MEASURING POLE FORCES IN SEATED SHOT PUT

Connor J.M. Holdback[1], Richard M. Kelso[1], David S. Haydon[2,3], Paul N. Grimshaw[4], Ross A. Pinder[5], Rony Ibrahim[6].

[1]Faculty of Sciences, Engineering and Technology, University of Adelaide, Australia, [2]Athletics Australia, Adelaide, SA, Australia, [3]South Australian Sports Institute, Adelaide, SA, Australia, [4]College of Health and Life Sciences, Hamad Bin Khalifa University, Doha, Qatar, [5]Paralympic Innovation, Paralympics Australia, SA, Australia, [6]Department of Physical Education, Qatar University, Doha, Qatar.

The measurement of throwing pole forces in seated shot put has not been reported previously in the research literature, forming a considerable gap in the understanding of seated throwing. In this research, two methods for pole force measurement are presented: a deflection-based and a direct load-sensing method. From the comparison of each method, the measurement of pole forces without an instrumented pole is found to be feasible (RMSE <10%), thus providing a simpler approach for the measurement of pole forces in seated throwing. In addition, an unexpected finding was made, where resonant pole effects are observed during the throw which may have an interaction with the way athletes apply force to the pole. The methods and findings presented are intended to provide a platform for future research.

KEYWORDS: Paralympic, Athletics, Disability, Sport, Seated Throw, Stationary Throw.

INTRODUCTION: Seated shot put accounted for 11 medal events across 22 classifications in the Tokyo 2020 Paralympic Games (for information on classification, see IPC, 2023), making it a key discipline for both participation and high-performance. Analysis of seated shot put at Tokyo 2020 presented the range of different ways throwing poles were used by athletes, where many medal winning athletes were seen to use a pole differently, even within the same class (Holdback et al., 2023). Given these observations, understanding more about how athletes use a pole to support their throwing is an important step in improving performance.

To date, no literature has reported the measurement of pole forces in seated throwing. However, some limited research has investigated the position of the throwing pole, showing that trunk parameters were impacted by changes in pole position (O'Riordan et al., 2017). The importance of further understanding the role of the throwing pole is later reiterated by O'Riordan and Frossard (2020). Since the throwing pole has been seen to impact other throwing parameters, pole specific measurements would enable these interactions to be investigated, and in the future, pole force measurements could then provide value for athletes and coaches. Despite the sparsity of research, relevant insights from other sports could be taken from Nikkola et al. (2018), where skiing pole forces were successfully measured using a load cell placed in each pole.

A crucial step in understanding the use of throwing poles in seated throwing is to develop a method for measuring pole forces. This research presents two methods for measuring pole forces in seated shot put with a comparison of their results.

METHODS: Load Sensing Method: The primary force measurement is achieved using a 3-component load cell and pivot joint at the base of the pole with an overhanging knife-edge support arrangement (Figure 1). This implementation is considered appropriate given small deflections ($\theta < 1°$) of the pole, although this assumption requires assessment post data collection. The cantilever support configuration was considered due to the scarcity of load cells that could measure the bending moment directly at the magnitude expected (estimated based on 0.5-1.0× bodyweight), i.e., the pivot-joint results in zero moment at the load cell. The ME Systems K3D120 load cell (1000N, ± 0.5% error) sampling at 1000Hz was used and later down-sampled to 200Hz by taking an average of the five adjacent samples. This was then filtered with a low-pass filter with a cut off frequency of 50Hz (Doyle et al., 2011).

The load cell system was calibrated with five known loads applied to the pole at a set height using a crane scale (100±0.05kg) to achieve a linear calibration curve ($y = 0.015x$, $R^2 = 0.99$).

