An Investigation into the Effect of Weight on Angle and Base of Gait

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Abstract:

The aim of this study was to evaluate changes in angle and base of gait when a person carries weight. This was undertaken using a sample of 15 participants. Wearing their own footwear, participants walked across a surface dusted with talcum powder and onto a long length of black paper to record their angle and base of gait. Participants did this several times, carrying a variety of weights up15 kg. The results indicated that when participants carried a 15 kg weight to the front of their body, the base of gait increased, and the left (nondominant) foot abducted more than the right. When they carried a 15-kg weight to the left side of the body, the base of gait decreased, and the left(nondominant) foot abducted excessively and the right foot marginally.

Introduction

Forensic gait analysis is a developing domain and is being used successfully with increasing frequency [1]. [Author-Please provide at least one or two additional references that support this statement.] There is a need for research to improve the understanding of the effects of variables on human gait given that the recognition and comparison of repeatable and exclusive features is important in forensic gait analysis. Payton and Bartlett [2] explained there are two ways to analyse human gait: (1) quantitative analysis through a cross-sectional study or (2) by comparative or repetitive trial and qualitative analysis, through providing a description of the features of gait.

Eckel et al. [3] conducted a study to investigate the effects of increased body weight on gait. They did not consider angle and base of gait as two of their parameters. They found that an increase in weight increased sagittal plane kinetics and spatial temporal mechanics. Singh and Koh [4] studied how backpacks of 10%, 15%, and 20% of bodyweight affect the gait of children. This study found that the increases in load destabilized the body during gait, leading to a reduction in velocity, a reduction incadence, an increase in double support time, and an increase in forward lean. Hong and Breuggemann [5] also investigated the effect of backpacks on gait in children in a similar experiment. However, they looked at slightly different parts of the gait cycle. They identified that there was no change to gait until the backpack was at least 10% of the child's body weight. They found that there was an increase in double support time, trunk lean, and stance phase. There was a reduction in swing phase and angle of the trunk. However, this study was carried out on a treadmill, which has been proven to affect gait [6–9]. One study that investigated the effect of carrying weight on the gait of soldiers was carried out by Attwells et al. [10] Weights of 8 kg, 16 kg, 40 kg, and 50 kg were used and worn on the backs.

They identified that weight did cause change in the form of increased internal and external rotation of the femur at the knee and increased forward trunk lean. The findings of this study are supported by a study by Martin and Nelson [11]. They investigated the effect of weight on human gait and identified that an increase in load would cause an increase in stride rate and double support time, and a reduction in swing time and stride length. They discovered that there are marked differences in the way that men and women walk when weight is applied. The study showed that there was an increase in double support time and decrease in stride length when weight was applied, which was more noticeable in females than in males. This was not a surprise to the researchers, because, although the weights used for both sexes were the same, the anatomical differences between the two sexes lead to different gait characteristics; their study just served to confirm this. Women were affected to a greater degree than males were by the increase in load. Fischer et al. [12] published a study investigating how bodyweight unloading affected gait. They concluded that an unloading of 30% of a participant's bodyweight resulted in a significant reduction in the use the tibialis anterior, lateral gastrocnemius, vastus lateralis, and rectus femoris. It might be assumed that an increase in bodyweight should be accompanied by an increase in the use of these muscles. During gait, the rectus femoris muscle is responsible for hip flexion and knee extension, and the vastus lateralis muscle is responsible for knee extension and stabilization. The gastrocnemius muscle is an ankle joint plantar flexor, and the tibialis anterior muscle provides dorsiflexion and inversion [13]. If these muscles are put under increased strain, then there should be an increase in these movements during gait that could possibly lead to changes in the parameters under investigation. What these studies do not take into consideration is that of muscle tone and ability to carry these weights. A body builder, for example, would find it a lot easier to manage a 15-kg weight than would a smaller person with less muscle bulk. This could be an interesting area for future study.

These findings were further reinforced in another study by Fischer et al. [14] They found that by unloading the body, there was a significant reduction in the range of motion at the hips, knees, and ankles. It might be assumed that an increase in bodyweight would lead to an increase in the ranges of motion for these areas. Using 50 Gujjar participants, Krishan [15] investigated differences in footprints (e.g., length and breadth of the big toe pads, heel breadth, and tarsal length) when they held 5 kg weights and when they held 20 kg weights. Although Krishan did not investigate angle of gait or base of gait, the parameters he used did not show any significant changes at 5 kg, but at 20 kg, the results were deemed to be statistically significant. At 20 kg, the length and breadth of a footprint were deemed to have increased. Qu and Nussbaum [16] investigated the effects of weight increases of 10% and 20% of bodyweight on a group of 12 children. They concluded that externally applied loads create mechanical changes within the body and destabilize the body. Lee et al. [17] investigated changes to angular positioning of knees, hips, and ankles when carrying hidden loads. They were able to conclude that these hidden loads did indeed cause changes to gait patterns. Gilette et al. [18] investigated changes to lower limb kinematics, such as ankle, hip, and knee ranges of motion and joint angles, using 0%, 10%, and 20% bodyweight loading. The researchers noted significant increases at the 20% level and indicated that age may have an impact on the results that were obtained.

The above studies investigated aspects of human gait but did not consider what effect weight has on angle and base of gait. Having considered the above, it is apparent that there is a requirement to investigate the effect of weight on angle and base of gait. This type of study would be useful in forensic gait analysis because perpetrators of crime often carry heavy objects. Our research specifically sought to determine the effect of weight on angle and base of gait when a person carries weight either to the left-hand side or to the front of the body.

Ethical approval for the study was obtained from the Ethics Committee of the Faculty of Health and Society at the University of Northampton United Kingdom.

Method

Fifteen participants (3 males and 12 females, ranging in age from 21 to 46) were recruited from the student population of a university in the United Kingdom. Participants were fully informed of the study by one of the authors, and each participant gave his or her consent to participate in the study.

