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Force Plate Use in Performance Monitoring and Sport Science Testing

by George Beckham, Tim Suchomel and Satoshi Mizuguchi

ABSTRACT

Force plates are useful for examining the kinetic characteristics of an athlete's movement. They provide information about the external forces involved in movement that can aid a coach or sport scientist to quantitatively evaluate the athlete's execution of a skill or his/her physical development. Obtaining data of the highest quality and minimising error requires an understanding of the inner workings of a force plate, as well as the process by which data are transferred, processed and analysed. Knowledge of these helps validate whether the results produced are representative of what is actually happening on the force plate rather than error. The aim of this article is to inform coaches and other practitioners about the principles of force plate operation, including the theoretical basis, forces plate design and function, key aspects of data acquisition and technical information of note. The authors also provide a discussion of their laboratory's set up and their work with force plates as a practical example of how these tools can be used.

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Introduction

All movements are better understood by examining the forces involved. Measurement of forces applied by an athlete can aid a coach or sport scientist to quantitatively evaluate an athlete's execution of a skill or physical development. For example, data of the forces applied to the ground in a vertical jump provide a picture of the explosive abilities of the athlete, as well as an indicator of his/her progress if measurements are made at multiple times.

Force plates and other force measurement devices (e.g. S-type load cells, pressure sensors) are used to assess external forces generated by athletes. Many force plates can simultaneously measure external ground reaction forces (GRFs) in three planes - vertical, anterior-posterior, and medial-lateral. These measurements provide a detailed picture of the interaction between an athlete and the ground. GRFs and other variables derived from them have been shown to have moderate relationships with a number of other performance measures, including one maximum repetition back squat[20,22], agility[20,22], and sprint performance[20,22,25,31]. Further, it is possible to use GRF data to differentiate between high-level senior and junior rugby players[12], power athletes, bodybuilders and recreational athletes[28], as well as younger and older adults[14].

Obtaining data of the highest quality and minimising error requires an understanding of the inner workings of a force plate, as well as the process by which data are transferred, processed and analysed. Knowledge of these processes helps validate whether the data produced are representative of what is actually happening on the force plate rather than error.

The aim of this paper is to inform coaches and other practitioners about the principles of force plate operation and, including the theoretical basis, forces plate design and function, key aspects of data acquisition and technical information of note. In addition, information about our laboratory is presented as a practical example of how these tools can be used for athlete performance monitoring and research.

Theoretical Basis

Movement is described by kinematic and kinetic characteristics. Kinematics studies the trajectories of points, lines and other geometric objects and their differential properties such as velocity and acceleration and contributes to a visual analysis of skill. In kinetics, we observe the torques and forces related to movement. Kinetic characteristics are ultimately what cause movement, but must be observed indirectly (e.g. using a force plate).

Newton's three laws of motion are important for understanding ground-based propulsion. The first law explains that an object with no force acting upon it will either remain at rest or at a constant velocity, i.e. without force, there will be no change in movement. The second law states that the acceleration or change in velocity of an object is proportional to the forces applied to it (represented by the equation *force* = *mass x acceleration*). The third law explains that when a force is exerted on an object, the object exerts a simultaneous force that is equal to and opposite in direction to the original force.

By combining laws two and three, it can be understood that when an athlete applies vertical force to the ground, the ground applies an equal, reactive force back against the athlete. It is this reactive force that ultimately results in the vertical propulsion of the athlete off the ground. In other words, forces always occur in pairs - an athlete pushes against the ground and the ground pushes back at the same time, with the same magnitude but in the opposite direction.

The reactive forces applied to the athlete are termed ground reaction forces or GRFs (see Figure 1). Key facts that should be understood with this concept are 1) all ground-based movement is a function of the forces applied to the ground, even during horizontal movements such as running, and 2) a difference in forces result in differences in how a movement in executed, for example if an athlete jumps two times with different amounts of total force, the jump with more total force will be higher.

