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Title: A device for testing the dynamic performance of in situ force plates

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Abstract

Background: Force plates (FPs) are often incorporated into motion capture systems for the calculation of joint kinetic variables and other data. This project aimed to create a system that could be used to check the dynamic performance of FP in situ. The proposed solution involved the design and development of an eccentrically loaded wheel (ELW) mounted on a weighted frame. Methods: The frame was designed to hold a wheel mounted in 2 orthogonal positions. The wheel was placed on the FP and spun. A VICON™ motion analysis system captured the positional data of the markers placed around the rim of the wheel which was used to create a simulated force profile, the force profile was dependent on spin speed. The RMS error between the simulated force profile and the FP measurement was calculated. Results: For nine trials conducted, the RMS error between the 2 simultaneous measures of force was calculated. The difference between the force profiles in the x and y directions is approximately 2%. The difference in the z direction was under 0.5%. Conclusions: The ELW produced a predictable centripetal force in the plane of the wheel which varied in direction as the wheel was spun and magnitude dependent on the spin speed. There are three important advantages to the ELW: 1) it does not rely on force measurements made from other devices; 2) The tests requires only 15 minutes to complete per FP; 3) the forces exerted on the plate are similar to those of paediatric gait.

Keywords: Dynamic calibration check, Force plate, Gait Analysis, Modelling/ Simulation [Biomechanics], Dynamics [Biomechanics]

Introduction

Force plates (FPs) are incorporated into motion capture systems for the calculation of joint kinetic variables. As part of a programme of quality assurance, routine calibration checks should be undertaken[1]. The accurate calibration of FPs is often checked using a rigid pole within which motion capture markers are embedded as described by Baker[2]. Integration of a force transducer allows the measurement of force magnitude[3], but requires an external calibration of the force transducer.

Gantry systems are also used to assess FP performance[4]. Criticism of these systems include, the time taken to conduct the tests and the size of the systems. Fairburn *et al*[5] created a pendulum device which compared the FP performance to a theoretical solution. Uncontrolled movement within the system contributed to disappointing results. The device was also required to be bolted to the FP. Morasso *at al*[6] used a similar principle to develop a device for spot checking the centre of pressure measurements. Their sophisticated device allows a mass to be moved along a spinning arm. Their results can be visually inspected to ensure the platforms are performing within their required limits.

In this technical note we describe a system that evaluates FP performance against a theoretical solution. The device was required to be removable, requiring no alterations to the FPs or laboratory and operational by an individual.

Methods

Design and construction

An eccentrically loaded wheel (ELW) was mounted on a weighted frame. The frame was designed to hold a quick release Invacare XTR (Invacare Corporation) wheel mounted in 2 orthogonal positions (Fig. 1), with an eccentric mass of 1.05kg mounted at a point on the rim.

Lead masses added weight serving the dual purpose of minimising movement between the device and the FP, and creating a dynamic profile that simulates paediatric gait. Castor wheels, with retracting rubber feet, allow the device to be wheeled onto FPs and secured. Once in place the wheel is spun by manually applying a perturbing force. Once the wheel in motion the simulated profile and the measured profile are compared. The static weight of the system is 37.2kg.

'Figure 1 inserted about here'

Theory

For a spinning ELW the only varying force on the system is a centripetal force due to the velocity of the eccentric mass. Equations 1 and 2 explain the conversion from the positional data to tangential and angular velocity when the wheel is orientated in the x-y plane (here, the horizontal plane). When the wheel is orientated perpendicular to the FP surface a calibration check can be performed of the vertical forces (here, in the x-z, or y–z planes).

$$v_{tan} = \frac{\sqrt{(x_t - x_{t-1})^2 + (y_t - y_{t-1})^2}}{dt} \qquad (1)$$

Where x and y denotes the position of the marker in the x and y directions, *dt* is the time elapse for each frame, t denotes the frame.

