaller than the baseline results. The 95% Ellipse area decreased from 1.9 $cm^2$ to 0.7 $cm^2$.

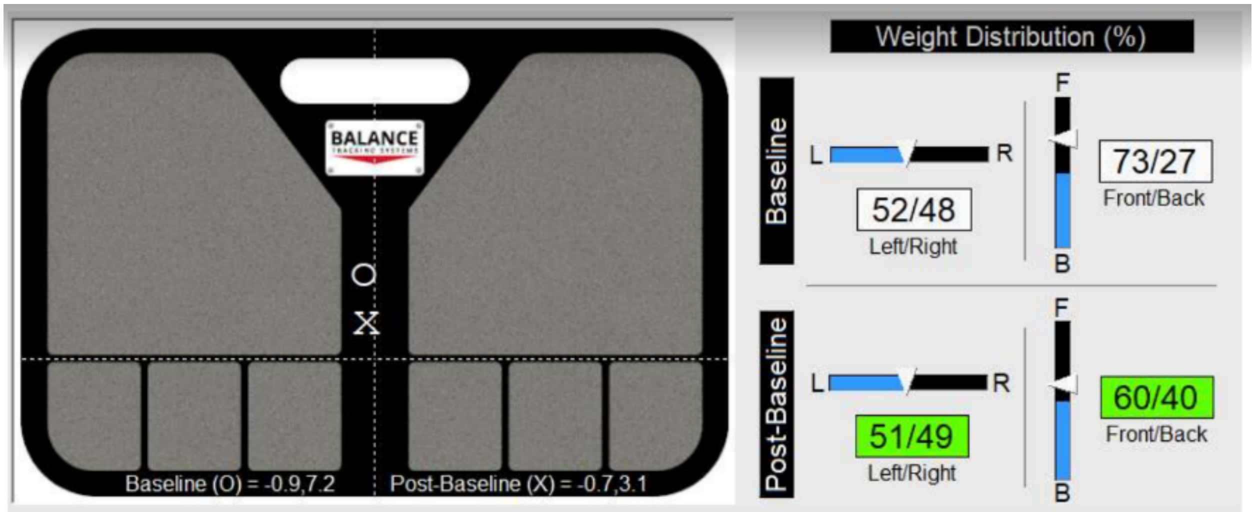


**Figure 8.** The Weight Distribution Test measured the left/right and front/back asymmetries of the subject while they stood naturally. The "O" marks the baseline test and the "X" marks the post-baseline test.

The Weight Distribution Test measured left/right and front/back asymmetries found while the subject stands with their normal posture. The percentage of weight distributed across the BTrackS balance board and the location of the center of pressure were measured. This result is compared to the optimal position midway between the malleoli. The ideal left/right distribution is 50/50 and the ideal front/back distribution is also 50/50. Without the heel wedges, the subject had a 52/48 left/right distribution and a 73/27 front/back distribution. After inserting the heel wedges, the left/right distribution was 51/49 and the front/back distribution was 60/40, shown in Figure 8.

The modified Clinical Test of Sensory Integration and Balance (mCTSIB) measured the subject's path length with their eyes open and closed while standing on the BTrackS balance board (firm), and also while standing on an uneven surface on top of the balance board (foam). Without using the heel wedges, the subject's path length with their eyes open on a firm surface was 24 cm, falling into the 9th percentile. When the subject added the heel wedges for the same test, they had a path length of 13 cm and fell into the 70th percentile. For the test with the eyes closed while on a firm surface, the subject's initial result without the heel wedges was a path length of 36 cm (9th percentile) and with the addition of the heel wedges, the subject had a path length of 15 cm (87th percentile). When the subject had their eyes open while standing on the foam, without heel wedges resulted in a path length of 28 cm (49th percentile) while with heel wedges was a path length of 32 cm (34th percentile). For eyes closed while standing on a foam, the subject had a path length of 51 cm (72nd percentile) when not wearing the heel wedges and a path length of 53 cm (68th percentile) when wearing the heel wedges. The composite baseline path length was 139 cm, while the composite post-baseline path length was 113 cm, displaying a 26 cm improvement. These results are illustrated in Figure 9.