To be included in the study, the participant must:

• have no neurological conditions (e.g., multiple sclerosis or spina bifida), • have no lower limb pathologies (e.g., a corn or callus),

• be right-handed, and

• be able to lift a weight of at least 15 kg with his or her arms.

Each participant was asked to walk for five minutes to become accustomed to the walking surface, which was a flat, nonslip floor in the gait analysis lab of the University of Northampton Podiatry Department, using footwear worn by the participant on a regular basis. Once five minutes had elapsed, each participant was asked to walk across talcum powder and onto a sheet of black paper, initially carrying no weights and then with different weights up to a maximum of 15 kg (because of the U.K. based Health and Safety Executive guidelines). This provided a record of each participant's angle and base of gait. Figure 1 shows how this was accomplished.

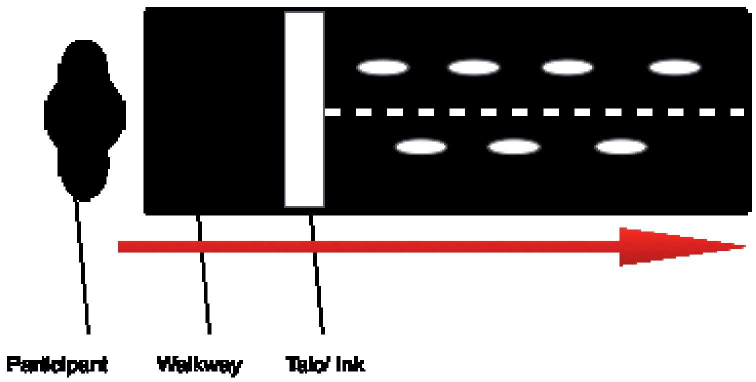


Figure 1 Top down view of experiment set-up.

Participants were asked to make one baseline pass, not carrying anything, followed by carrying aplastic crate to their front, with increasing weights of 5 kg, up to the safe maximum load of 15 kg identified earlier or until they did not feel that they could safely carry the load specified. The crate measured 28 cm wide, 35 cm long, and 8 cm deep and weighed 100 g. Participants were then asked to carry a bag to the left-hand side of their body with increasing weights of 5 kg, up to the safe maximum loads identified earlier or until they did not feel they could safely manage the load. A new walkway of plain black paper was laid down for each pass. If a participant was observed to have modified his other gait to “hit the target” of walking onto the paper, the pass would be discounted, and the participant would be asked to carry out another pass, until a pass was completed where the participant did not modify his or her gait. The bag that was used was a standard backpack with two adjustable straps for wearing over the shoulders, plus a handle on top for carrying to the side. The bag had a maximum capacity of up to 20 kg of weight. The weights that were used were 5 kg proof load test weights, which offered a good balance of accuracy and value for money [19]. The weights came with calibration certificates and were small enough so that three of these could be used to make up a 15 kg load in a backpack.

Once all the data were collected from the participants, the angle and base of gait needed to be measured for each set of shoeprints. The base of gait was determined by bisecting the heel area of two successive steps on an ipsilateral line of progression. This was achieved by marking the outline of the footsteps and then marking the midpoints of the heels. Because a fixed point on each foot was used (the midpoint of sole of each shoe), the method was reliable and repeatable. The midpoint of the heel was identified from the shoeprint. The talc shoeprint was traced around to give an outline of the impression.

This was then bisected from the midpoint of the forefoot to the midpoint of the rear foot (Figure 2). The identified midpoint of the rear foot was then used. The distance between the two bisections (measured with a recalibrated rule) was the base of gait [20, 21]. Three pairs of shoeprints per pass were used to reduce the chance of using an anomalous pair of shoeprints (e.g., if a participant scuffed the floor, slid, or tried to “hit the target”). The angle of gait was measured, using Dougan’s method, from the midline of the shoeprint in relation to the direction of travel [22, 23]. This method was chosen because it is the most established method and has been subjected to the greatest amount of repeatability and reliability testing [24–26]. The measurements were taken with a calibrated goniometer (Figure 3). The data was then analysed in SPSS version 22 to generate box and whisker plots.

