Institution: University of Lincoln		
Unit of Assessment: 24 – Sport and Exercise Sciences, Leisure and Tourism		
Title of case study: Embedding Scientific Principles into Trampoline Product Development		
Period when the underpinning research was undertaken: May 13 – Dec 20		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
MULLINEAUX David	Professor in Sports Science	5 Jan 11 to date
MULLOY Francis	Lecturer in Biomechanics	1 Feb 14 to date
BROWN Olivia	Research Associate	1 Oct 18 to date
Period when the claimed impact occurred: Oct 18 – Dec 20		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

Research conducted in the School of Sport and Exercise Science, University of Lincoln has influenced trampoline safety and knowledge on a global level. Trampoline design is regulated by the placement of a 'static' load to assess stretch limits, but as trampolines are used dynamically, we developed a new 'dynamic' testing methodology to assess safety. [text removed for publication] The UK's leading producer of trampolines used our dynamic test findings to modify trampoline designs to improve safety, and subsequently support expansion into the USA and Canadian domestic trampoline markets resulting in [text removed for publication] increase in global sales. This led to this UK company becoming a world leading manufacturer by volume. Our dynamic testing research has also informed the European regulation committee responsible for trampoline health and safety.

2. Underpinning research (indicative maximum 500 words)

Accelerations influence whether the body is able to perform effectively creating day to day movement, although inappropriate accelerations have been linked with injury. Repetitive accelerations can cause micro-trauma injuries, whilst high accelerations experienced during impact can cause acute injuries. Researchers within the University of Lincoln collaborated with Harvard Medical School in the USA to produce one of the few prospective injury studies demonstrating that the rate of change of acceleration (i.e. jerk) is a major contributing factor from repetitive impacts **[3.1]**.

To widen the capability of measuring accelerations and risk, we extended our collaboration to investigate using wearable accelerometers to better understand how the human body tolerates accelerations. In analysing 320 Boston marathon runners, and the only biomechanical study to measure accelerations for an entire marathon, we showed that jerk is reduced by certain running techniques upon ground contact, such as, by landing on your toes **[3.2]**

Over the last decade there has been a boom in the use of wearable devices including inertial measurement units (IMUs) for measuring accelerations experienced by people during everyday movements. However, the validity of IMUs to measure accelerations had not been comprehensively explored or empirically verified, hence we experimentally explored calibration methods to improve accuracy. Specifically, we found that by expanding the range of known calibration input, and incorporating a novel mathematical optimisation technique, measurement error was reduced **[3.3]**.

Prior to our work there was limited research on the magnitude of accelerations in recreational trampolining, and no research on the effect of trampoline design on these accelerations. To address this we conducted research to develop a novel and rigorous testing method [text removed for publication]. Over a series of 480 drops across 22 different trampoline iterations,

our research identified trampoline components (e.g. spring stretch characteristics; number of springs) that influenced the accelerations generated on the masses and the movement of the trampoline bed. We developed two predictive equations to estimate peak accelerations and maximal vertical bed deformation [text removed for publication]. These equations were highly accurate, and best for predicting peak accelerations with an explained variance of 96% and standard error of the estimate of 3% **[3.4]**.

To better understand how the human musculoskeletal system develops and tolerates trampoline accelerations, we then conducted research using children. Two age groups, representing different maturation stages of trampoline users (5-7 and 9-11 years old) performed repetitive bounces on trampolines with varying stiffness qualities. Using simple analyses, no interaction between age and stiffness was found, but it was demonstrated that in jumping, age had an effect where older children were found to use their knees more in comparison to younger children who used their ankles more **[3.5].**

Extending our research to explore how different age groups interacted with varying trampoline stiffness, we explored theories related to joint coordination, such as how the ankle and foot move in relation to each other when bouncing. Using this approach, we found that the younger children adopted a strategy of using the ankle to distribute accelerations during impact. Specifically, the ankle was the predominant joint used for 42% of the bed contact time during bouncing with a low stiffness trampoline which increased to 62% on high stiffness trampolines. In comparison, older children used both the ankle and foot, extending simultaneously in a coordinated fashion, for 98% of the bed contact time during bouncing on a low stiffness trampoline and this decreased to 67% on high stiffness trampolines. Our findings are important for trampoline safety demonstrating that the interaction between age and trampoline stiffness should be considered together in designing trampolines for different age groups **[3.6]**.

3. References to the research (indicative maximum of six references)

3.1 Davis, I.S., Bowser, B.J., and Mullineaux, D.R. (2016) Greater vertical impact loading in female runners with medically diagnosed injuries: a prospective investigation. British Journal of Sports Medicine, 50 (14), 887-92. https://doi.org/10.1136/bjsports-2015-094579

3.2 Ruder, M., Jamison, S., Tenforde, A., Mulloy, F., and Davis, I.R. (2019) Relationship of footstrike pattern and landing impacts during a marathon. Medicine and Science in Sports and Exercise, 10, 2073-9. https://doi.org/10.1249/MSS.0000000000002032

3.3 Mulloy, F., Brown, O., and Mullineaux, D.R. (2019) Comparison of simple gravity-based accelerometer calibration procedures. ISBS Proceedings Archive, 37 (1), article 124. https://commons.nmu.edu/isbs/vol37/iss1/124

3.4 Brown, O., Mulloy, F., and Mullineaux, D.R. (2019) The Science of Trampoline Mechanisms and their Contribution to Trampoline Function. Confidential internal report for Plum Products Ltd.