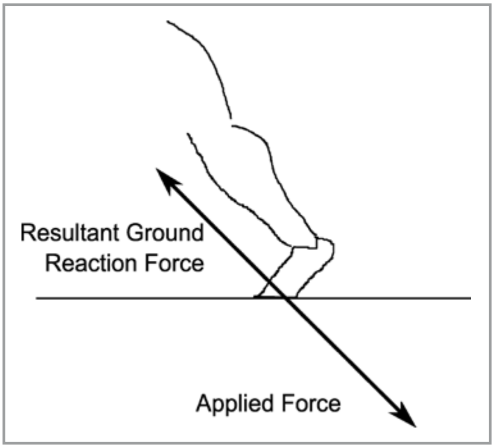


Figure 1: Example of ground reaction force

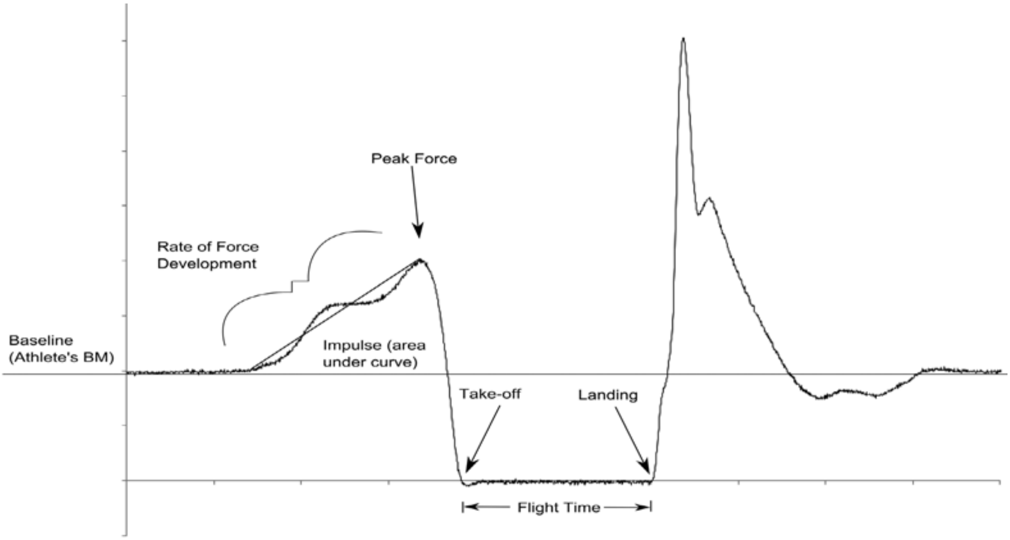


Figure 2: Jumps with variables

Measurement of forces involved with ground-based activities is typically made using force plates. Figure 2 is an illustration of some of the many characteristics of interest in a countermovement vertical jump. It should be clear that there is a vast amount of information available from force plate data that is not necessarily available from other testing methods. For example, vertical jump height is often used as a performance marker of explosive ability. While jump height is an important measure, it is not necessarily detailed enough to illuminate some of the differences between jumps. Figure 3 is an example of a number of jumps over time that shows negligible differences in jump height, but larger differences in other variables (e.g. peak force, rate of force development, impulse). A sport scientist or coach may not have seen differences between jumps if jump height was the only measure used.