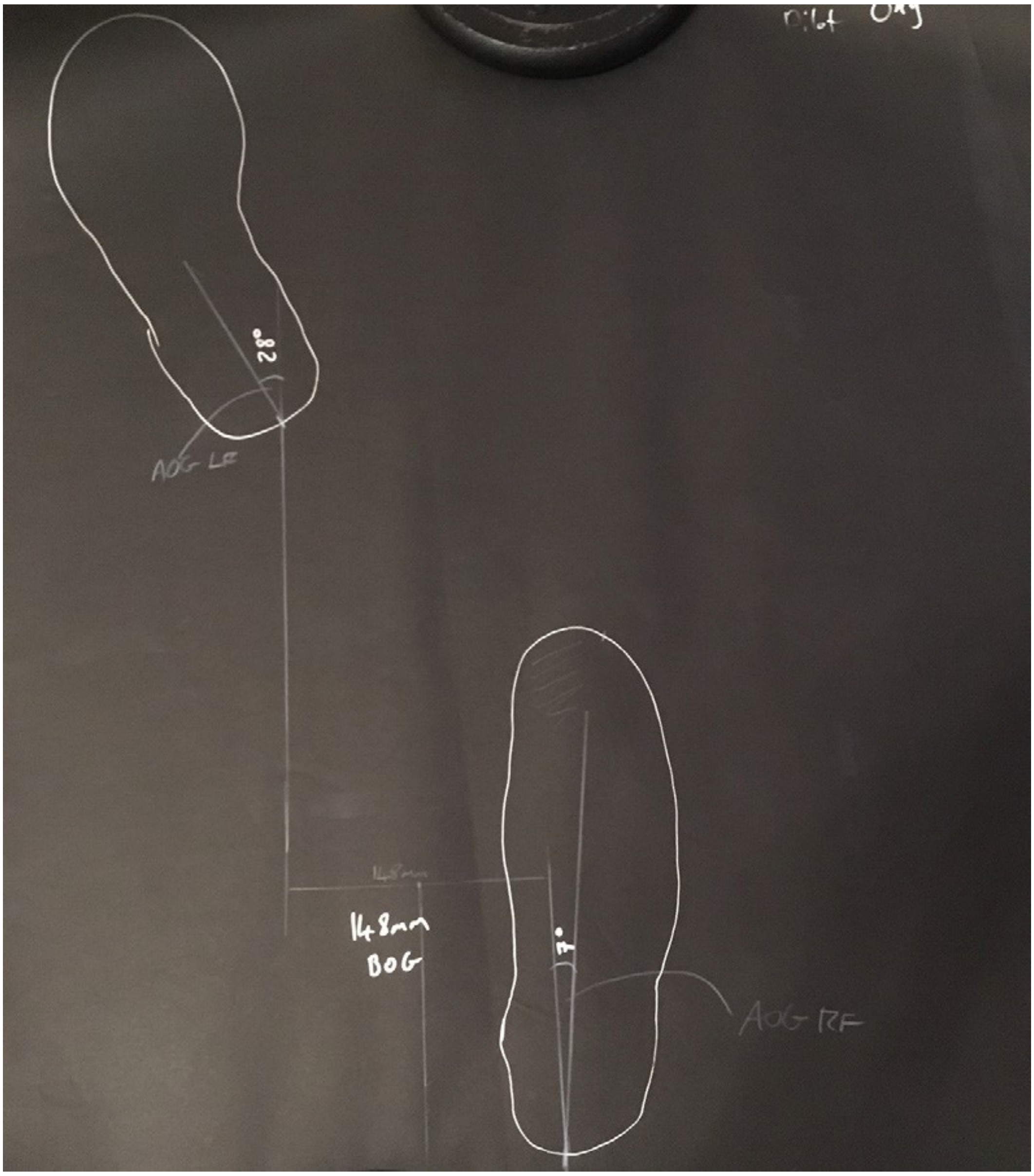


Figure 2 examples of measurements

Figure 3 Example of calibrated goniometer.

Results

Tests Involving Carrying the Weight to the Front of the Body

Graph 1 shows that, as weight was applied, the base of gait increased. There was very little difference in the base of gait between the 5 kg and 10 kg weight, but there was another marked increase at the 15-kg weight.

Graph 2 shows that there was an increase in the angle of gait of the right foot. This occurred between 0 kg and 10 kg, then between 10 kg and 15 kg, the angle decreased slightly.

Graph 3 shows the angle of gait for the left foot angle gradually increased as weight was increased.

The results show that when carrying weight to the front, there was a linear increase in the combined angle of gait as weight was increased. When carrying weight to the front, at 0 kg, the mean base of gait was 103 mm and the left and right feet were abducted by an equal amount for both sexes. When a weight of 5 kg was applied, there was a small increase in the mean base of gait of 3.88% (4 mm) and a slight increase in the mean abduction of the feet as the angle of gait increased slightly for both feet, more for the right foot than for the left. The right foot increased by 33.3% (2 degrees), whereas the left increased 16.7% (1 degree). For both left and right feet, this gave a combined mean increase of 33.3% (3 degrees). When the weight was increased to 10 kg, there appeared to be very little change to the mean base of gait; it increased 0.93% (1 mm). The mean angle of gait did increase further, and it was greater in the right foot than in the left foot. The right foot increased another 25% (2 degrees) and the left foot another14.3% (1 degree). For both left and right feet, this gave a combined mean increase of 12.5% (3degrees). When the 15-kg load was applied, this appeared to have a large effect on the results and mean base of gait increase. According to the raw data, the mean base of gait increased by 13 mm, which was an increase of 13%. There was an overall combined increase in the mean angle of gait for both feet, on average 16.7% (3 degrees). However, angle of gait for the right feet reduced between 10kg and 15 kg, a mean reduction of 10% (1 degree), but it was still more abducted than it was at 0 kg.

The left foot abducted. The left foot abduction had a mean increase of 20% (2 degrees). In summary, from 0 kg to 15 kg, the mean base of gait increased 12.6% (13 mm). The mean abduction of the right foot increased 50% (3 degrees), the mean left foot abduction increased 100% (6 degrees), and the overall combined mean angle of gait increased by 75% (9 degrees). Although the study focuses on mean values, there is a wide range of variance. Base of gait, for example, had anything from a reduction of 17.4% to an increase of 27.3%. Right foot angle of gait had a range of changes from zero up to125%. Left foot angle of gait had a range of increases from 14% to 175%. The combined angle of gait had increases from 7% to 138%.

Tests Involving Carrying the Weight to the Left Side of the Body

Graph 4 shows how the base of gait reduced as soon as weight was applied to the participant and then steadily increased as the weight increased.

Graph 5 shows that the angle of gait remained relatively constant at 0 kg and 5 kg. At 10 kg and then at 15 kg, the angle of gait for the right foot increased.

Graph 6 shows the angle of gait for the left foot increased between 0 kg and 5 kg before reducing between 5 kg and 10 kg. It then increased again between 10 kg and 15 kg.