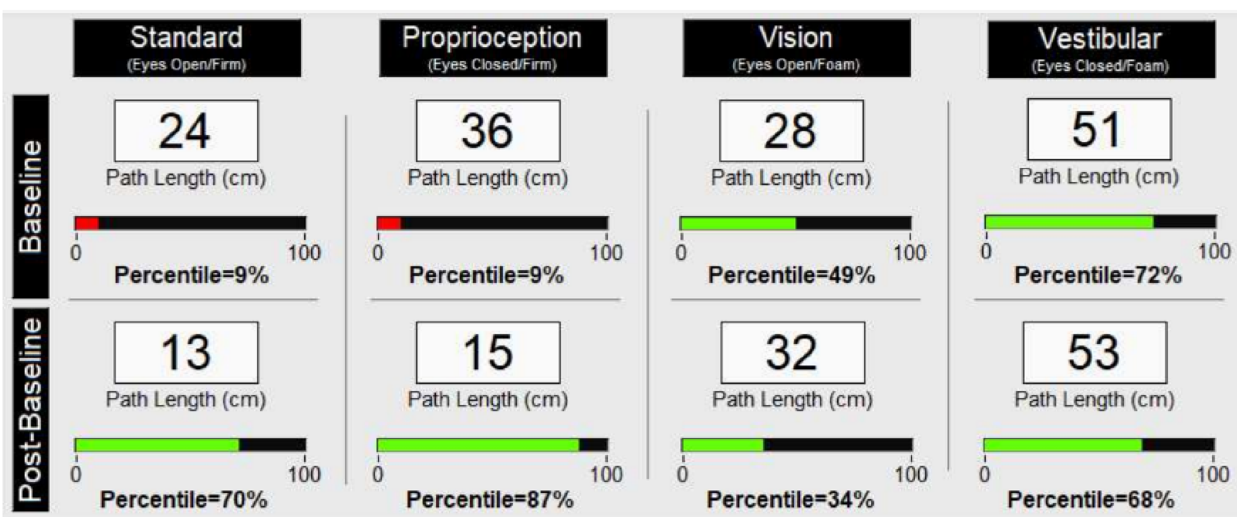


**Figure 9.** The modified Clinical Test of Sensory Integration and Balance evaluated the subject's path length in four different conditions with eyes open/closed on firm/uneven ground.