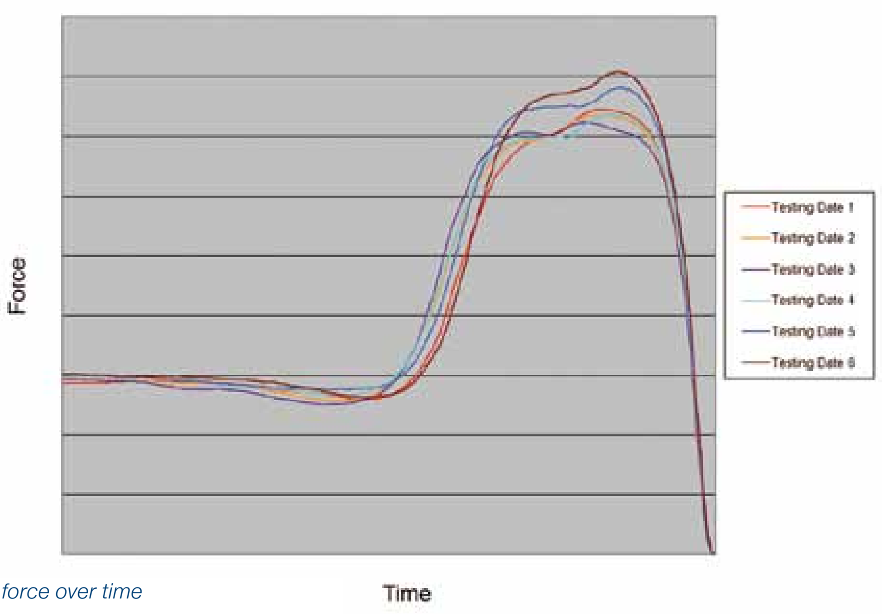


Figure 3: Jump force over time

Force Plate Design and Function

One of the qualities of force, the tendency to distort, is the reason force plates are able to measure applied forces. When an athlete applies any kind of force to the force plate, sensors within the plate distort, causing measureable voltage changes coming from the sensors. In a properly constructed force plate, these voltage changes are proportionate to the magnitude of the forces applied. In many force plates, sensors are configured in different orientations allowing for the direction and magnitude (i.e., vector) of the forces to be ascertained. Important pieces of information can be obtained from a modern, full-featured force plate include:

- force in the X, Y, and Z directions,
- the centre of pressure,
- the centre of force,
- the moment (torque) around each of the axes.

The data collected allows the investigator to calculate a multitude of other variables from the initial measures. For example, using trigonometry, the magnitude and direction of applied forces can be monitored.

Force Transducers

Within a force plate, forces are measured through a force transducer, which functions to convert "physical states into electrical signals”[26]. The force applied to the plate is converted or transduced into a measureable, electrical voltage by what are known as load cells. There are a variety of load cell types including piezoelectric transducers, strain gages, and beam load cells. Each type of load cell receives an “excitation” voltage input, which in turn produces a different electrical current proportional to the load experienced by the transducer[1]. After that, the operation of the various types differs in a few distinct ways.

Piezoelectric transducers operate on the basis that when a force is applied to a piezoelectric material, such as certain crystals, ceramics and even bone, a charge proportional to the force appears on the surface of the material. Recording the resultant voltage allows calculation of the applied force. Strain gages and beam load cells operate on the basis that changes in electrical current occur when a metal or semiconductor is deformed[1,24]. A thin sheet of metal or semiconductor material is bonded to a metal object, providing a solid structural device on which to apply the force. Deformations from a force result in changes of the electrical resistance of the bonded sheet, modifying the current moving through it. Piezoelectric cells, strain gages, and beam load cells all have an excitation voltage that is run through them, with the initial input voltage known. Monitoring of the changes in voltage with applied force allows for calculation of the force applied to the device.

A typical tri-planar force plate is constructed with four three-component load cells[17], with each cell measuring force in the X, Y and Z direction. The four cells are arranged in each corner of the force plate allowing for the calculation of the moments about the axes, centre of pressure and centre of force from the individual cells and their location on the force plate

Typically, the forces that are transduced with individual sensors within force plates are summed to obtain a single resultant force as an easy to interpret measure of performance. In a force plate with four vertically-oriented load cells, the forces measured by each of the sensors is summed to give the total vertical force. Likewise, in a force plate with load cells oriented in the anterior-posterior directions, the total force in the anterior-posterior direction is the sum of measured forces in all the anterior-posterior cells.

Signal Flow

Figure 4 shows the flow of the force plate data. Data flows from the initial analog signal output (continuous voltage) obtained from the load cells, to the final digital input signal leading into the final analysis by computer software. The modifed charge is then sent to an amplifier to be scaled up in voltage (the data acquisition device requires a higher voltage than what is output by the load cells). Analog signal processing can occur here. After the signal has been amplified, the current goes to a data acquisition device, where it enters an analog-to-digital (A/D) converter to convert the continuous analog signal to a series of discrete, evenly spaced, digital signals. Further signal processing can occur on the signal, after which the recorded digital signal can be analysed in a software program.