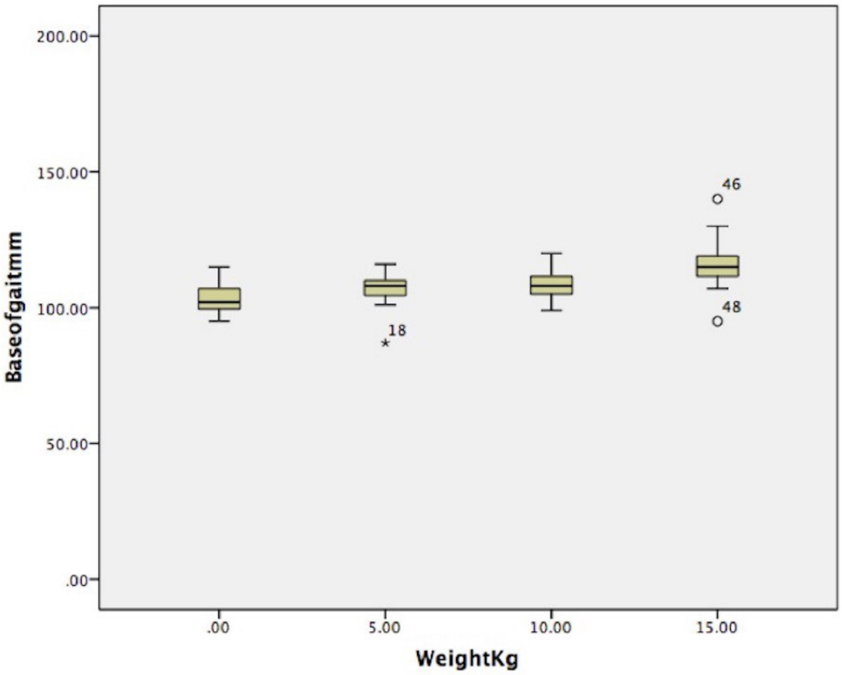
Graph 7 shows that overall, the angle of gait showed an increase between 0 kg and 5 kg. A decrease occurred between 5 kg and 10 kg, with another increase between 10 kg and 15 kg.

When carrying weight to the left-hand side of the body, at 0 kg, there was an average base of gait of103 mm, and the left and right feet were equally abducted. When a load of 5 kg was applied, the base of gait reduced, and the angle of gait increased. The average base of gait decreased by 28.2% (29mm). There was no change to the angle of gait of the right foot, but abduction of the left foot increased by 83.3% (5 degrees).

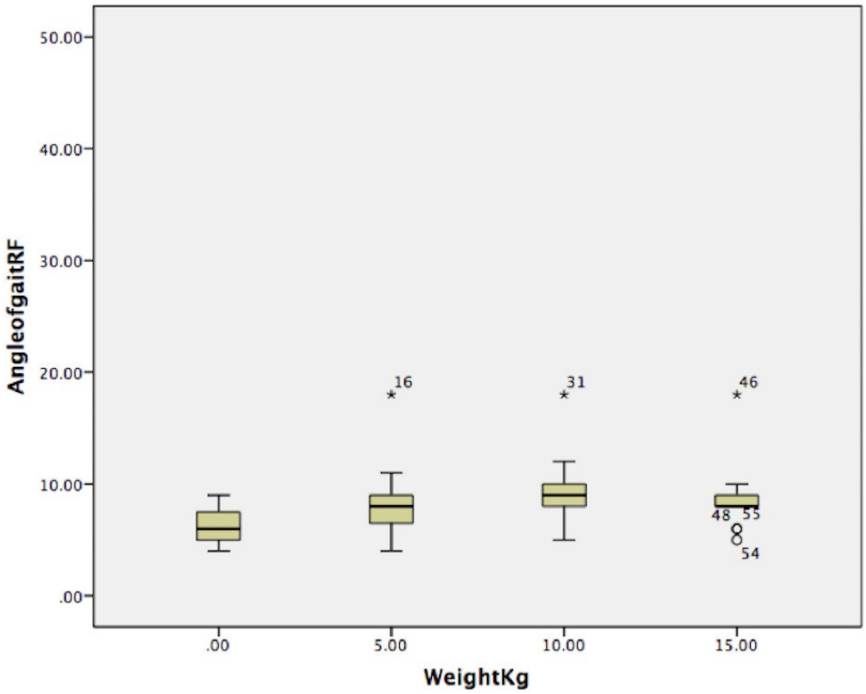
Discussion

Normal podiatric biomechanics looks at the closed kinetic chain from the foot up. Pronation at the subtalar joint cause’s internal rotation of the tibia and femur, which in turn causes external rotation of the hip. If the weight is being carried above the hip (so the force is going through the arm, to the spine, hip, femur, tibia, and subtalar joint), then it could be suggested that the weight carried is causing external rotation of the hip, causing the foot to abduct.

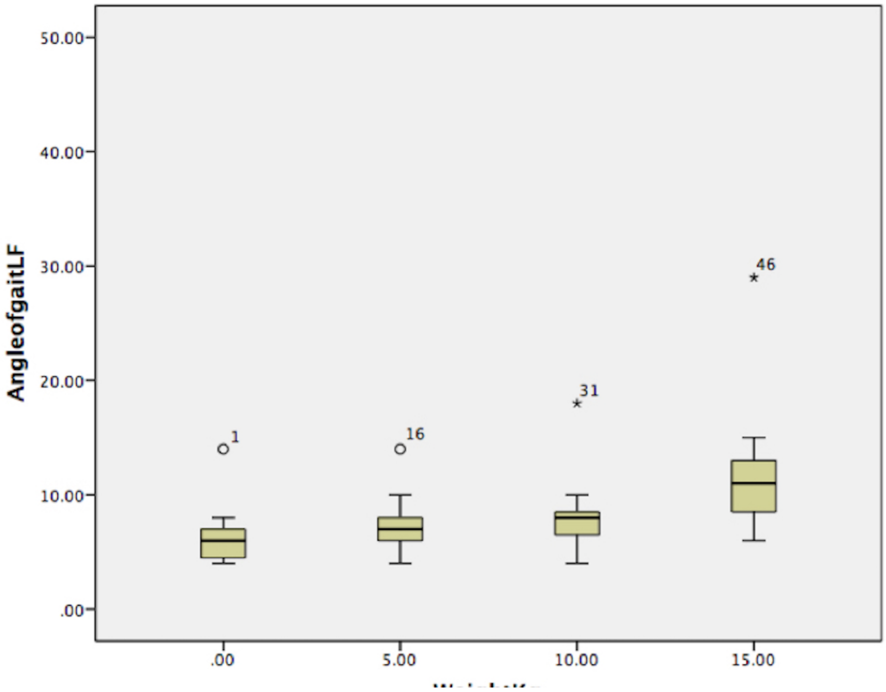
Graph 1



Graph 1 Base of gait (mm) against weight carried, carrying weight to the front.