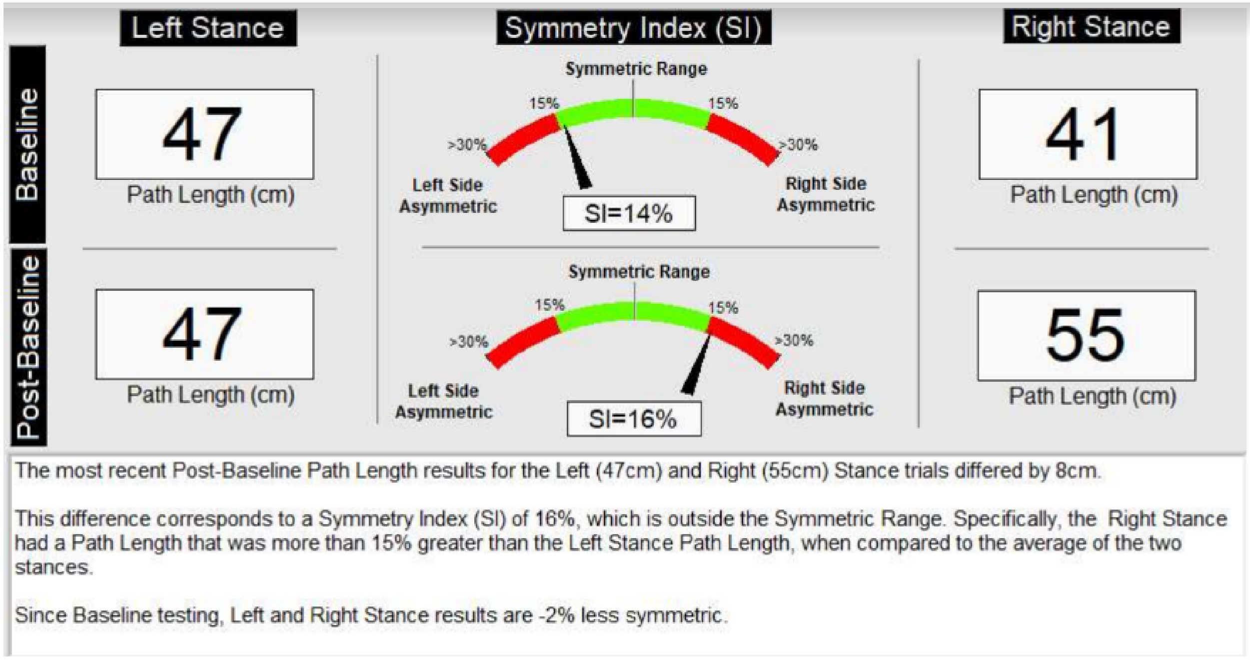


**Figure 10.** The Single Leg Stance Test results with and without the use of the heel wedges.

The Single Leg Stance Test, depicted in Figure 10, compares the postural sway generated by the subject when they stand on their left foot versus their right foot. The left versus right results are compared with a "Symmetry Index" which considers an individual to be within the Symmetry Range if the difference between the left and right stances is under 15%. Without the heel wedges, the subject's path length was 47 cm for the left foot and 41 cm for the right foot, resulting in a Symmetric Index of 14% towards the left side. With the heel wedges inserted in the shoes, the path length was 47 cm for the left foot and 55 cm for the right foot, leading to a Symmetric Index of 16% towards the right side.

## Discussion

The collective results suggest that balance is improved in an adult idiopathic toe walker when heel wedges are implemented. The Balance and Fall Risk results show that the heel wedges decreased the COP path length of the subject from 29 cm to 19 cm, marking a 34% improvement in path length. The Fall Risk Assessment percentile increased from 15% in the baseline trial to 68% in the post-baseline trial. This increase percentage in the Fall Risk Assessment represents the subject's improvement and increase in balance among people of a similar age and sex by 53%. This illustrates the substantial effect the heel wedges had on enhancing the subject's balance. While the subject was already at a low risk according to the Fall Risk Assessment, after adding the heel wedges, the subject was at an even lower risk of falling according to the scale. The COP Path Length and 95% Ellipse visuals in Figure 7 also indicated an improvement because the ellipses in the post-baseline had a decrease in mediolateral (ML) distance from 1.4 cm to 0.6 cm. This considerably less deviation from side to side denotes the subject was able to keep their center of pressure in the middle more often than without the heel wedges.

The Weight DistributionTest is designed to show the left/right and front/back asymmetries of an individual in their natural standing posture. The subject's left/right distributions before and after implementing the heel wedges were both close to the optimal 50/50 distribution, however the heel wedges marginally improved the left/right distribution, seen in Figure 8 by the "X" position being slightly closer to the center midline than the "O" position. It is also noted that the "X" is much closer to the horizontal dashed line that represents the ideal 50/50 front/back distribution. As shown in the Harris Mat impressions, idiopathic toe walkers place most of their body weight on their forefeet. The heel wedges offered the subject greater heel contact, allowing them to put more weight on the posterior aspect of their feet, and shifted the subject's weight distribution from a large forward lean to a more moderate forward lean.