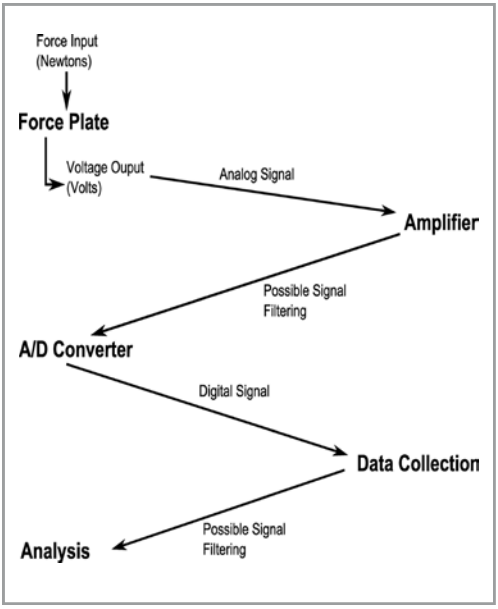


Figure 4: Signal flow diagram

Data Acquisition

Sampling

Monitoring the changes in force applied to the force plate requires sampling at regular intervals. Substantial research has examined sampling frequency in a wide variety of applications (e.g., engineering). In sport science, however, less has been done to examine sampling frequency, although several authors have evaluated the variability of vertical jump performance at different sampling frequencies[2,13,27,29]. VANRENTERGHEM et al[29] found that frequencies above 100 Hz were adequate while HORI et al[13] indicated that 200 Hz was precise for measurement of various force-time variables. Contrary to the previous authors, STREET et al[27] found that sampling rates of less than 1080 Hz could lead to an underestimation of jump height (calculated via the impulse method) by up to 4.4%. Other authors recommend that a sampling frequency of 500 Hz or 1000 Hz ensures greater accuracy, especially when impact is involved[2].

Sampling frequencies must be high enough to ensure precision of measurement and reduction of signal aliasing (where the recorded digital signal fails to accurately show the original signal due to inadequate sampling). The Nyquist Theorem suggests that the absolute minimum sampling frequency is two times the frequency of interest.[2] BARTLETT recommends a sampling frequency of at least 500 Hz[2], however 1000 Hz is a common choice for force plate capture of human motion[17].

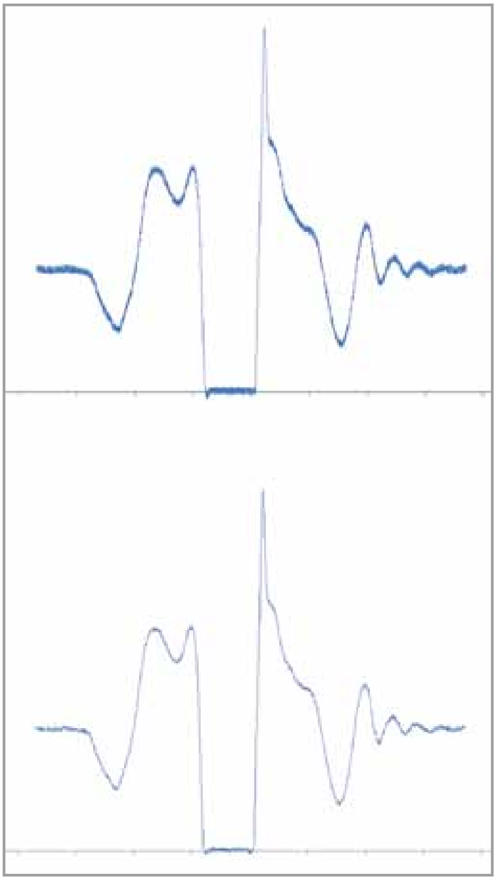
High sampling frequency is important for providing sufficient resolution with regards to force-time curves. If the frequency is low (i.e. 200 Hz) during the first 50ms of force application, this corresponds to a force-time curve consisting of only 11 data points. This will not provide ample resolution with which to examine the changing forces in this short period.

Signal Amplification and Processing

Data collected from the force plate is not useable until signal amplification occurs. Typically, analog signals (the raw voltage values) from the force plate are amplified and sent to an A/D converter[17]. The A/D converts the analog voltage signal into a scaled digital signal, which can then be processed by computer software. Even with an ideal setup, there remain many environmentally-based sources of error in the collected signal. Such sources may include thermal and chemical noise, as well as electrical interference. Thermal noise is associated with the temperature of the device in use. Part of the reason for allowing a device to warm up is to minimise or stabilise thermal noise, as rising component temperatures result in changing electrical noise. Chemical noise is random noise existing everywhere, originating from variations in temperature, humidity, pressure, and other sources. Electrical noise results from devices around the testing area that use electricity. Electrical noise exists at 60 Hz and is progressively weaker at its harmonics - 120 Hz, 180 Hz, etc. For example, if a force platform is placed in a room that has fluorescent lights, air conditioning/heat, and the building is located near power lines, electrical noise may be a substantial source of interference.