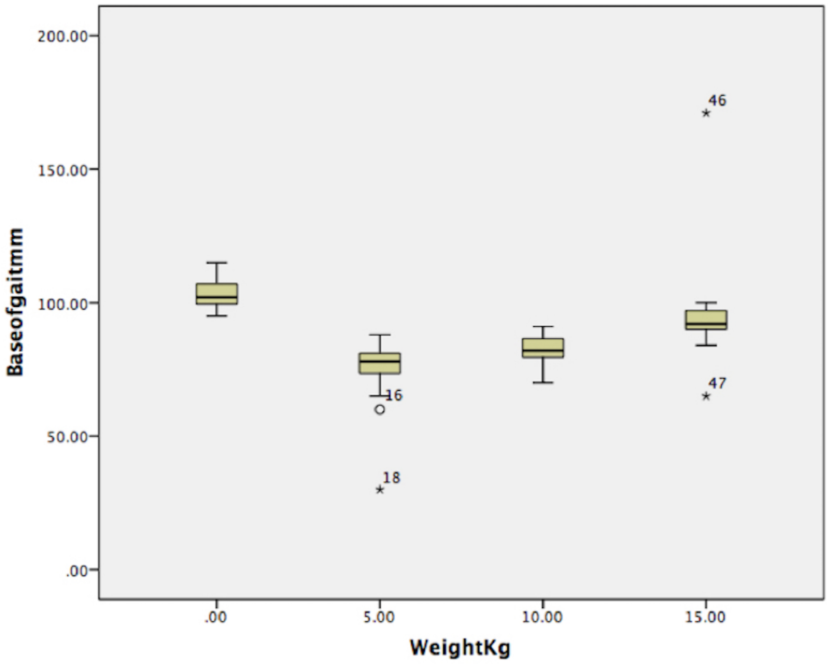


Graph 2 Angle of gait of right foot (degrees) against weight carried, carrying weight to the front.



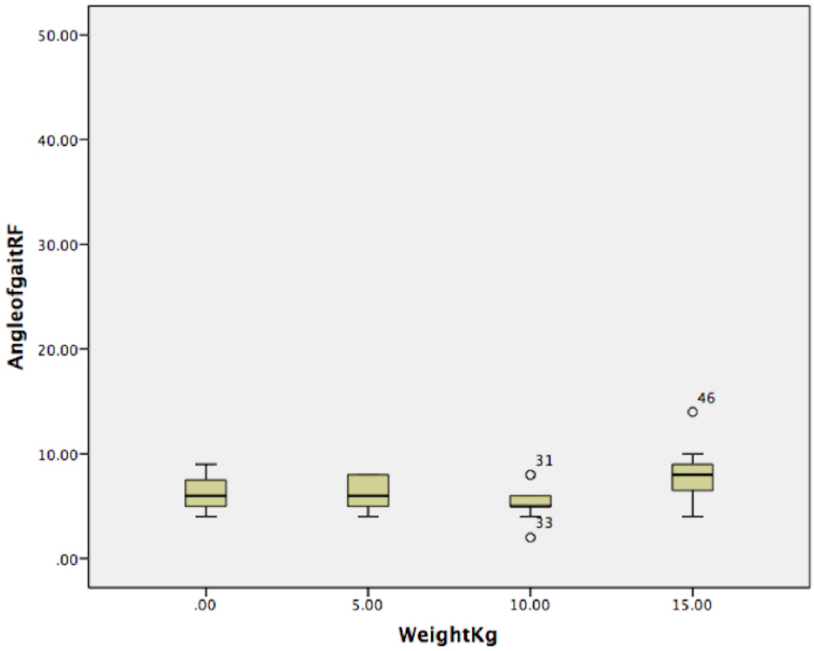
Graph 3

Angle of gait of left foot (degrees) against weight carried, carrying weight to the front.



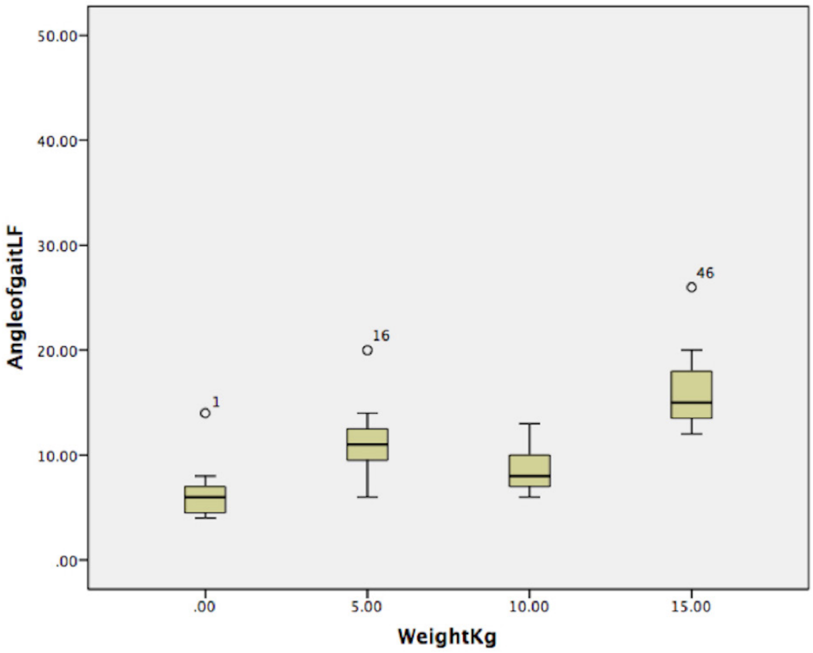
Graph 4

Graph 4 Base of gait (mm) against weight carried, carrying weight to the left-hand side.