The mCTSIB Test evaluates how different senses affect balance based on the center of pressure path length. The "Standard" Test was eyes open while standing on a firm surface, which allowed the subject to use all their senses to stand as still as possible. The baseline results showed a decrease in path length from 24 cm to 13 cm, which was a 61% increase in percentile ranking. The "Proprioception" Test forces the subject to rely on their body's ability to sense movement, as they cannot have their eyes open. The subject presented with a path length decrease from 36 cm to 15 cm for standing eyes closed, displaying a 78% percentile ranking jump. These results demonstrate how the heel wedges helped the subject have better balance while standing and also improved their proprioception. The "Vision" Test causes the subject to use their sense of sight to stand as still as possible, because the subject is on an uneven surface and must rely on looking at their surroundings to stay balanced and still, while the "Vestibular" Test makes the subject use their inner ear for balance since they can no longer see or use proprioception. The baseline results for both those tests placed the subject in a significantly higher percentile than the baseline tests standing on a firm surface. This could be due to the subject placing their body weight on their forefeet, which then sink into the foam, allowing the foam to be displaced and rise underneath the heels, offering some plantigrade support. In a way, the foam block serves as unintentional wedges that give the subject's heels contact with the ground. The increase in path length for the post-baseline tests could be due to the combination of the foam and heel raise overcompensating and raising the subject's heels higher than comfortable, making the subject slightly more unstable.

The Single Leg Stance Test results show the subject's right foot versus left foot balance. These results suggest that the subject has little to no change in the postural sway from the baseline to the post-baseline. The baseline result for the left stance was 47 cm, and the post-baseline was also 47 cm. However, the right stance increased from 41 cm baseline to 55 cm post-baseline. This could possibly be because the heel wedges were initially designed to be used together and testing the subject's balance on one foot after introducing a heel wedge might not be an accurate assessment of the effects of heel wedges on balance. The results could also indicate that the height of the wedge was not optimal for the right foot, although further analysis would be required.

## Conclusion

Adult idiopathic toe walkers are particularly difficult to treat because of how long they have lived with their condition. Children who toe walk have a higher rate of success when undergoing surgery, therapy, or fittings for a custom brace. This is due to having more flexible calf muscles and Achilles tendons at a young age, whereas when time goes by, the calf muscles and Achilles tendon begin to tighten and they become less susceptible to treatment. Currently, there is no notable treatment for curing an adult toe walker, which is what stimulated this research project.

The study investigated the impact of heel wedges while standing. As seen from the results, the subject displayed a significant improvement with the addition of heel wedges in several of the BTrackS balance tests, especially the mCTSIB Test with a 61% percentile improvement with eyes open on firm ground and a 78% percentile improvement with eyes closed on firm ground. The wedges also assisted in decreasing the amount the subject was leaning forward, and brought the center of mass closer to the optimum area. The results show that the heel wedges offer more plantigrade contact which increases the base of support and therefore more stability while standing.

Due to this study being a case report, the next step would be to collect results from a large group of adult toe walkers to validate the current results. The heel wedges would be customized for each individual based on their foot size and the heel lift height that feels the most comfortable without increasing instability, and each subject would be assessed with the same BTrackS balance tests. The degree of improvement for the tests will be noted and averaged among the participants to find the overall results, which are predicted to show an increase in stability for the Balance & Fall Risk Test, Weight Distribution Test, and mCTSIB Test.

Further research conducted in this area could examine how the heel wedges improve ambulation and performing other activities. While the heel wedges were comfortable when the subject was standing, research would need to be performed to study if the wedges can withstand daily wear and tear of users taking the shoes on and off, as well as moving around in the shoes when wearing them. Additionally, while cork is known for its shock absorbing properties, another study could look at how patients feel when wearing the wedges and if they need more or less cushioning beneath their heel. If these heel wedges were to be used by toe walkers during daily activities, they could decrease ankle and hindfoot instability and associated injuries such as lateral ankle sprains that result from the decrease in the base of support seen with smaller forefoot contact.

If the above research continues to indicate the successful impact of heel wedges for ITW, the heel wedges could be further customized and modified to accommodate sports such as running, skating, or skiing, which require a solid balance. The heel wedges offer an alternative solution that is not as invasive as surgery and injections, and not as time consuming as long term rehabilitation.

## Bibliography

[1] R. O'Sullivan, K. Munir, and L. Keating, "Idiopathic toe walking—a follow-up survey of gait analysis assessment," *Gait & Posture*, vol. 68, pp. 300–304, Feb. 2019. doi: 10.1016/j.gaitpost.2018.12.011.