$$v_{angular} = \frac{v_{tan}}{R_{wheel}} \qquad (2)$$

To compute the numerical solution the eccentric mass was divided into elements, of 0.0001m depth. The angular velocity at the marker was calculated as angular velocity was constant across the mass. The tangential velocity of each element (from the angular velocity) and the force (Equation 3) exerted due to each element was computed. These centripetal forces were then summed (Equation 4) to compute the overall centripetal force.

$$F_{\partial m} = \frac{m_{\partial m} {v_{tan\partial m}}^2}{R_{\partial m}} \qquad (3)$$

$$F = \sum F_{\partial m} \qquad (4)$$

The force measurements from the FP were split into the 3 components of force so the forces were resolved for direct comparison. The direction of the force vector was computed as the vector from the centre of the wheel to the marker on the rim of the eccentric mass. This is the rotational component of centripetal force, there is a tangential component however this was omitted as its contributions were considered negligible.

Experimentation

An AMTI OR6 (Advanced Mechanical Technology, Inc, USA) FP's performance was tested. A VICON™ (Vicon Motion Systems Ltd, UK) motion capture system comprising of 7 T-10 Series Cam infrared cameras, sampling at 120Hz, was used. Data were processed using Nexus™ 1.8.5 (Vicon Motion Systems Ltd, UK). FP data were filtered using a 4th order Butterworth filter and marker data were filter using a woltring filter. A C3d file was generated. Matlab 7.0 (The MathWorks, Inc) was used to read the C3d file and generate the simulated profile. FP data was superimposed onto the simulated profile (Fig 1), the RMS error was calculated. The wheel was placed on the FP and spun 9 times. A marker was placed on the eccentric mass at the rim and its position was recorded; this marker defined the velocity of the mass and the direction of the centripetal force.

Results

The results are displayed in Table 1. The RMS error between the two force profiles was calculated. The initial perturbation was not included in the error calculation as this was not a controlled force. The difference between the measured and simulated force in the x and y directions were under 2.5% of the total force in the x and y direction. The difference in the z direction was under 0.5% of the total force in the z direction.

'Figure 2 and Table 1 inserted about here'

Discussion

We developed a device for in situ calibration checks of FPs. The ELW produced a predictable centripetal force in the plane of the wheel which varied in direction as the wheel was spun. When the wheel was spun in the plane of the z direction it was clear that gravity influenced the force. The velocity of the mass was tracked directly by the VICON system and therefore the effects of gravity were built into the numerical solution. The reaction to the oscillating force vector was recorded by the FP and could be compared to the numerical solution.

Figure 3 inserted here

Figure 3 is a plot of the measured force against the calculated force in the x-direction for 5 cycles in a representative trial. There is an energy loss and recovery effect, this is likely to be due to a gravitational force which is not factored into the calculated profile when the wheel is mounted in the horizontal orientation.

The ELW may complement other tests of FP performance which provide estimates of the accuracy of the centre of pressure (e.g. the poker test[2,3]). The usefulness of the device was illustrated in the results from our laboratory which demonstrate a systematic under-reading of forces in both the horizontal and vertical plane.

There are three important advantages to the ELW: 1) it does not rely on force measurements made from other devices (e.g. an instrumented pole[3]); 2) The tests requires only 15 minutes to complete per FP; 3) the forces exerted on the plate can be similar to those of paediatric gait (Fig. 1). The force exerted is dependent on the speed at which the_wheel is spun, to increase the force the wheel needs to be spun quicker. In our experiment the x and y forces varied by 40-50N and the static force in the z direction is approximately 370N and varied by approximately 100N. The force calculation relied on the performance of the VICON™ system, and was therefore susceptible to marker error due to distortion within the capture volume. However, these errors were insignificant in comparison to the error induced by the uncontrolled movement in the system.

Conclusion

The ELW was effective for evaluating FP performance and is now incorporated into the quality assurance protocol at the One Small Step Gait Laboratory. The simplicity of the design for manufacturing allows for a cheap and reliable option for performance checking.

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