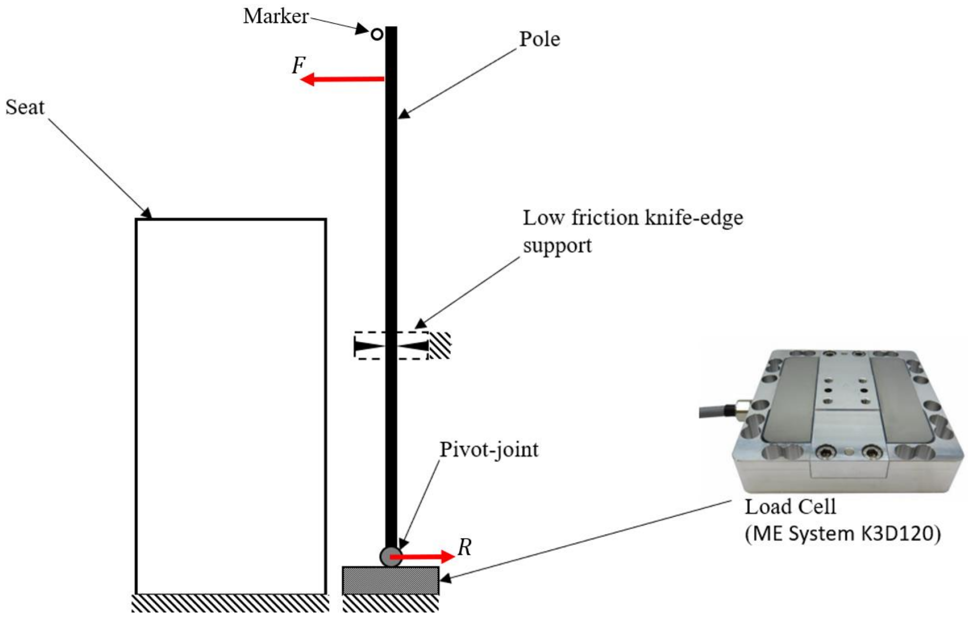

Figure 1: Pole apparatus with the load cell and optical tracking marker.

Deflection Based Method: Pole deflection was captured in 3D using Vantage V8 infrared motion capture cameras (200Hz, VICON, Oxford, UK) with low pass filtering at 10Hz. A marker was placed as high as possible on the pole to maximise the marker displacement, improving optical motion detection. Pole deflection can be compared to the measured loads to establish the characteristics of the system. Once this is established, it can be used to calculate the horizontal forces applied with Equation 1.

$$F = k\Delta_{x_M} \quad (1)$$

Equation 1: Linear elastic equation, F = Force applied to the pole by the athlete, Δ_{x_M} = Deflection of the marker (horizontally), k = System Stiffness, determined experimentally.

The testing protocol had an athlete (female, F34) perform six maximum-effort throws, one of which is presented in Figure 2. The athlete used their own frame with their seat strapping as it would be for competition, but with their usual pole removed to accommodate the instrumented pole which is placed in the same position.

Figure 2: Throw phase visualisation; Preparation Phase, Power Position, Delivery, and Release from left to right respectively.

RESULTS: Figure 3 presents the time normalised mean pole forces ± one standard error over the six trials for both the deflection method and the load cell method, where the duration of the throw is presented from the power position to the point of release (Figure 2). The vertical (Z) component of force measured using the load cell is presented on both graphs for context. The three components of force are defined as follows: X – horizontal force (lateral to medial), Y – horizontal force (back towards the athlete), Z – vertical force (positive down).

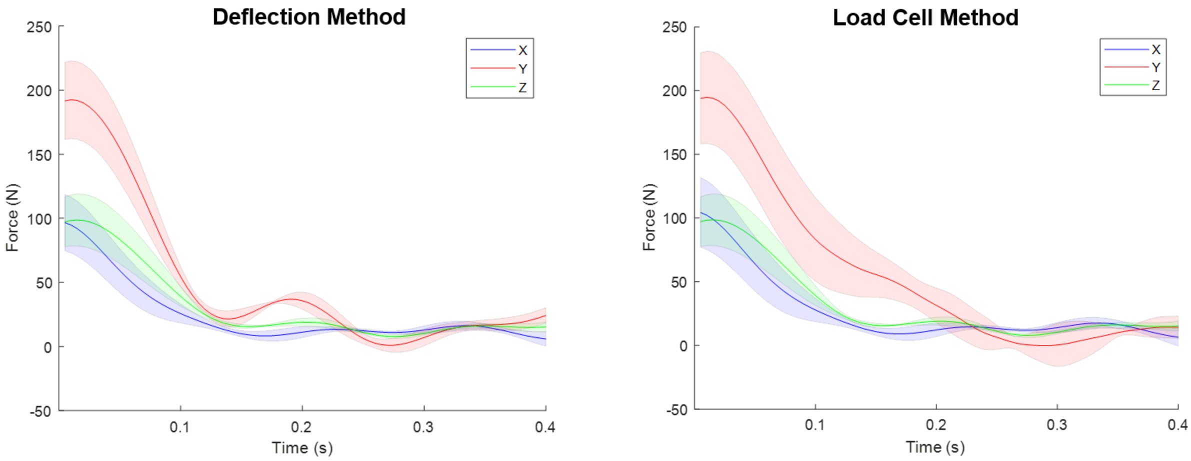

Figure 3: Mean ±SE pole force components for the 6 trials (solid lines = mean, shading = SE).

When compared over the six trials, these two approaches show general agreement with a root mean squared error (RMSE) of 4.8% in the X direction, and 8.1% in the Y direction. However, the deflection method appears to exhibit a transient vibration in the Y-component, seen by a second peak following the first. This cyclic behaviour in the pole deflection suggests a resonant effect may be present at approximately 5-6 Hz. A method for calculating the natural frequencies of overhanging beams is outlined by Blevins, 1979 in Equation 2.

$$f_i = \frac{\lambda_i^2}{2\pi L^2}\sqrt{\frac{EI}{m}} \qquad (2)$$

Equation 2: Natural frequency for overhanging beams, λ_i = modal parameter, L = beam length, E = Young's modulus, I = area moment of inertia, m = beam mass per unit length (Blevins, 1979).