Graph 5

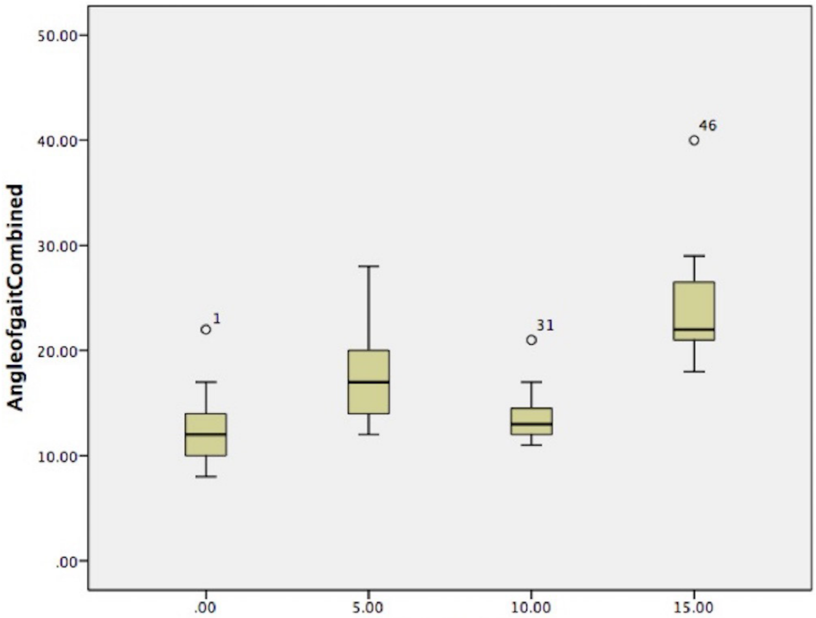
Angle of gait of right foot (degrees) against weight carried, carrying weight to the left-hand side.



Graph 6

Angle of gait of left foot (degrees) against weight carried, carrying weight to the left-hand side.

Graph 7



Angle of gait of left and right foot combined (degrees) against weight carried, carrying weight to the left-hand side.

Normal angle of gait is anywhere between 7 to 10 degrees of abduction per foot, as identified by Orien et al. [27] Therefore, anything over 10 degrees of abduction could be classed as excessive. The body might have been struggling to stabilize and used the left foot to achieve stabilization. The base of gait might have been narrowed because of the changes in the angle of gait, bringing the heels closer together, and the load possibly pulling the body over to one side. Krishan's study [15] showed that changes in footprints were observed only with loads of 20 kg. However, because Krishan's study used only 5 kg and 20 kg loads, it is conceivable that similar results to our own may have arisen with 15kg loads had these been used. The results also align with the results of Fischer et al. [12] and Fischer and Wolf [14]. They investigated the unloading of bodyweight but did not gain any significant results until 30% unloading of bodyweight had occurred.

Tests Involving Carrying the Weight to the Front of the Body

When carrying a 5-kg weight to the front, there was a small increase in base of gait and a slight increase in abduction of the feet, more so for the right foot than for the left foot. One of the exclusion criteria for this study was that of left-handedness. Cawley [28] identified that dominance may influence the lower limb, so it might be postulated that the right foot was abducting more than the left because it was the more dominant foot and was providing more compensation. The base of gait was measured as the distance between the midpoints of the two heels, as per Wilkinson et al's method [21]. [Author Please confirm that reference 21 is an appropriate reference to support this "per Wilkinson" comment.] When weight was increased to 10 kg, there was very little change to the base of gait. The angle of gait did increase further; this was more pronounced on the right foot than on the left foot. The right foot was abducting more than the left; it might be postulated that this abduction was because it was the dominant side of the participants. Left-handedness was an exclusion criterion, meaning all participants were dominant on the right side. Perhaps if the opposite were true, then the left foot may have abducted more. Until the application of the 15-kg load, the mean changes for angle and base of gait were relatively small. This may suggest that the body was able to cope with this extra load with minimal effort and there was no need to markedly compensate. When a load was added, the mean base of gait widened and there was a small increase in mean abduction of both feet. When the 15-kg load was applied, this appeared to have a large effect on the results. The mean base of gait increased and there was an overall combined increase in the mean angle of gait for both feet. However, angle of gait for the right feet reduced, but they were still more abducted than they were at 0 kg. The left feet abducted, suggesting that at this point they may have taken over, providing stability from the right feet.

The mean base of gait increased 12.6% and the mean abduction of the right foot increased the mean left foot abduction increased whilst the overall combined mean angle of gait increased the final measurements were taken at 15 kg. The base of gait increased against the 5 kg and 10 kg loads, but it was still reduced overall against the baseline figure. The mean base of gait had increased further still at 15 kg, and the overall angle of gait increased.

The left foot accounted for this increase. The right foot was more abducted than it was at 0kg, and the combined angle of gait had increased. It might be that at 0 kg, the left and right feet were equally abducted. When a load of 5 kg was applied the base of gait reduced and the angle of gait increased there was no change to the angle of gait of the right foot, it could have been that abduction of the left foot increased. [Author-This sentence is confusing. Please recast it for clarity.] The nondominant foot (left foot in this study) was identified as a stabilizer in two studies [28, 29]. It could be postulated that the increase in load was too much for the body and instead of prioritizing propulsion (where the right foot would dominate), the body just wanted to stabilize and keep steady, so the left foot increased its workload. This would be supported by previous work by Gentry and Gabbard [29] and Ledebet et al. [30], who identified the dominant foot was involved in propulsion and the nondominant foot was a stabilizer. It is also supported by the work of Krishan [15], who demonstrated that changes in footprints were observed only with loads of 20 kg. He observed only a 5kg and 20 kg load, but it might be conceivable that he would have had similar results at 15 kg if he had used incremental loads. The results also aligned with studies by Fischer et al. [12] and Fischer and Wolf [14]. They looked at bodyweight unloading but did not gain any significant results until 30% of bodyweight had unloaded. The mean bodyweights for their studies was 67.9 kg. They observed significant change when the body was unloaded by 21 kg, therefore it might be considered that a 21 kg load would provide a significant result, but perhaps for their study, this was an unsafe load.

