INSTRUMENTED TREADMILLS: REDUCING THE NEED FOR GAIT LABS

Kimberly A. Edginton, H. Cenk Güler, Jan J. Ober and Necip Berme
Bertec Corporation, Columbus, Ohio, USA

INTRODUCTION

Gait analysis can provide significant information regarding the kinetics and kinematics of human motion. Such an analysis has become a standard collaboration of engineers and medical professionals determining force and motion characteristics of individuals coming to a gait analysis laboratory for evaluation. Tools such as motion capture systems, force platforms or pressure sensors, and EMG are necessary for a full analysis.

To evaluate the ground-reaction forces exerted by each subject, it is most common to use at least one force platform in the analysis of gait. Force platforms can accurately measure the six force and moment components, making them useful in the collection of kinetic information.[1] These platforms are often mounted flush with the floor, hidden from observation of the subject, so that the subject does not attempt to alter gait to step on the plate. To collect usable information it is necessary that the subject steps entirely on the force platform, with only one foot. If the subject misses the force plate, places only part of the foot on the force plate, or has contact of both feet on the force plate, the trial is disregarded.[1] The data collection process continues until a series of successful trials are collected, sometimes a tedious process.

Limitations of Gait Analysis

The necessity of proper foot placement on the force platform is a recognized weakness in gait analysis.[1] It is especially problematic in testing individuals with compromised gait patterns, such as those walking with a cross-over pattern making it nearly impossible to strike the force plate without both feet falling on it.[2] There are several solutions to this problem, each with their own associated disadvantage. One commonly used method to achieve successful trials is to have the subject target the force plate by instructing the subject to start from a specific location with a specific foot. Using this method, subjects often begin to get an idea where the force platform might be, and adjust their gait to obtain a successful trial, which leads to inaccurate data.[1] To prevent this, it is possible to have individuals start at a self-selected location. However, successful trials are harder to achieve, making for a longer and more frustrating process. Oggero et al. reviewed a series of gait analysis cases to find the probability of a successful trial when the subjects self-selected their starting location. Their study found that on average, even with a size 60 cm plate, the optimum size for the majority of their patient population, only 25% of subjects would require 3 or less trials for every successful trial, and as many as 42% would have no successful trials.[1] This process can be very tiring and fatigue affecting gait performance becomes an issue.[2] As data regarding the right foot and left foot are often looked at individually, this process becomes even more time consuming and frustrating.

The limitations attributed to the force platforms end up costing the laboratory in terms of both time and money. The entire testing procedure, including patient preparation, commonly takes two hours at minimum to complete, limiting the lab in number of evaluations that can be run in a week.[3] With the high costs required to perform the analysis, the

limited reimbursement received, and the constraints on the number of evaluations that can be performed, it becomes difficult for gait laboratories to be profitable. A gait study can cost as much as $2000 US, with an expected reimbursement of $500 or less.[3] This is in addition to the extensive costs to set-up a facility, reaching as high as $300,000 if no facility renovations are needed.[3] In the late 1990s, the National Institutes of Health Consensus Conference recognized economic issues as a significant obstacle to the success of gait laboratories and encouraged research to be focused on improving cost-effectiveness of the gait analysis process.[3]

INSTRUMENTED TREADMILLS

In recent years, developments in instrumented treadmills have shown promise as a means of overcoming the limitations of standard gait analysis laboratories. Instrumented treadmills are those treadmills able to measure forces, most commonly by means of at least one force platform built under or into the treadmill structure. Such treadmills were originally built for research purposes, like the one designed by Kram, but have slowly emerged in the commercial market.[4] Only a handful of groups, including both research and commercial interest, have successfully manufactured such treadmills. Many incorporate at least a single force plate between the belt, while some feature a fore-aft force plate arrangement, or the more popular arrangement of side-by-side force plates with a split-belt.