Customizable software such as LabVIEW™ (National Instruments, Austin, TX, USA) or Matlab (Mathworks Incorporated, Natick, MA, USA) can perform signal processing to clean up some the noise from the data. Microsoft Excel™ (Microsoft Corporation, Redmond, WA, USA) has also been used for the smoothing out of data. However, it should be noted that many force plates come with proprietary software with both filtering and smoothing methods included. Moreover, most force plates can perform electronic signal smoothing during the amplification process.

A method of data processing referred to as a "moving average" can be calculated with the use of Excel. Figure 5a represents a countermovement jump, with simulated random noise. Figure 5b is the same countermovement jump after applying a 5 ms "moving average" in Excel. There is a direct tradeoff between the method's ability to 'average' out (relatively) random noise, and the sensitivity to change in the signal. If the signal of interest involves very high rates of change, then shorter averaging windows are warranted, as longer windows will soften a curve with a sharp change. Conversely, a noisy signal that does not entail rapid changes may be better processed with a longer moving average. One criticism of this technique is it does not distinguish between noise and true signal, thus it may not actually isolate the true signal as well as a more advanced processing method[6].



Figures 5a & 5b: Samples of moving average

Splines are another smoothing method commonly used in the literature. This method applies sequential polynomial functions to a noisy data signal, creating a "smooth" line closely representing the true signal[2,4]. Piecing together the polynomial functions allows for a more accurate fitting of the curves, since the force patterns of many movements on a force plate are not easily represented by a single polynomial function. Cubic splines (pieced together 3rd degree polynomials) as well as quintic splines (pieced together 5th degree polynomials) are often used in force plate research. Quintic splines may better fit signals with very rapid changes, although the problem of polynomial oscillations can occur (where false oscillations are introduced into the smoothed out signal).

The Fast Fourier Transform (FFT) is useful for identifying noise that tends to occur at certain frequencies, as it transforms data from time- to frequency- based, indicating the "amount" of signal at different frequencies in the newly transformed data[9]. The FFT shows both the signal of interest and the noise in the signal, which then allows for relative ease in identifying in which frequencies the data is noisy. For example, an FFT would reveal a high density of signal around 60hz (and harmonics of 120hz, 180hz) if there was a significant amount of electrical noise collected into the signal. The FFT can be very useful for identifying consistent noise in a signal, so that a particular filter can be applied to reduce the noise that tends toward certain frequencies. Further, an FFT can also help to identify the range of the frequencies of the data of interest, so that noise outside of the key range can be filtered out using another type of filter.

Filters are generally termed high-, low-, band- pass, notch, and stop-band[6,9]. Filtering can be done on either the analog or digital signal, or both. A low-pass filter eliminates frequencies in the signal above a certain frequency, while a high-pass filter eliminates frequencies below a cut-off frequency. Sometimes it is necessary to restrict the data collected to a range of frequencies, in which case a band-pass filter is appropriate. Other circumstances necessitate eliminating a certain range of frequencies from a signal; a notch (small range) or stop-band filter (larger range) will be able to accomplish that task.

Butterworth filter methods are commonly used in biomechanics, and are considered well-suited for biomechanical variables[6]. Butterworth filters operate sequentially through time-series data, causing a phase-shift, which is usually re-run backwards through the data, correcting the shift[6,9]. The order of the filter refers to the "sharpness" of the filter's transition through the transition band. A higher order filter will have a sharper cutoff, thus the transition between frequencies that are kept and those that are discarded is more distinct.