Tests Involving Carrying the Weight to the Left Side of the Body

When weight was carried to the left-hand side of the body, the results showed the same starting point as carrying weight to the front. At 0 kg, the left and right foot were equally abducted. When a load of 5 kg was applied, the base of gait reduced, and the angle of gait increased. There was no change to the angle of gait of the right foot, but abduction of the left foot increased. There might be two reasons this happened: (1) The load was to the left, so it was pulling the body to the left. Had the load been on the right-hand side, perhaps there would have been an increase in abduction towards the right side of the body. (2) If the nondominant foot was a stabilizer, the body might have been made so unstable that the left foot was working hard to stabilize the body, and propulsion became a secondary priority. There was a definite reduction in base of gait, no change in the angle of gait of the right foot, but a very marked increase in the angle of gait of the left foot. At 10 kg, there was a slight increase in the base of gait from 5 kg (but still an overall reduction from 0 kg), mean of 10.8% (8 mm), and a decrease in overall angle of gait for both feet combined. Compared to 5 kg, there was a reduction in the angle of gait of both the left and right feet, but compared to 0 kg, the left foot was still more abducted and the right foot adducted. The mean right foot angle of abduction decreased, and the mean left foot angle decreased. This might be attributed to the load being on the left-hand side of the body, so it was pulling the left foot away from the midline of the body (abduction) and the right foot towards the midline (adduction). The left foot might be working more to stabilize a body that has been pulled to one side and was very unstable. The right foot might have been involved in propulsion of the body, but it could have been pulled off the ground, so it was not accomplishing this propulsion effectively. When participants were walking with increased loads to the left-hand side, it was observed that they were spending less time on the right foot and more on the left. Although observation was not part of the methodology, relevant observations were noted. As soon as ground contact was made with the right foot, and the left foot was taken off the ground, it was observed that they were quickly pulled back to the left-hand side and unable to properly complete a gait cycle. [Author-What is “they” referring to? The participants?] This was observed to happen to all participants.

The final measurements were taken at 15 kg. The base of gait increased against the 5 kg and 10 kg loads, but it was still reduced overall against the baseline figure. The mean base of gait increased, and the overall angle of gait increased. The left foot accounted for this increase, and the right foot was more abducted than at 0 kg. The combined angle of gait had increased. The body might have been quite unstable, so the nondominant foot was working hard to stabilize the body, and propulsion might not have been a priority at this point.

In summary, overall from 0 kg to 15 kg, the mean base of gait had reduced, the mean angle of gait of the right foot had increased, and the mean left foot angle of gait had increased. The mean overall combined angle of gait had increased. Although mean values have been the focus for this study, there is a wide range of variance when looking at individuals. For base of gait, there is anything from a decrease of 24% to an increase of 56%. The angle of gait for the right foot ranged from zero to 100%.

The angle of gait for the left foot showed an increase in abduction from 71% to 325%. Finally, the combined angle of gait for both feet showed an increase from 33% to 163%.

When carrying a weight of 15 kg to the left-hand side of the body, there was an effect on the angle and base of gait. The base of gait decreased and the left (nondominant) foot abducted excessively, whereas the right foot abducted marginally. Where these increases and decreases in abduction come from are unclear at present.

Limitations on the Study

The study had a sample size of only 15, which precludes meaningful statistical analysis. However, as a pilot study, it provides some useful results and indication of direction for future research. Fischer et al.

[12] used bodyweight unloading as a percentage of the participants' own bodyweight. It may have been better to consider weight as a percentage of the participants' bodyweight because different participants could have carried different loads. This way of keeping carried weight relative to bodyweight and perhaps ability to carry those loads, would make for a much fairer application of stress to the participants.

Further Research

Further research should investigate carrying weight to the right-hand side of the body. It was visibly obvious during data collection that carrying the weight to the left pulled the participants over to the left.

It was hypothesized that this pulling effect to the left-hand side may have affected the abduction of the left foot. Further research would be needed to identify whether this would happen to the right foot when carrying the weight to the right-hand side. Future studies would benefit from increased sample sizes, with a more detailed biomechanical screening of participants. It would also be beneficial to look at other joints in the body, such as hip and knee, to determine what compensation, if any, is happening at these levels.

Conclusion

This pilot study was based on a small sample size of 15 participants, which prevented analysis using inferential statistics. However, it does go some way to support some of the previous research carried out in this area. It also gives a good indication of where future research in this area should focus. When analysing the angle and base of gait for a person carrying weight, the effects of the following variables should be considered:

• When carrying weight to the front of the body, there was an effect on angle and base of gait at15 kg. The base of gait increased and the left (nondominant) foot abducted more than the right.

[Author-Please confirm this statement is applying to when the weight was carried to the left side.]

• When carrying weight to the left side of the body, there was an effect on angle and base of gait at 15 kg. The base of gait decreased and the left (nondominant) foot abducted, whereas the right foot adducted. [Author-Please provide text to indicate whether these results came from the front-loaded or left-side loaded.]

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References

1. Vernon, W. The Development and Practice of Forensic Podiatry. J. Clin. For. Med. 2006, 13(6–8), 284–287.

2. Payton, C.; Bartlett, R., Eds. Biomechanical Evaluation of Movement in Sport and Exercise Sciences–The British Association of Sport and Exercise Sciences Guidelines, 1sted.; Routledge: London, U.K., 2008.

