Data to Complete Your Gait Analysis

Version 2.0

A gait lab can employ several pieces of equipment—a force plate, a motion capture system, and maybe even EMG. So what technology can complement these systems to provide a complete picture for your analysis?

Tekscan

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Introduction

Capturing something as complex as human movement or gait is difficult and requires several pieces of equipment. The equipment in your gait lab may vary depending on your area of focus for research, whether you are treating patients clinically, and the amount of funding available.

Labs often rely on force plates, motion capture systems, and maybe even EMG to collect the majority of your data, but what about when you want/need to collect data outside the lab?

Tekscan technology offers portability, versatility and unique complementary information for your gait lab.

EMG

Image courtesy of Delsys

Force Plate

Tekscan's F-Scan

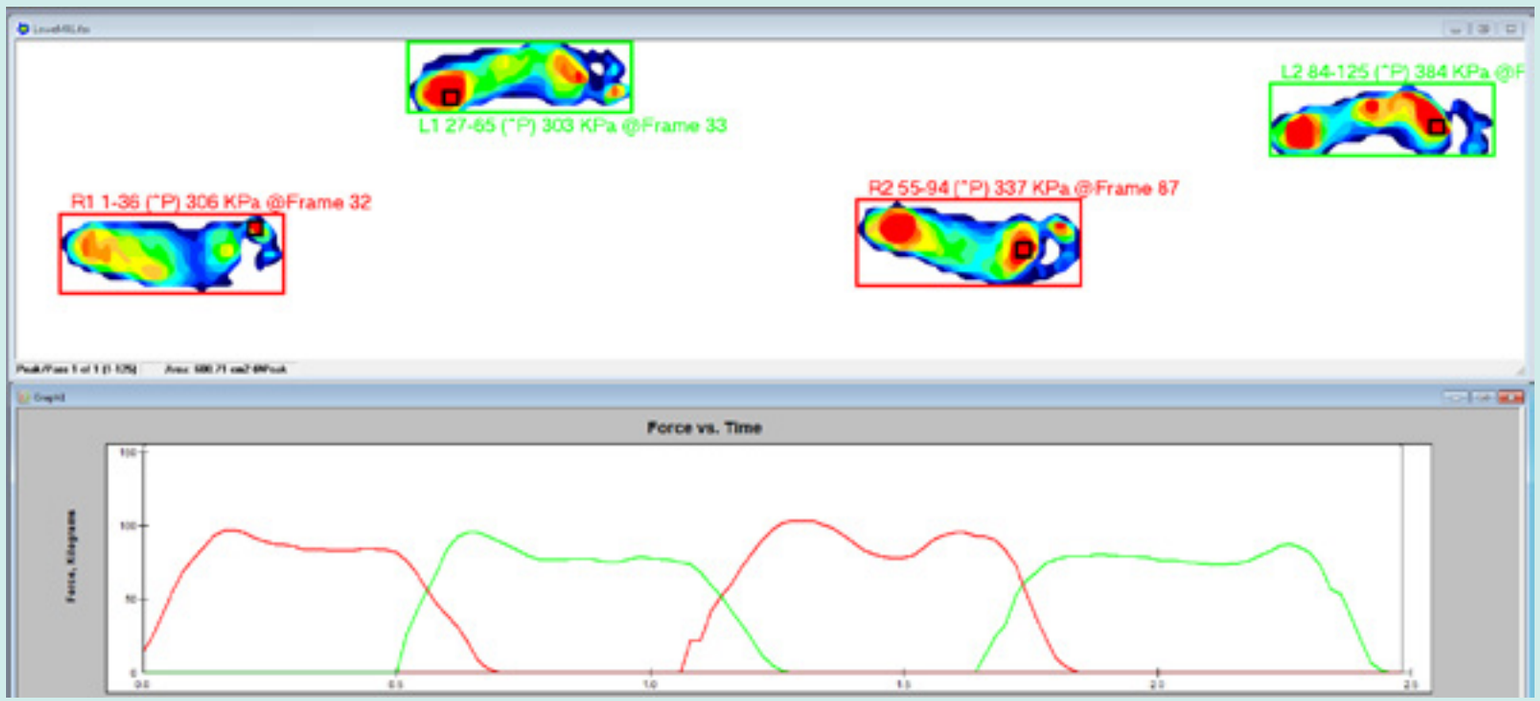
Tekscan's Force & Pressure Systems Provide Unique Information

1 Capture Multiple Sequential Foot Strikes

While force plates are considered the gold standard, this technology can present some challenges:

- **Budgetary constraints:** Purchasing multiple force plates can be costly and the buying process can be complicated.
- **Potential for targeting by subjects.** When someone alters their gait to ensure they are stepping in a specific location or on a piece of equipment, you are no longer gathering accurate data.

Tekscan offers in-shoe analysis and pressure measurement walkways that can freely capture multiple foot steps allowing you to collect data to analyze natural gait.