Benefits of Instrumented Treadmills

The major benefit of the use of instrumented treadmills in gait analysis is the elimination of the need for proper foot placement. Most commonly, the force plates are nearly as long and wide as a treadmill belt, making it possible to ensure the entire foot easily strikes the force plate. Using side-by-side plates allows right foot and left trials to be collected simultaneously. Data can be taken continuously, recording each foot strike, right and left, rather than the cumbersome process of multiple trials that may or may not be successful. This translates to much quicker data acquisition, with the benefits of reduced patient fatigue and frustration, leading to a more accurate evaluation. Secondary benefits of this improved efficiency mean reduced costs associated with individual patients, and increases in the number of patients that can be seen, increasing the overall profit of gait analysis.

Lowered costs and increased revenue can also be attributable to the reduced space and facility requirements associated with an instrumented treadmill as opposed to the traditional laboratory layout. Some instrumented treadmills are only slightly larger than standard retail treadmills, making them appropriate to place in a variety of environments where space often comes at a premium. Existing facilities such as rehabilitation centers, or even physician offices, can feasibly have an in-house instrumented treadmill for gait analysis rather than having to rely on a large outpatient laboratory. Additionally, facility renovations requiring pits in the floor to mount standard force plates and other extensive work necessary for traditional analysis, all associated with a high cost, become unnecessary.

An additional benefit includes controllable speed of the treadmill to more appropriately adapt to the locomotor patterns of the diverse range of individuals evaluated. An instrumented treadmill can be set on speeds appropriate for the laborious gait of an elderly individual or the quick sprint of a healthy athlete. This inevitably leads to reduced set-up time, improved testing, and greater profit.

Limitations of Instrumented Treadmills

To be thorough, it is necessary to recognize the limitations that exist in some models of instrumented treadmills. For the most part, these limitations can be overcome by proper selection of a treadmill and slight modification to the general testing procedure.

One concern in the use of instrumented treadmills is how individuals might adapt their gait from traditional over-ground walking.[5,6] This is especially a concern in older populations and

individuals with disability who may not have had experience using any sort of treadmill before. It was found that when individuals begin to walk on the treadmill, they shorten their stride length and cadence.[5] However, within 1-3 minutes most subjects reported being comfortable on the machine, and were visually observed to be walking similarly to over-ground walking.[5] Zeni and Higginson recommend that though the necessary adaptation time may be dependent on the subject, at least 4 or 5 minutes should be given to accustom oneself to the treadmill before data is taken, at which time step width and variability closely reflects over-ground walking.[6]

Another concern is how to analyze the data when both feet are on the instrumented treadmill at one time, which happens approximately 30% of the time when walking.[5, 7] This problem can be avoided altogether by performing gait analysis on an instrumented treadmill with side-by-side mounted force platforms. With such a machine each foot strikes a separate platform and even during double contact, each plate is recording the forces of each foot separately.

PROPERTIES OF INSTRUMENTED TREADMILLS

This section focuses on design properties and features, which should be considered while selecting instrumented treadmills. These features will be evaluated by comparing instrumented treadmills from three companies: Bertec Treadmill, AMTI Treadmill, and ADAL 3D from Hef Group:

a) Accuracy: As with the conventional force plates, two basic technologies are available for load measurement: strain-gage (Bertec and AMTI) and piezoelectric load cells (ADAL 3D). Due to the high stiffness of the piezoelectric load cells their measurement accuracy is usually lower than strain-gage based load cells. Strain-gage based treadmills like the Bertec Instrumented Treadmill, shown in Figure 1, cover a wide measurement range combined with a high accuracy in load and Center of Pressure (CoP) measurements.

Figure 1 The Bertec Instrumented Treadmill

b) Dynamic Response: Instrumented treadmills should be able to measure loads under a variety of load conditions ranging from slowly varying to high impact loads. Therefore, systems with higher structural natural frequencies will cover a wider range of loading conditions. Bertec treadmill has the 1st natural frequency above 200 Hz in all measurement directions.

c) Effect of Belt Motion: Load measurements in all commercially available instrumented treadmills are prone to be affected by the motion of the tread belt. Special design precautions should be taken to avoid excessive vibration of the treadmill due to the rotating parts. As a general rule, light and compact treadmills (like Bertec and ADAL 3D) will have less vibration issues.

d) Single Belt vs. Split Belt: Both the single belt and split belt (dual belt) treadmills have their advantages and disadvantages. Single belt treadmills are more cost effective since they incorporate less mechanical parts and electronics. Split belt treadmills, on the other hand, will yield more information by measuring the load distribution under each foot separately. Bertec treadmill is a dual belt treadmill for which the belt width can be customized between 6-16" (1.7 m total length) based on application requirements.