3. Eckel, T. T.; Abbey, A. N.; Butler, R. J.; Nunley, J. A.; Queen, R. M. Effect of Increased Weight on Ankle Mechanics and Spatial Temporal Gait Mechanics in Healthy Controls. Foot and Ankle Int. 2012, 33 (11), 979–983.

4. Singh, T.; Koh, M. Effects of Backpack Load Position on Spatiotemporal Parameters and Trunk Forward Lean. Gait & Posture 2009, 29 (1), 49–53.

5. Hong, Y.; Brueggemann, G. P. Changes in Gait Patterns in 10-Year-Old Boys with Increasing Loads When Walking on a Treadmill. Gait & Posture 2000, 11 (3), 254–259.

6. Jeng, S. F.; Liao, H. F.; Lai, J. S.; Hou, J. W. Optimization of Walking in Children. Med. Sci.Sports & Exercise 1997, 29 (3), 370–376.

7. Fischer, A. G.; Debbi, E. M.; Wolf, A. Effects of Body Weight Unloading on Electromyographic Activity During Overground Walking. J. Electromyography and Kinesiology 2015, 25 (4), 709–714.

8. Riley, P. O.; Paolina, G.; Della Croce, U.; Payola, K. W.; Kerrigan, D. C. A Kinematic and Kinetic Comparison of Overground and Treadmill Walking in Healthy Subjects. Gait and Posture 2007, 26 (1), 17–24.

9. Strathy, G. M.; Chao, E. Y.; Laughman, R. K. Changes in Knee Function Associated with Treadmill Ambulation. J. Biomech. 1983, 16 (7), 517–522.

10. Attwells, R. L.; Birrell, S. A.; Hooper, R. H.; Mansfield, N. J. Influence of Carrying Heavy Loads on Soldiers' Posture, Movements and Gait. J. Ergonomics 2006, 49 (14), 1527–1537.

11. Martin, P. E.; Nelson, R. C. The Effect of Carried Loads on the Walking Patterns of Men and Women. J. Ergonomics 1986, 29 (10), 1191–1202.

12. Fischer, A. G.; Debbi, E. M.; Wolf, A. Effects of Body Weight Unloading on Electromyographic Activity During Overground Walking. J. Electromyography and Kinesiology 2015, 25 (4), 709–714.

13. Jarmey, C. The Concise Book of Muscles, 2nd ed.; Lotus Publishing: Chichester, U. K.,2008.

14. Fischer, A. G.; Wolf, A. Assessment of the Effects of Body Weight Unloading on Overground Gait Biomechanical Parameters. Clinical Biomechanics 2015, 30 (5), 454–461.

15. Krishan, K. Establishing Correlation of Footprints with Body Weight–Forensic Aspects. For. Sci. Int. 2008, 179 (1), 63–69.

16. Qu, X.; Nussbaum, M. A. Effects of External Control on Balance Control During Upright Stance: Experimental Results and Model-Based Predictions. J. Gait & Posture 2009, 29 (1),23–30.

17. Lee, M.; Roan, M.; Smith, B.; Lockhart, T. E. Gait Analysis to Classify External Load Conditions Using Linear Discriminant Analysis. J. Human Movement Sci. 2009, 28 (2),226–235.

18. Gillette, J. C.; Stevermer, C. A.; Miller, R. H.; Meardon, S. A.; Schwab, C. V. The Effects of Age and Type of Carrying Task on Lower Extremity Kinematics. J. Ergonomics 2010, 53 (3),355–364.

19. Scales and balances. Cast Iron Proof Test / Proof Load Weights. 2016.

http://www.scalesandbalances.co.uk/acatalog/Cast_Iron_Proof_Test_Load_Weights.html (accessed February 20, 2016).

20. Bodziak, W. J. Footwear Impression Evidence: Detection, Recovery, and Examination,2nd ed.; CRC Press: Florida, 2000.

21. Wilkinson, M. J.; Menz, H. B.; Raspovic, A. The Measurement of Gait Parameters from Footprints. The Foot 1995, 5 (2), 84–90.

22. Whittle, M. W. Gait Analysis: An Introduction, 2nd ed.; Butterworth-Heinemann: Edinburgh, U.K., 1996.

23. Dougan, S. The Angle of Gait. Am. J. Phys. Anthrop. 1924, 7 (2), 275–279.

24. University of Northampton. Angle of Gait Search. https://nelson.northampton.ac.uk/primoexplore/search?query=any,contains,angle%20of%20gait&tab=default_tab&search_scope=Local%2BRemote&vid=44NORTH_V1&lang=en_US&offset=0 (accessed February 3, 2018).

25. NCBI. Angle of Gait Measurement–PubMed Search. https://www.ncbi.nlm.nih.gov/pubmed/?term=Angle+of+gait+measurement (accessed February3, 2018).

26. Google Scholar. Angle of Gait Measurement. https://scholar.google.co.uk/scholar?hl=en&as_sdt=0%2C5&q=angle+of+gait+measurement&btnG=&oq=angle+of+gait+measurem (accessed 3 Feb. 2018).

27. Orien, W. P.; Root, M. L.; Weed, J. H. Normal and Abnormal Function of the Foot. Clinical Biomechanics Corp: New York, 1977; Vol. 2.

28. Cawley, D. T.; Guerin, S. J.; Walsh, J.; Simpkin, A.; Masterson, E. L. The Significance of Hand Dominance in Hip Osteoarthritis. Seminars in Arthritis and Rheumatism 2015, 44 (5),527–530.

29. Gentry, V.; Gabbard, C. Foot-Preference Behaviour: A Developmental Perspective. J. Gen. Psych. 1995, 122 (1), 37–45.

30. Ledebt, A.; van Wieringen, P. C. W.; Savelsbergh, G. J. P. Functional Significance of FootRotation Asymmetry in Early Walking. Infant Behaviour and Development 2004, 27 (2),163–172.