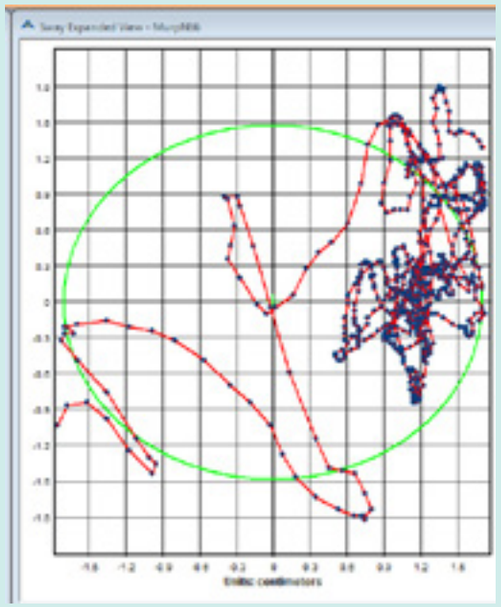
2 Insights into Gait, Balance, Stability and More

Did you know pressure measurement systems offer more than just pressure insights?

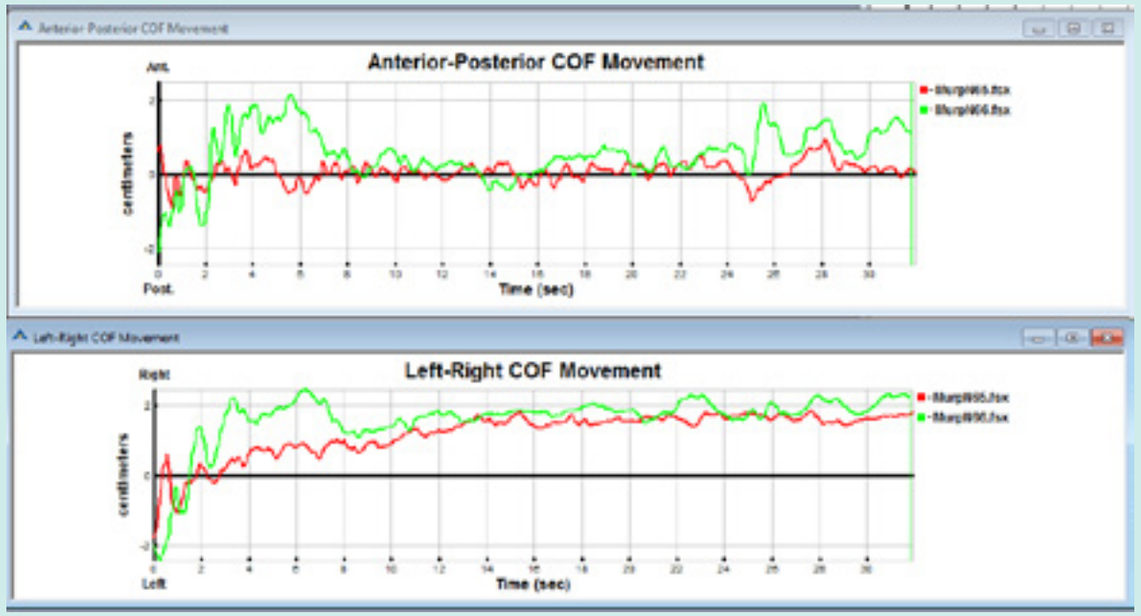
While pressure is a major piece of information provided by Tekscan technology, the systems provide much more than just pressure. Tekscan provides a multitude of data measurement and analysis tools, such as:

- Force & Pressure
- Sway
- Center of Force Trajectory
- Center of Pressure
- Temporal & Spatial Parameters
- Plantar Surface Visualization to Evaluate Foot Motion

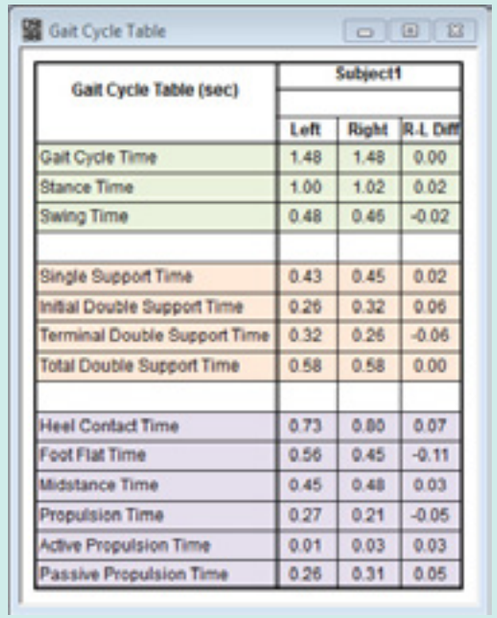
Below is a sampling of data provided by Tekscan Software.



Sway Movement



CoF Movement



Gait Cycle Table (sec)	Subject1		
	Left	Right	R-L Diff
Gait Cycle Time	1.48	1.48	0.00
Stance Time	1.00	1.02	0.02
Swing Time	0.48	0.46	-0.02
Single Support Time	0.43	0.45	0.02
Initial Double Support Time	0.26	0.32	0.06
Terminal Double Support Time	0.32	0.26	-0.06
Total Double Support Time	0.58	0.58	0.00
Heel Contact Time	0.73	0.80	0.07
Foot Flat Time	0.56	0.45	-0.11
Midstance Time	0.45	0.48	0.03
Propulsion Time	0.27	0.21	-0.05
Active Propulsion Time	0.01	0.03	0.03
Passive Propulsion Time	0.26	0.31	0.05

Gait Parameters

3 View Your Data the Way You Want

All Tekscan systems provide the freedom for data export, so you can perform additional calculations to ensure you are capturing the data you need for your research.