Each of these methods operates differently. When the optimal filter or smoothing technique is applied to a signal, the end result will be the same i.e., less choppy and smoother, with the data being “cleaner” and easier to analyse. Unfortunately, it is difficult to provide recommendations on filtering methods that would apply to all situations. In turn, it is not wise to rely entirely on previous literature, as not all laboratory situations and movements are affected by the same noise and sources of error[6,9]. However, use of prior literature with similar testing procedures can be a starting point, but ultimately filter selection should be made on an individual basis[4,6,9]. Frequency-domain techniques, like the FFT, can be very useful in determining which filter or smoothing method to use on signal data.

There are a number of automated selection procedures for choosing a filtering/smoothing method, but the methods are "to some extent 'black box' techniques, which should be used with caution"[4]. For more detailed information on signal processing, the reader is directed to BARTLETT[2], CHALLIS[4], DERRICK[6] and STREET et al[27]. Regardless of the end-user’s final choice on a filter, the general recommendation for filter choice is the one that most effectively and accurately isolates the signal of interest, without sacrificing data accuracy.

Calibration

Force plate calibration is necessary to establish a regression equation to calculate GRFs from the output voltage of the force plate. Since force plates only provide an output voltage, a calibration equation is required to calculate the actual GRFs. Too often, little is done by scientists and coaches to address the proper calibration of force plates or to re-evaluate currently used methods[11]. While calibration of some of the testable variables of the force plate can be difficult, it is absolutely necessary given the immense error that can be introduced into variables of interest[11].

The general idea behind calibration is that a range of known forces is applied to the force plate observing the resultant voltage given by the load cells. This method creates a regression equation[1]. For instance, a common method for calibrating in the Z-direction, is to place a range of “dead weights” of known value on top of the plate. This weight is associated with an output voltage allowing the researcher to calibrate the force plate. Calibration of the horizontal forces, torque, and centre of pressure or centre of force can be a more difficult endeavor. However, researchers have proposed methods of calibration that are possible in the laboratory environment, such as a pulley system for X- and Y- direction recommended by HALL et al[11]. With this system, a regression equation is created from the output voltages in relation to progressively higher (horizontally) applied loads. A pendulum system for dynamic calibration designed by FAIRBURN et al[8] is also a possibility for more advanced calibration.

Technical Information of Note

Force plate technical reports typically contain a data table with information about some or all of the following: linearity, hysteresis, crosstalk, and/or natural frequency. Each of these items provides valuable information about the characteristics of the force plate, as each affects the data obtained (for recommended ranges refer to Table 1).

Table 1: Guideline values for force plate characteristics

Linearity---------------------------	≤0.5% of full-scale deflection
Hysteresis-------------------------	≤0.5% of full-scale deflection
Crosstalk--------------------------	≤0.5% of full-scale deflection
Natural Frequency----------------	≤800 Hz
Maximum Frequency Ratio-------	≥0.2

Linearity

Linearity is the maximum deviation of collected force plate data from a straight line[2]. Perfect linearity is ideal, but is not necessarily a requirement for accurate data collection and analysis, as it can be calibrated by applying a higher order polynomial to the data points[2]. Linearity can be expressed as: $y \cdot Y^{-1} \cdot 100$ (where: y = maximum deviation from linearity, and Y = full-scale deflection[2]. Full-scale deflection refers to the voltage output with the highest load within the limit of the force plate. Dividing deviation from linearity by the highest voltage achieved gives a relative measure of linearity, which can be compared to the standard given in Table 1.

Hysteresis

Hysteresis is the difference in output values seen during the loading and unloading of a material[2]. Hysteresis should be minimised, as many force plate measurements involve both a loading and unloading component (see Figure 6). For example, large hysteresis in a load cell might over-estimate the forces in the eccentric portion of a squat, while correctly estimating the forces during the concentric portion. Hysteresis is sometimes seen as a result of a mechanical lag in deformity during the return to normal shape occurring during loading of the force transducers. Hysteresis can be calculated with the equation: $(X_L - X_U) \cdot Z^{-1} \cdot 100$, where X_L = output voltage for a given load, X_U = output voltage for the same load during unloading, and Z = full scale deflection[2].