One side of a 16" wide belt can also be used as a single belt treadmill.

e) Control of Belts: A state-of-the-art treadmill should allow the user to have full control over the belt motion. Bertec treadmill allows the user to have full control over the belts including individual speed control (0-15 miles/hour) of both belts in forward and backward directions. The treadmill accepts user defined motion profiles in the form of text files on a computer. This allows the users to perform detailed motion studies by using their own movement protocols. For example, perturbations can be created by stopping or reversing belt speed, creating a tripping sensation appropriate to evaluate reaction ability in a falls prevention context.

f) Incline: The ability of the treadmill to incline is a feature necessary to test uphill and downhill walking. Only Bertec (27% grade) and AMTI (25% grade) offer inclined versions of their treadmills. Unlike AMTI, the incline mechanism of the Bertec treadmill and the associated electronics is a modular add-on feature, which can be installed to complement an existing treadmill.

g) Optional Attachments: Instrumented treadmills are mainly used in research environments where there are a large variety of applications. Optional modules might be very useful for different applications. As discussed above, the Bertec treadmill offers an incline as an add-on module. Another useful option, available only with Bertec's treadmill, is the instrumented handrail, which can be used to measure the grip forces from both hands independently. Unlike similar systems, the standard adjustable handrails of the Bertec treadmill can be replaced with instrumented ones for complete analysis of forces acting on the body. Another useful module is the harness attachment that will provide an additional safety while testing patients and elderly people. Bertec treadmill offers such an attachment as a completely modular unit. Laboratories, which do not use the treadmill for continuous testing, prefer a unit that can be wheeled away when it is not used. Bertec's modular caster attachments are a feasible solution to store away the treadmill.

CONCLUSION

Though useful in improving clinical decision-making, gait analysis as performed in traditional laboratories is subject to a number of limitations, many based around the necessity of successful foot strike on a force platform. These limitations result in an inefficient laboratory, often with low profitability. Recent advances in instrumented treadmills seek to overcome these limitations. This paper details some of the properties of three commercially available instrumented treadmills.

REFERENCES

[1]Oggero E, Pagnacco G, Morr DR, Simon, SR, Berme, N. Probability of valid gait data acquisition using currently available force plates. Biomed Sci Instrum. 1998;34:392-297.

[2]Paolini G, Croce UD, Riley PO, Newton FK, Kerrigan DC. Testing of a tri-instrumented-treadmill unit for kinetic analysis of locomotion tasks in static and dynamic loading conditions. Med Eng Phys. 2007;29:404-411.

[3]Simon SR. Quantification of human motion: gait analysis-benefits and limitations to its application to clinical problems. J Biomech. 2004;37:1869-1880.

[4]Kram R, Griffin TM, Donelan JM, Chang YH. Force treadmill for measuring vertical and horizontal ground reaction forces. J Appl Physiol. 1998;85:764-769.

[5]White SC, Yack, HJ, Tucker CA, Lin, HY. Comparison of vertical ground reaction forces during overground and treadmill walking. Med Sci Sports Exerc. 1998;30:1537-1542.

[6]Zeni J and Higginson J. Familiarization to walking on a split-belt treadmill: kinetics, kinematics and spatio-temporal parameters. Proceedings of the 30th annual meeting of the American Society of Biomechanics; 2006 Sept 6-9; Blacksburg, VA.

[7]Verkerke GJ, Hof AL, Zijlstra W, Ament W, Rakhorst G. Determining the center of pressure during walking and running using an instrumented treadmill. J Biomech. 2005;38:1881-1885.