Perform detailed analysis with Tekscan data by using API software to access raw data directly or by exporting to the following formats:

- ASCII
- MatLab
- Excel

1	Gait Cycle Table	Human-High-Arch.fsx		
2		Tekscan Patient		
3		Left	Right	R-L Diff
4	Gait Cycle Time	100	100	0
5	Stance Time	70	66.4	-3.5
6	Swing Time	30	33.6	3.5
7				
8	Single Support Time	34.5	32.5	-1.9
9	Initial Double Support Time	15.8	17.4	1.6
10	Terminal Double Support Time	17.8	15.4	-2.4
11	Total Double Support Time	33.5	32.8	-0.8
12				
13	Heel Contact Time	49	41.5	-7.6
14	Foot Flat Time	38.5	32.7	-5.8
15	Midstance Time	33.4	20.5	-12.9
16	Propulsion Time	22.9	24.4	1.5
17	Active Propulsion Time	7.7	8	0.2
18	Passive Propulsion Time	15.2	16.4	1.3

Perform your own calculations with access to raw data from Tekscan

Tekscan's Pressure & Force Measurement Solutions

Tekscan offers pressure and force measurement solutions ranging from platform based systems to in-shoe systems that provide unique insights for gait labs. These research validated systems have been published in numerous research publications. Below is a sample of our solutions available for lower extremity assessments.

			
Strideway	**F-Scan**	**F-Scan64**	**MobileMat**
• Capture multiple sequential footstrikes	• High-resolution in-shoe system with fast scanning rates	• Cord-free in-shoe system with an effortless set-up process	• Versatile footstep & balance assessments
• Modular tile-based design	• Wireless capabilities	• Pre-sized sensors	• Quick setup
• Multiple resolutions & lengths available	• Use anywhere	• Lightweight, Bluetooth-enabled electronics	• Portable

Research Examples Using Tekscan Systems

Tekscan technology is used in gait and motion analysis labs around the world for some really unique research projects. In the following examples you'll see why Tekscan technology was chosen to either complement or replace a standard force plate or motion capture system.

Common reasons include:

- Synchronization with External Systems
- Versatility of Data Collection Environments
- Unique In-Shoe Data
- Thin, Flexible Sensors
- Foot Segmentation Capabilities

Image courtesy of Simi

Image courtesy of Delsys

Version 2.0 Validation of In-Shoe System Against a Force Plate

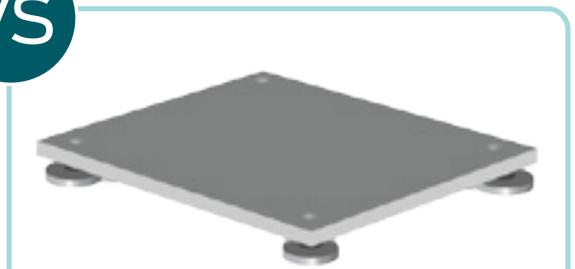
As research helps drives clinical treatments and procedures, it is becoming increasing more important to evaluate humans in real-life environments. Data collected in a static environment like a laboratory does not always translate to the dynamic environments in which athletes perform in sporting events or how people function in the real world.

In-shoe pressure mapping systems, like the F-Scan, allow researchers to capture ground reaction force measurements. This, in turn, complements force plate data to provide the complete story of the patient or subject's gait.

The purpose of this research study was to determine the accuracy of the F-Scan with respect to the gold standard force platform, and to conclude if a neural network (NN) would be capable of reducing any discrepancies.

F-Scan™
in-shoe system

VS



Force Plate

Smale, K.B., Graham, R.B. 2019. 'The Application of a Neural Network to Improve Plantar Pressure Mapping Accuracy.' Presented at the 2019 International Society of Biomechanics[1]

Click to Watch an Interview with the Researcher

Sixteen healthy adults participated in a test-rest (one week later) study. Each subject performed 10 walking and five jogging trials while connected to the F-Scan system. While performing these trials, the subject made contact with an embedded force plate with their dominant leg.

All data was analyzed in a MATLAB program, where each trial was cut to the stance that occurred on the force plate. The F-Scan data was used to predict the force plate vertical ground-reaction force using a time series NN.

The researchers found that the **F-Scan force readings were very strongly correlated to the force plate readings for both the jog (r = 0.97) and walking (r = 0.95) trials**. The neural network slightly improved these correlations to r = 0.99 in both tasks.

> *If we can use more technologies and be confident in the results, we can be more dynamic in our abilities, and take us outside of the lab to capture humans in their natural environment.*
>
> *- Kenneth Brent Smale, PhD.*

Version 2.0 Validation of a Modular Gait Analysis Platform Against a Force Plate

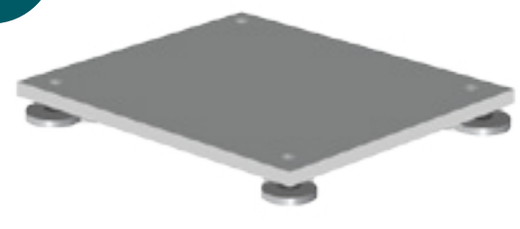
Similar to force plates, pressure mapping platforms can calculate most temporal/spatial gait parameters, and the Center of Force (CoF) and Center of Pressure (CoP) information during various motion activities. However, while force plates offer the total-force-versus-time, they are not able to provide pressure profiles of the foot, and ultimately characterize foot functions.

Add in the fact that force plates are stationery, and thus, not suitable for certain dynamic applications, a need exists for a more convenient force-plate alternative that can provide comparable data to the gold standard.