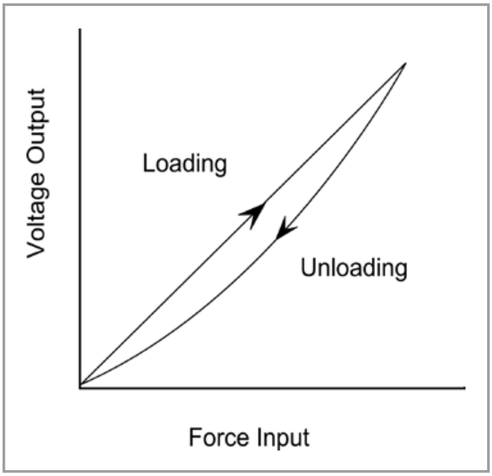


Figure 6: Example of hysteresis of a force plate

Cross-Talk

Cross-talk refers to the interference of force in one component direction with the measurement of force by a component in another direction[2]. Many force plates measure forces in multiple planes; the components required to measure the different directions generally have at least a minor amount of cross-talk. It is important that this quality is minimised, preventing an error in measurement, falsely attributing forces to an incorrect source. BARTLETT has stated that less than 3% of full-scale deflection is preferable[2].

Natural Frequency & Maximum Frequency Ratio

When struck, every object has a frequency at which it will tend to vibrate[4]. Force plates are constructed of multiple materials, and may contain multiple frequencies. Force plate manufacturers often report this natural frequency in order to insure the proper set up. Force plates generally have high natural frequencies aiding in the ease of isolation through filtering. For example, the Kistler Type 9281E Triplanar force plate (Kistler Group, Winterthur, Switzerland) has a natural frequency of 1000 Hz. The high natural frequency of this force plate allows the measurement of the impact activities of sports, which can surpass 100 Hz[2]. The ratio of frequency of the measured skill to natural frequency of the force plate (Maximum Frequency Ratio) should be less than or equal to 0.2, so that the information of interest in the signal can be effectively isolated from the natural frequency of the plate (refer to Table 1 and 2).

Table 2: Frequencies of selected cyclic movements

Study	**Skill**	**Frequency (single limb)**
Mackala[18]	0-20m of 100m Sprint	2.16 Hz
	70-80m of 100m Sprint (Max Velocity Phase)	2.28 Hz
Ounpuu[21]	Walking at 1.2 m/s	1.1 Hz
	Running at 2.23 m/s	1.67 Hz

Minimising Error

The possibility of inaccurate measurements must be minimised if accurate conclusions are to be drawn. Certain steps can be taken to reduce the possibility of error, although even the most optimal setup will have at least a small amount of error. First and foremost, if a user does not know how to properly use the force plate and the associated software he or she may be the source of error, which is an argument for this article and general education about the basics of force platform use. Adherence to the recommendations by BARTLETT[2] will also ensure accuracy of the data obtained from the plate, as any deviance of the force plate characteristics outside of the recommendations increases the risk of inaccuracy. For example, LEES & LAKE[17] and HALL et al[11] have demonstrated how cross-talk of even 1% could introduce a large degree of error in some gait measurements.

Calibration should occur over a range of loads, from unloaded to above the highest expected load, within the manufacturer-specified loads (if the expected loads are outside of the range, then a new plate with greater load range is necessary). Without calibration up to at least the highest expected forces it cannot be known if the calibration equation acquired represents the higher-range forces that will be measured. For example, in an isometric mid-thigh pull, where measurements of vertical GRF can exceed 7000 N[3], the force plate should be calibrated in the Z-axis with loads ranging from 0kg to more than 700kg. For horizontal calibration, a pulley system, similar to the one designed by HALL et al[11] should suffice. Dynamic calibration is more tricky, requiring expensive equipment or complex methodology. If such a calibration is required, it is best to enlist the services of major force plate companies or private metricians.

In all devices, the measured value is the result of a "true" plus "error" score. Even though steps can be taken to eliminate as much error as possible, a degree of error will always be present in the collected data. It is up to the tester to eliminate and reduces as many sources of error as possible, and to make a theoretical

Figure 7: Force plate and computer set-up in the sports science laboratory

and logical judgment as to how much error in the collection is acceptable.

Finally, the methodology and calculation methods must be sound for the specific tests being used (e.g. DUGAN et al[7]), although this is outside the scope of this article.

Our Laboratory

The following is a discussion of the use of force plates at the Sport Science Laboratory at East Tennessee State University in Johnson City, Tennessee, USA, as an example of a working laboratory.