Using this method, the natural frequency was calculated to be 6 Hz. Thus, it seems that the natural frequency mode of the system could explain the transient vibration seen in the data.

DISCUSSION: The pole deflection method was seen to agree with the load cell data regarding peak and overall force (<10% RMSE). Due to this, the deflection method could provide adequate measurements of the horizontal force components in the absence of an instrumented pole. Such measurement of the X and Y pole forces could be achieved using two off-the-shelf cameras placed perpendicular to the intended force measurement directions. However, it is important to note that this is not a direct measure, and unexpected features such as transient vibrations may impact the results, as illustrated by the findings shown above.

Key insights were gained from measuring pole deflection as well as the forces measured by the load cell. The pole deflection indicated a transient vibration that approximates the resonant frequency of the pole. This transient vibration shares characteristics seen with spring-mass systems in response to a ramped force function, similar to that observed by the load cell (Raboud and Westover, 2023). The instrumented pole used here exhibited similar deflection to the athlete's competition pole, suggesting such resonant effects may be occurring in competition that are not visible to the human eye. This is more significant when considering this level of pole flex is observed to be visually similar to many other athletes that competed in the Tokyo 2020 Paralympic Games. Since all athletes must use poles with similar materials and cross sections, as dictated by the rules, it is possible that a resonant effect, although different, may be present with many athletes. This is complicated by the existence of different types of pole-supports used by different athletes. Based on this data, it cannot be claimed that the same type of resonant effect is present for all athletes, but there is likely some resonant effect present that is unique to their specific pole configuration. The effect this may have is unknown, and further investigation is warranted.

The maximum angular deflection of the pole was, in fact, found to be small ($\theta < 1°$), and the knife-edge support and pivot joint implementation are therefore reasonable, however any angular deflection of the pole could introduce error into the measurement of the Z force component. This limitation could only be overcome by measuring pure moments in an unsupported cantilever arrangement, but as previously stated, the load cell used would have to be rated to accommodate such moments. This is something that could be pursued based on the results of this study.

The discovery of a transient vibration, while relevant and important, also presents a limitation to these results. The pole configuration effects the resonance of the system, and while care was taken to approximate the athlete's competition pole, it cannot be said to be the same. Due to this, it is expected that the observed peak forces and ramped load patterns would be similar for the competition pole, but the vibrational features may be different and the effect this might have on the overall forces exerted on the pole is unclear.

CONCLUSION: In this research, the first example of pole forces measured in seated throwing is presented, along with a comparison of two methods for such measurement. In doing so, this work demonstrates the feasibility for measuring pole forces without an instrumented pole, along with the limitations of such an approach. From this, an unexpected finding was made, where resonant pole effects are present during the throw, and the impact this has on the athlete is unknown. However, this poses an interesting question as it is expected that these resonant effects are present for athletes with various types of throwing poles used in competition. Pole forces have not been reported previously, so measuring them is the first step in gaining understanding, but more work is required to better interpret what they mean (i.e., are higher pole forces beneficial and how do different pole positions and grips affect this?) These questions are valuable inquiries for future investigation, and such work can be aided by the methods and findings presented in this research.

REFERENCES

Blevins, R. (1979). Formulas for natural frequency and mode shape. *Van Nostrand Reinhold Company*, 135.

Doyle, M., Warburton, T., Lyttle, A., James, R., Alderson, J. (2011). Measurement of 3-dimensional pole plant forces in an elite pole-vaulter over various approach distances. *Procedia Engineering, 13*, 168-175. doi:10.1016/1877705811009829

Holdback, C. J., Ibrahim, R., Haydon, D. S., Pinder, R. A., Grimshaw, P. N., & Kelso, R. M. (2023). Seated-Shot-Put Equipment in Para Athletics - A Review and Presentation of Data from the Tokyo 2020 Paralympic Games. *Adapted Physical Activity Quarterly, 1*, 1-18.

International Paralympic Committee. (2023). *World Para Athletics Classification Rules and Regulations*. Retrieved from https://www.paralympic.org/athletics/classification.

Nikkola, A., Särkkä, O., Suuriniemi, S., Kettunen, L. (2018). Pole force and inertial measurements to analyze cross-country skiing performance in field conditions. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology,* 232. doi:10.1177/1754337118759359.

O'Riordan, A., Frossard, L., Greenhalgh, A., Miller, S. (2017). Influence of pole position on trunk angle in seated shotput. *XI International Council on Coaching Excellence (ICCE) Global Coaches Conference. Liverpool, United Kingdom,* 264-266.

O'Riordan, A., Frossard, L. (2020). Coaching seated shot put: New perspectives. *Australian Track and Field Coaches Association - Coaching Journal*, 21-29.

Raboud, D., Westover, L. (2023). *Vibrations and Sound*. University of Alberta, 7, 1-5. https://engcourses-uofa.ca/books/vibrations-and-sound.