The purpose of this research study was to validate vertical force measured by the Strideway modular gait analysis system compared to a force platform.

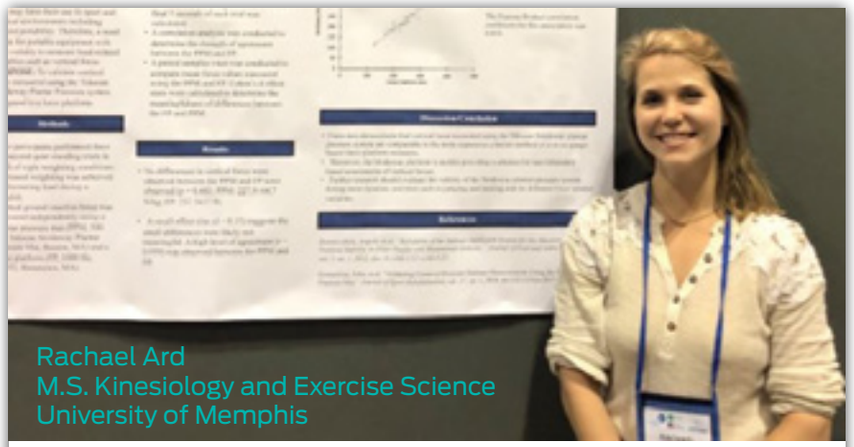
Strideway™ modular gait analysis platform

VS



Force Plate

Ard, R., Melaro, J., Carnall, A., Nelson, A., Blackmore, S., White,V., Paquette, M., Powell, D. 2019. '**Validation of the Tekscan Strideway Plantar Pressure Mat Compared to a Force Platform.**' Paper presented at 66th Annual Meeting of American College of Sports Medicine, Orlando, FL.[2]



Click to Watch an Interview with the Researcher

Five participants performed three 10-second quiet standing trials in eight weight lifting conditions. Increased weighting was achieved by increasing load while the subject held a barbell in a deadlift. Vertical ground reaction forces was measured independently by the Strideway and a force plate.

The results showed no differences in vertical force between the Strideway and force plate ($p = 0.483$; Strideway: 227.9±64.7 N/kg; Force Plate: 237.5±57.9) with a high level of agreement ($r = 0.959$). While more research is needed to determine validity for more dynamic activities, the researchers suggested the Strideway captured vertical force data similiar to a strain-gauge-based force platform in this study.

> *The force plate was slightly more accurate, but not statistically significant from the Strideway. We concluded that any small differences between the two were not due to the data quality or collection method.*
>
> *- Rachael Ard, M.S. Kinesiology and Exercise Science*

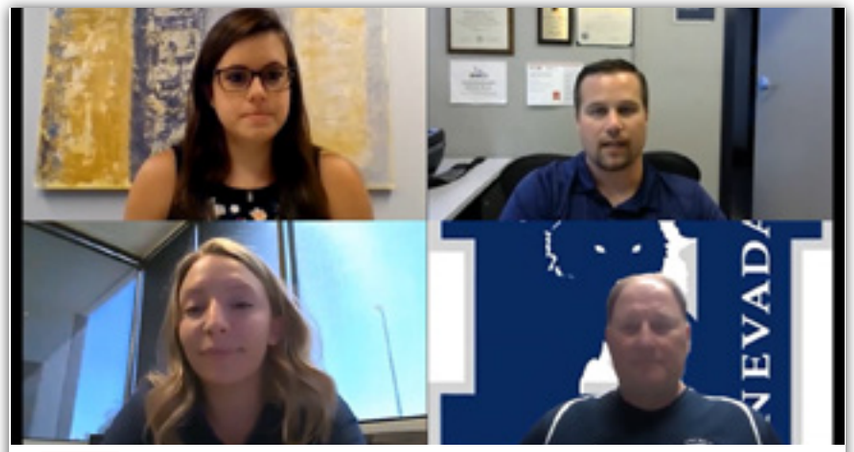
Version 2.0 Employing Modular Gait Analysis to Support Sports-Related Concussion Testing

The discovery of clinically viable methods to track the concussion recovery of athletes has been a focal point in sports & athletics research. Most professional and collegiate athletics have implemented methods to gauge an athlete's recovery from concussion; though, most methods rely on visual observation as a primary metric.

Tandem Gait Exam – which is the process of walking in a straight line, touching each foot heel-to-toe with each step – has emerged as a practical test of dynamic motor control following sports-related concussions. While this is primarily a visual observation, incorporating pressure mapping technologies, like Strideway, can help researchers or clinicians identify Center of Pressure (CoP) of the subject. This becomes an important metric for understanding a subject's balance and sway.

The purpose of this research study was to evaluate the differences in center of pressure (CoP) performance during a Tandem Gait Exam 24-48 hours after a sports-related concussion diganosis.

Murray, N., Moran, R., Islas, A., Pavilionis, P., Szekely, B., Alphonsa, S., Howell, D., Buckley, T., Cipriani, D. 2020 '**Sport-related Concussion Adopt a More Conservative Approach to Straight Path Walking and Turning during Tandem Gait**.' University of Nevada-Reno.[3]



Click to Watch an Interview with the Researchers

Eighteen adults with sports-related concussion (SRC) and 18 nearly-matched controls (CON) completed a vestibular ocular motor screening test (VOMS). This was followed by a series of walking trials on the Strideway. The fastest overall Tandem Gait Exam (based on the amount of time to complete the walking trials) was exported and further analyzed in a custom computer program.