3.5 Brown, O., Mullineaux, D.R., and Mulloy, F., (2020) Lower limb kinematics of children jumping on domestic trampolines. ISBS Proceedings Archive, 38 (1), article 237. https://commons.nmu.edu/isbs/vol38/iss1/237

3.6 Mulloy, F., Brown, O., and Mullineaux, D.R. (2020) Lower limb joint coordination strategies of 5-7 and 9-11-year-old children on domestic trampolines of different stiffnesses. ISBS Proceedings Archive, 38 (1), article 236. https://commons.nmu.edu/isbs/vol38/iss1/236

4. Details of the impact (indicative maximum 750 words)

Putting a UK company at the forefront of global industry, increasing both financial revenue and market shares

The application of our research to trampoline design and international safety standards was facilitated through a 3-year Innovate UK Knowledge Transfer Partnership (KTP) between the University of Lincoln and Plum Products Ltd (£224,835). Plum Products Ltd (from here on 'Plum') have offices in the UK, Hong Kong and Australia, and with our partnership became a world leading supplier of recreational trampolines with annual sales rising from [text removed for publication] million in April 2018 to [text removed for publication] by December 2020. Our partnership helped this UK based company to become a world leading trampoline manufacturer by volume:

> *"In summary, incorporating research through the partnership with the University of Lincoln biomechanics group, namely Prof. Mullineaux, Dr Mulloy, and Dr Brown, has undoubtedly supported our global development as a company with research from the academic team providing an impact to our business"* **[5.1]**.

At the commencement of the KTP in October 2018, Plum produced 30% of the global domestic trampoline market by volume, with no presence on the North American continent. Their closest business rival produced around 50% of the global volume, mostly due to a large market in the USA. Our research underpinning trampoline design [3.4] and how humans interact with equipment [3.5, 3.6] provided Plum with evidence to demonstrate the safety of their products and enable them to alter strategic plans and enter the USA and Canadian domestic trampoline markets in July 2019. Plum were able to enter these markets with more certainty about meeting stringent health and safety regulations prior to USA and Canadian testing, and with enhanced marketing strategies (e.g. new USA user weight limits) because of our research. The USA trampoline testing is more stringent than the UK, and the rest of the world, due to population differences and liability protection requirements. Plum were able to sell their trampolines through large consumer chains including Walmart (https://www.walmart.com/ip/Plum-Play-Junior-7-Trampoline-with-Safety-Enclosure-Pink-Purple/707138919), Canadian Tire (https://www.canadiantire.ca/en/all-brands/plum.html) and Dicks Sporting Goods. Through this market expansion, Plum have shown a 39% increase in annual sales turnover **[5.1].**

Distributing safer designs into the world through Plum Products Ltd

Our research facilitated changes to how the New Product Development Team at Plum design trampolines in three core areas:

- **Customising designs**: Based on our findings related to trampoline components [3.4] and age specific trampoline interactions [3.5, 3.6], Plum developed a trampoline design 'flow chart' [text removed for publication] **[5.2, 5.3].** This enabled them to better tailor designs for specific customer demographics. [text removed for publication] This process has also helped staff knowledge and their ability to inform customers about safety features **[5.2]**

- **Enhancing safety and maximising efficiency**: Using our accurate predictive equations [3.4], Plum are now able to test trampoline designs to ensure peak accelerations are within acceptable ranges, and maximal vertical bed deformation would be within safe limits. This new predictive, 'virtual' testing enabled Plum to develop safer trampolines without the staff and resource costs of physical production:

  > *"Our partnership with the University has changed our practice in a number of ways. We now use research to inform design and predict outcomes…..We are now also able to predict the outcome of dynamic performance testing, ensuring that our trampolines will pass safety standards before we create the product"* **[5.2]**.

- **New designs** [text removed for publication]: Our research identified unique trampoline performance and safety functions, providing the opportunity for Plum to

innovate their product line. [text removed for publication] will enhance Plum's competitive advantage to provide greater income and an increased global market share.

Informing Global Health and Safety trampolines Regulations

Plum elected to integrate new science, beyond existing logic, in developing safer products **[5.2]**. However, our findings have implications well beyond a single company, and our research, amplified through partnership with a world leading trampoline manufacturer, has generated evidence to directly challenge and influence global trampoline health and safety regulations [3.4]. European (British Standards: EN 71 part 14) safety standards, which have been adopted across the world, have been developed with limited empirical evidence. A primary element of the standards involves statically loading the trampoline with a mass 5 times the stated maximum user mass, and requiring the resulting bed deformation to be less than 80% of the trampoline height (i.e. so that the trampoline bed is unlikely to hit the ground when jumped on). Our research identified that 37% of trampolines that we tested, that had passed the above standards, then failed the standard when dynamically tested [3.4].

As a result of our research, the Plum Director of Product Compliance and Development, was able to raise awareness at the European Standardisation Committee (known as CEN) meeting in April 2020 that existing European safety standards for trampolines may not be fit for purpose [5.4]. Drawing on the UoL research [3.1-6], the Director presented the twenty-seven European representatives from nine countries with a series of suggestions to modify standards which would provide safer recommendations across the industry **[5.2, 5.4]**

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1 Testimony from Paul Schaffer (Managing Director, Plum Products Ltd) to corroborate benefits of the partnership with the University. January 2021.

5.2 Testimony from David Woodman (Director of Product Compliance and Development, Plum Products Ltd, and European Toy Safety Standards Committee Member) to corroborate benefits of the partnership with the University. January 2021.

5.3 New Product Design 'Flow Chart' (created by Plum Products Ltd) to summarise the University's research findings to enable the company to customise trampoline designs for specific users. October 2020.

5.4 European Committee for Standardisation (CEN) Trampoline safety regulation meeting. Meeting minutes raising the University's research indicating that static safety testing may not be adequate (end of section 6). April 2020.