[2] K. Radtke, N. Karch, F. Goede, B. Vaske, G. von Lewinski, Y. Noll, and A. Thren, "Outcomes of noninvasively treated idiopathic toe walkers," *Foot & Ankle Specialist*, vol. 12, no. 1, pp. 54–61, Feb. 2018. doi: 10.1177/1938640018766609.

[3] K. Davies, A. Black, M. Hunt, and L. Holsti, "Long-term gait outcomes following conservative management of idiopathic toe walking," *Gait & Posture*, vol. 62, pp. 214–219, May 2018. doi: 10.1016/j.gaitpost.2018.02.014.

[4] N. Berger, M. Bauer, A. Hapfelmeier, M. Salzmann, and P. M. Prodinger, "Orthotic treatment of idiopathic toe walking with a lower leg orthosis with circular subtalar blocking," *BMC Musculoskeletal Disorders*, vol. 22, no. 1, Jun. 2021. doi: 10.1186/s12891-021-04327-0.

[5] S. Kibar, F. Yavuz, and B. Balaban, "An accelerated multi-modality rehabilitation protocol combined with botulinum toxin-a injection in adult idiopathic toe walking: Case report," *Journal of Clinical and Diagnostic Research*, vol. 10, no. 6, Jun. 2016. doi: 10.7860/JCDR/2016/19595.7946.

[6] N. A. Hoffman, J. R. Dallum, S. Hinshon, and M. D. Finch, "Carbon fiber two-pull solid ankle-foot orthoses versus serial casting in the treatment of idiopathic toe walking with ankle equinus contracture," *Journal of Prosthetics and Orthotics*, vol. 34, no. 3, pp. 140–151, Jul. 2022. doi: 10.1097/JPO.0000000000000365.

[7] "BTrackS™ Balance Plate," *BTrackS – Affordable Force Plate Balance Systems*, 2023. [Online]. Available: https://balancetrackingsystems.com/balance-plate. [Accessed: 02-Apr-2023].

[8] "Plastazote Foam: What is it and why should you use it?," PottertonPacs, 21-Sep-2022. [Online]. Available: https://pottertonpacs.co.uk/resource-hub/industrial-engineering/plastazote-foam-what-is-it-and-why-should-you-use-it/. [Accessed: 12-Feb-2023].

[9] F. Gonçalves, P. Correia, S. P. Silva, and C. Almeida-Aguiar, "Evaluation of antimicrobial properties of cork," *FEMS Microbiology Letters*, vol. 363, no. 3, 2015. doi: 10.1093/femsle/fnv23.

[10] E. Weinberg, "Why cork insoles?," *Urstil*, 11-Nov-2019. [Online]. Available: https://urstil.com/why-cork-insoles/. [Accessed: 12-Feb-2023].

[11] LibreTexts, "9.9D: Muscles that Cause Movement at the Ankle." 17-Jan-2023.

[12] I. Ghanem, A. Massaad, A. Assi, M. Rizkallah, A. J. Bizdikian, R. El Abiad, R. Seringe, V. Mosca, and P. Wicart, "Understanding the foot's functional anatomy in physiological and pathological conditions: The Calcaneopedal Unit Concept," Journal of Children's Orthopaedics, vol. 13, no. 2, pp. 134–146, Apr. 2019. doi: 10.1302/1863-2548.13.180022.

[13] Online Browsing Platform , "ISO 20691:2022(en) Biotechnology — Requirements for data formatting and description in the life sciences," 2022. [Online]. Available: https://www.iso.org/obp/ui/#!iso:std:63598:en. [Accessed: 02-Apr-2023].

[14] Online Browsing Platform , “ISO 27799:2016(en) Health informatics — Information security management in health using ISO/IEC 27002,” 2022. [Online] Available: https://sii.isolutions.iso.org/obp/ui#!iso:std:iso:27799:ed-2:v1:en. [Accessed: 02-Apr-2023].

[15] “Health Insurance Portability and Accountability Act of 1996 (HIPAA),” *Centers for Disease Control and Prevention*, 27-Jun-2022. [Online]. Available: https://www.cdc.gov/phlp/publications/topic/hipaa.html. [Accessed: 02-Apr-2023].