With the help of the Strideway, the researchers determined that the SRC had slower CoP excursion (p=.003; SRC=1.6±0.2cm, CON=1.9±0.4cm) and lower CoP velocity (p=.004; SRC=54.2±7.7cm/s, CON=66.1±14.2cm/s) during a single-task tandem gait exam. There were no differences during the dual-task tandem gait, which is the single-task tandem gait performed concurrently with a cognitive test.

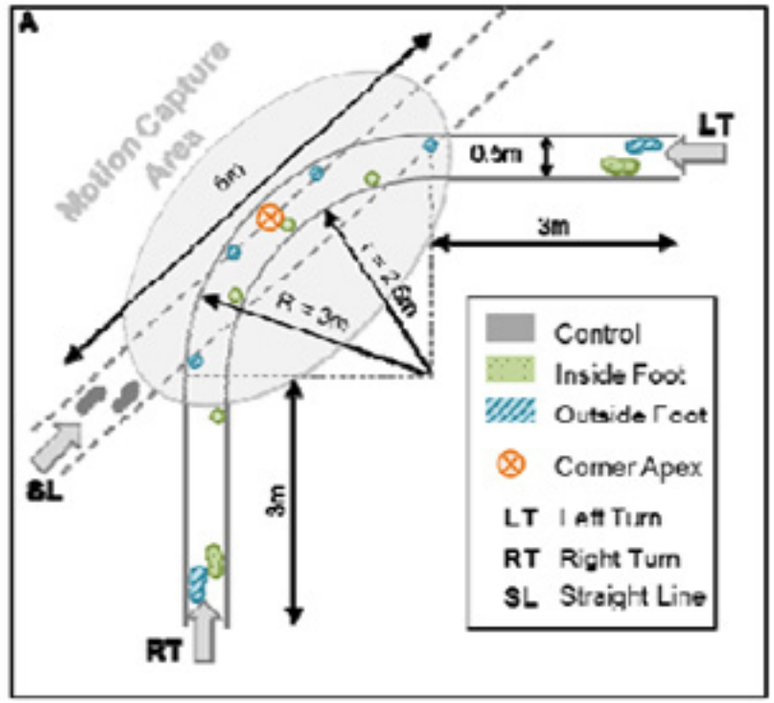
> *The Strideway was able to affirm some of the literature that exists on the Tandem Gait Exam, and made conducting the exam more efficient.*
>
> *- Nicholas Murray, PhD., CIC, University of Nevada-Reno*

Complement Motion Capture Information for a Complete Picture

Motion capture systems can provide insights into joint angles and how the body is moving, but a full picture of potential bilateral asymmetries, pressure, and forces exerted by the feet while walking or running is helpful for researchers trying optimize performance or clinicians looking to improve patient outcomes.

Advantages to combining motion capture systems with pressure measurement systems:

- Synchronize visual movements with forces and pressures
- Evaluate lower extremity angles along with pressure and force
- Understand the relationship between movements and the corresponding pressure on lower extremities



In this research example, 3D motion capture and in-shoe pressure measurement were used to quantify footfall kinematics and joint angle ranges during gentle turning in healthy subjects. Using both technologies allowed for a complete picture of function during movement which wouldn't have been possible with a singular system.

Peyer, K., Brassey, C., Rose, K., and Sellers, W., 2017. '**Locomotion Pattern and Foot Pressure Adjustments During Gentle Turns in Healthy Subjects.**' Journal of Biomechanics, 60: 65-71.[4]

Peyer, et al. comment about their reason for selecting an in-shoe pressure measurement system:

> *One drawback with force plate setups is that the participants may adjust their walking pattern in order to plant the desired foot on the force plate area.*

Additionally, they noted the challenge of the surface area of a force plate being potentially only large enough to capture sharp turns rather than more gentle turns.

Their research found participants decreased their walking speed during turning and increased the stance duration of the inside foot.

The research conducted by Peyer, et al. is a useful example of how combining in-shoe pressure measurement with motion capture can fill in the information gaps that one or the other system might be lacking. The result is well-informed data. While step time is not available from all in-shoe systems, complementary motion capture data provides the flexibility necessary for turning space in this particular example.

Muscle Activation & Plantar Forces & Pressures

Electromyography (EMG) provides insights into timing and intensity of muscle activation. Evaluating muscle activation alone will not provide a complete picture of function. Combining data from pressure and forces on the lower extremities along with muscle activation provides insight into potential issues or pathologies.

EMG & Tekscan Technology combined can provides insights into:

- Phases of gait and timing/amplitude of muscle firing
  - Identify asymmetries between anterior/posterior and medial/lateral
- Insights into balance
  - Evaluate the relationship between postural control and muscle strength

In this example, researchers studied the characteristics of lateral plantar pressure distribution using the F-Scan System and EMG to evaluate lower extremity muscle activation. With particular interest in the relationship between them for patients with lateral ankle sprains.

Mineta, S., Inami, T., Mariano, R, & Hirose, N., 2017. **'High Lateral Plantar Pressure is Related to an Increased Tibialis Anterior/Fibularis Longus Activity Ratio in Patients with Recurrent Lateral Ankle Sprain'** Journal of Sports Medicine. 8: 123-131.[5]

Prior research found that muscle activity has a large influence on plantar pressure distribution. The authors state:

> *Since plantar pressure distribution is influenced by factors such as static alignment, ankle strength, and postural control, we have to measure many factors comprehensively to elucidate the relationship.*

By looking at muscle activity and plantar pressure distribution together, researchers can gain a deeper understanding of factors affecting stability, especially for patients with lateral ankle sprains. This highlights one example of how pressure measurement can be combined with electromyography (EMG) to develop a greater understanding of foot function.