Equipment and Processing

To reduce contamination of data from extraneous sources, all force plates in the laboratory sit on a level concrete pad that is on the ground floor of the building. While the laboratory uses tri-directional force plates, the majority of the force plates we, the authors, use are unidirectional, and measure only vertical forces (see Figure 7). Although it is a drawback to only allow collection in the vertical direction, the plates offer a substantial reduction in cost compared to other plates offered by Kistler™ or AMTI™. Furthermore, a number of studies have demonstrated that vertical forces and vertical-oriented skills have strong relationships to explosiveness and speed in sporting movements; thus measurement of vertical forces is of substantial importance[10,16,30,31]. In addition, we use force plates (0.914 x 0.46m; Rice Lake Weighing Systems, Rice Lake, WI) situated side-by-side to allow for the collection of unilateral (i.e., single leg) force data. For bilateral data collection, the forces from each force plate are summed.

Each plate in the laboratory is interfaced to an amplifier and conditioner module (Transducer Techniques TM0-2, Temecula, CA, USA). The amplifier provides both the excitation signal (the initial current going to the load cell) and amplification of the analog signal. Situated between the amplifier/conditioner and the A/D converter is a shielded connector block, [BNC-2110 (National Instruments, Austin, TX, USA)], which transfers the analog

Table 3: Example of force plate applications

Study	Measure
Kraska, et al.[16]	Jump Height for Countermovement and Static Jumps at Various Loads
Leary, et al.	Instantaneous Force at 30 ms, 50 ms, 90 ms, 100 ms, 200 ms, and 250 ms in measured in the isometric mid-thigh pull
Mizuguchi	Evaluated the use of vertical jump net impulse as a variable for athlete performance monitoring
Sato and Heise[23]	Investigated weight distribution asymmetry between right and left legs during the barbell back squat
Jensen and Ebben[15]	Various rate-of-force development measures across multiple plyometric exercises
Beckham, et al.[3]	Isometric peak force, measured at 3 key conventional deadlift positions and the isometric mid-thigh pull

signal to the A/D converter. In turn, the block is connected to another instrument [DAQCard-6063E (National Instruments, Austin TX, USA)], which converts the analog to a digital signal.

The acquired signal is analysed with custom software developed in LabVIEW™ (National Instruments, Austin TX, USA). This software samples the analog signal at 1000 Hz and has been set up to save the digital signal file and filter the digitised signal using a 4th order low-pass Butterworth filter at 100 Hz. From there, the signal is now ready to be analysed for any variables of interest.

The Data Collection Process

Prior to calibration, force plates, amplifiers, A/D converters, and computers are turned on so that all of the collection equipment can warm up, thus stabilising thermal and instrumentation noise. Calibration of the force plates is performed immediately before data collection, assuring that the calibration equation used in data analysis is established under similar environmental conditions as the data collection. This also avoids a potential shift of voltage output over time. After the warm-up period, force plates are calibrated using loads from 0 to 350kg or 500kg, depending on the specific use of the plate (either jumps or isometric pulls, respectively). The plates are progressively loaded in 25kg increments, with the output voltage recorded with each new plate. A linear regression equation is then applied to the calibration load. This regression equation is saved, and used in the LabVIEW™ program during analysis.

Data Use

The majority of information we obtain from the aforementioned set-up is related to one aspect of performance monitoring conducted on a regular basis (2-4 times per year). As we evaluate variables related to maximal strength, isometric rate of force development, and explosive performance in static and countermovement jumps with a variety of loads, we have a very good picture of the general abilities of the athletes. Single assessments provide information for valuable normative comparisons against normative data while multiple assessments over time provide a worthwhile view of changes in performance that an athlete or group of athletes experience over the training process. In both testing cases, this data can help substantially in programme development and future planning of training.

Conclusion

A full understanding of a testing device and its characteristics is an integral part of accuracy, validity and reliability of testing. The force plate is a rather complex device. The complexities of the device and its peripherals allow the user to collect a large variety of high-quality data for analysis that are difficult to obtain via other means. This diversity of data gives options for a large variety of analysis projects (see Table 3). While it is somewhat difficult to master use of the device, the information obtained from a force plate makes the endeavor worthwhile.

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