Image courtesy of Delsys

Versatility for Data Collection

Research is no longer strictly confined to just labs at universities or hospitals. It's important to collect data in as close to true/natural environments as possible. Due to the complicated installations of a force plate or a motion capture system, they are not easily transportable. Therefore, projects using these technologies to capture data are often confined to lab environments.

Tekscan's systems are portable and have the ability to collect data in nearly any environment. For example, our in-shoe pressure measurement systems can collect data anywhere, without requiring access to a power outlet. Subjects are capable of moving freely during data collection.

In the example below, data was collected on a bus using Tekscan's F-Scan System.

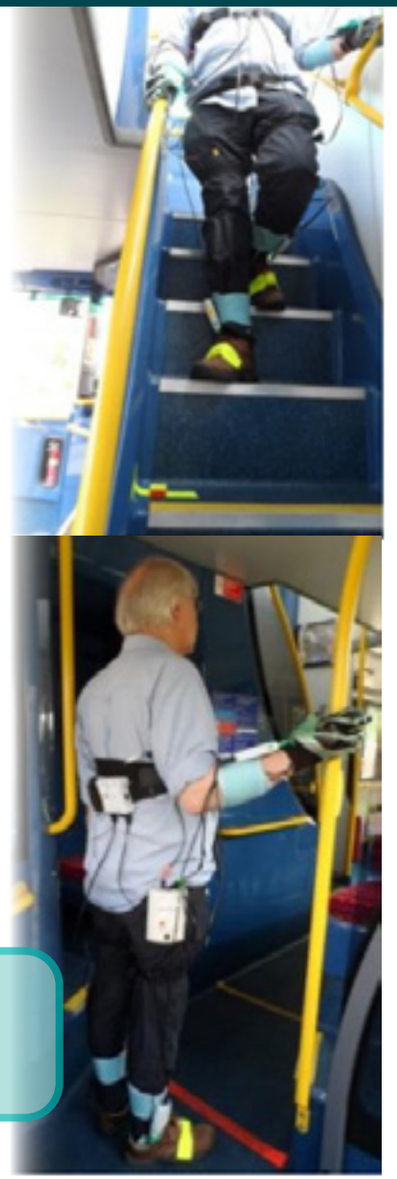
Karekla, Xenia & Tyler, Nick. (2015). **'Gait and Balance of Moving Bus Passengers'.** [6]

Twenty-nine healthy participants were observed in order to establish whether moving inside a bus, which was stationary, affected their walking mechanisms and balance in any way, compared to a static environment. The analysis was focused on two gait characteristics, walking speed and double-support time, as well as the type of steps that defined participants' gait throughout the tests.

Karekla and Tyler mention future research could include evaluating the effect of acceleration (of the bus) on passengers' gait, which could benefit from the flexibility of an in-shoe system.

> *One drawback with force plate setups is that the participants may adjust their walking pattern in order to plant the desired foot on the force plate area.*

As more research is conducted to understand human movement and optimize our lives, studies are now perfomed in a variety of environments to learn about the effects on our bodies. It is essential to have measurement tools which enable flexibility and portability so it's possible to conduct these types of studies.



Walking on flat (a) and negotiating stairs (b) in a static environment on the bus

System Portability Permit Flexible, Real-life Environments

Much of biomechanics research focuses on improving/optimizing human movement and since life is not lived inside a lab, it's important this type of research can be performed in real life environments, performing real-life activities. Some acitvities, like rowing or bike riding, are just not compatible with the typical gait lab technology, like force plates, and require a system like Tekscan's in-shoe measurement system.

In the example below, Becker et al. evaluated forces under the feet during rowing when participants were either pushing through the balls of their feet or their heels.

Becker, J. Jackson, R., Nakajima, M., & Wu, W. (2016). **'Changing Where Force is Applied Influences Force Parameters During Ergometer Rowing'**. Paper presented at American College of Sports Medicine Annual Meeting, Boston, MA. [7]

The researchers found:

> *For most rowers it appears pushing through the balls of feet yields better force curves during ergometer rowing*

For research applications studying unique applications, like rowing, in-shoe systems provide the ability to capture the pressure and forces in environments where using a force plate could be challenging.

Trimmable Sensors Allow for Versatility in Footwear

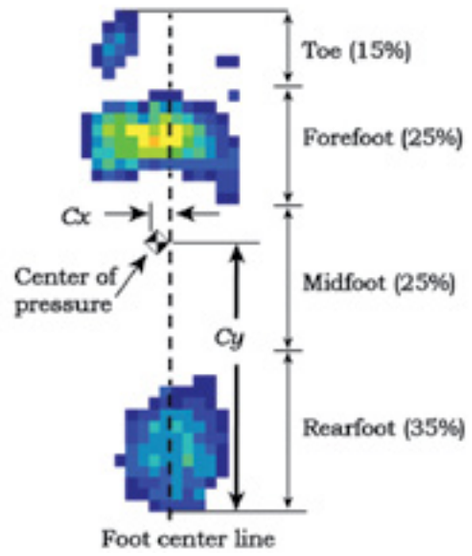
Tekscan's unique ability to trim sensors to specific shoe sizes is beneficial for more than just the simplicity of not ne
specific shoe sizes. This is helpful because certain types of shoes fit differently, so the sensors can be adapted to e
For example, barefoot shoes or a pair of pointed toe high heel will have narrower toe areas than the typical in-sho

**"This study evaluated the effects of the HBS [heel base size] of high-heeled shoes on the COP trajectory, pl
and perceived stability. Different walking speeds and slope angles were assessed to determine possible int
among the HBS, walking speed, and slope angle. The results can be a reference for designing ergonomic hi
shoes and walking healthily."**

Luximon, Y., et al. 2015. '**Effects of Heel Base Size, Walking Speed, and Slope Angle on Center of Pressure Trajectory and Plantar Pressure When Wearing High-Heeled Shoes.**' Human Movement Science. 41: 307-3019.[8]

The authors found:

> *The HBS [heel base size] significantly influenced the trajectories of the COP and the plantar pressure distributions, thus changing the walking stability and perceived stability.*



A View Inside the Shoe

A force plate can collect data barefoot or shod, but it cannot capture the movements and interaction between the foot and the shoe. This is where in-shoe pressure measurement can provide insights into exactly how the foot is functioning inside the shoe. This is essential information for certain pathologies and especially for shoe manufacturers.

- Test effects of orthotic materials
- Evaluate foot function/movement in various shoe designs and styles

Pressure Mapping for Footwear Testing

SATRA is a research and testing organization in the U.K. which has been in existence for over 100 years. It is a leading organization in the testing of footwear. One tool used by SATRA for footwear testing is in-shoe pressure mapping.

'SATRA's Pressure Mapping Capabilities'. SATRA Bulletin. January 2019.[9]

> *The ability to visualize and measure underfoot force and pressure has been invaluable to many researchers and medical personnel wanting to better understand the dynamics of underfoot forces and foot-shoe interaction. It offers an excellent way of quantifying the comfort of footwear.*

Some benefits of using in-shoe pressure measurement for footwear testing or manufacturing:

- Ability to test differences in:
  - Cushioning
  - Inserts
  - Gel
  - Sole materials
  - Evaluate comfort of feel-through footwear, like studded or cleated sports shoes
- Freedom to test a variety of conditions
  - Jumping
  - Running
  - Navigating obstacles

Cost Effective Alternative for Balance Testing

The force plate is considered the gold standard for balance/gait research, but for labs searching for alternative and affordable ways to capture balance information, like Center of Pressure (CoP), pressure measurement technology could be a viable solution. More research is being conducted to help improve the lives of patients with a variety of conditions. For some of those patients, travel to a gait lab could be difficult, so the portability this technology provides along with the affordability and ease of set-up are beneficial.

In the research example below, the study examined standing balance with both a pressure measurement mat and a force plate for 30 typically developing children and 30 children with Cerebral palsy, to determine the validity of a pressure mat. Additionally, they were looking to determine specific variables to evaluate, for discriminating differences between the two populations.

Bickley, C., et al. 2019. '**Comparison of Simultaneous Static Standing Balance Data on a Pressure Mat and Force Plate in Typical Children and in Children with Cerebral Palsy.**' Gait & Posture. 67: 91-98.[10]

The researchers found that:

> *Reliable and valid measures of static standing balance can be produced with a plantar pressure mat for typically developing and children with CP.*

The authors comment, 'this study provides the clinician with a small set of variables that can be tested on a portable device, encouraging the utilization of balance assessment in a variety of settings.' By validating an additional tool for clinicians to conduct balance assessments and providing specific variables evaluate this will hopefully make balance testing more accessible to clinicians in smaller facilities without access to force plates.

Conclusion

Every piece of equipment and technology in a gait lab should offer valuable insight to help fulfill your needs and goals - but those can vary. What is standard in one facility may be less useful in another. Objective data is one element that is helpful in nearly all situations. That is what Tekscan aims to provide. The aforementioned examples only scratch the surface of a deep collection of applications for this technology.

Additional Resources

Visit **www.Tekscan.com/Medical** to Download these Free Resources

To browse even more examples of Tekscan systems in action, Check out Tekscan's bibliography here:

Tekscan.com/medical-bibliography

For help choosing the right system for your needs, check out Tekscan's Guide to Gait Analysis Solutions here:

Tekscan.com/gait-guide

Citations

[1] Smale, K.B., Graham, R.B. 2019. 'The Application of a Neural Network to Improve Plantar Pressure Mapping Accuracy.' Presented at the 2019 International Society of Biomechanics

[2] Ard, R., Melaro, J., Carnall, A., Nelson, A., Blackmore, S., White,V., Paquette,M., Powell, D. 2019. 'Validation of the Tekscan Strideway Plantar Pressure Mat Compared to a Force Platform.' Paper presented at 66th Annual Meeting of American College of Sports Medicine, Orlando, FL.

[3] Murray, N., Moran, R., Islas, A., Pavilionis, P., Szekely, B., Alphonsa, S., Howell, D., Buckley, T., Cipriani, D. 2020 'Sport-related Concussion Adopt a More Conservative Approach to Straight Path Walking and Turning during Tandem Gait.' University of Nevada-Reno.

[4] K.E. Peyer, C. Brassey, K. Rose, W.I. Sellers, '**Locomotion Pattern and Foot Pressure Adjustments During Gentle Turns in Healthy Subjects**.' Journal of Biomechanics (2017), doi: http://dx.doi.org/0.1016/j.jbiomech.2017.06.025

[5] S. Mineta, T. Inami, R. Mariano, n. Hirose, '**High Lateral Plantar Pressure is Related to an Increased Tibialis Anterior/Fibularis Longus Activity Ratio in Patients with Recurrent Lateral Ankle Sprain**.' Journal of Sports Medicine 2017. 8: 123-131.2

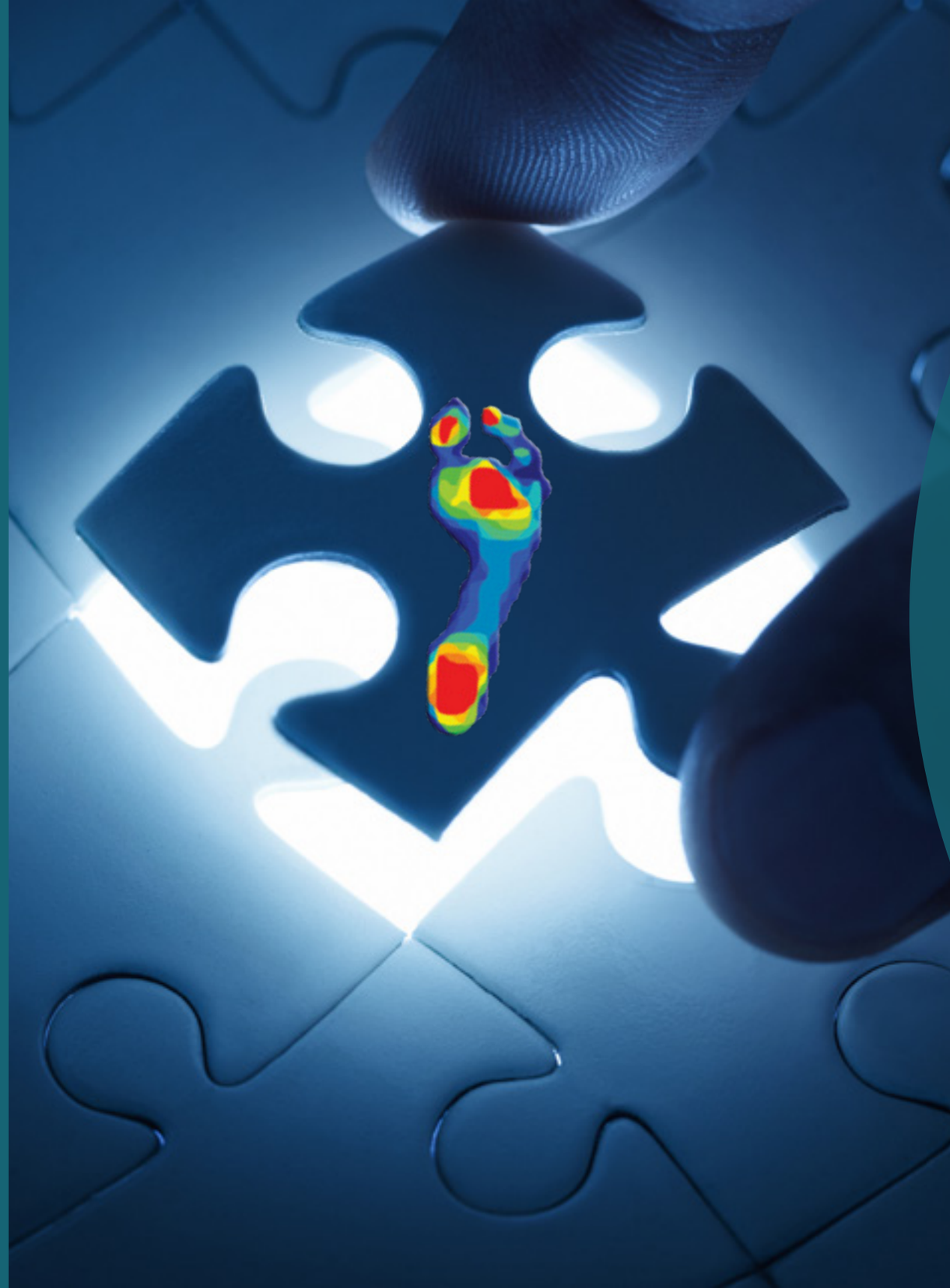
[6] Karekla, Xenia & Tyler, Nick. (2015). '**Gait and Balance of Moving Bus passengers**'.

[7] Becker, J. & Jackson, R. & Nakajima, M. & Wu, W. (2016). '**Changing Where Force is Applied Influences Force Parameters During Ergometer Rowing.**' 2191 Board #343 June 2, 2:00 PM - 3:30 PM. Medicine and science in sports and exercise. 48. 621. 10.1249/01.mss.0000486864.49544.f4.

[8] Luximon, Y. et al. 2015. '**Effects of Heel Base Size, Walking Speed, and Slope Angle on Center of Pressure Trajectory and Plantar Pressure When Wearing High-Heeled Shoes**.' Human Movement Science. 41: 307-3019.

[9] **SATRA's Pressure Mapping Capabilities'**. SATRA Bulletin. January 2019.

[10] Bickley, C., et al. 2019. '**Comparison of Simultaneous Static Standing Balance Data on a Pressure Mat and Force Plate in Typical Children and in Children with Cerebral Palsy.**' Gait & Posture. 67: 91-98.7



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Tekscan™