LOWER LIMB KINEMATICS OF CHILDREN JUMPING ON DOMESTIC TRAMPOLINES

Olivia Brown, David Mullineaux and Francis Mulloy

School of Sport and Exercise Science, University of Lincoln, UK

Domestic trampolines are a globally popular recreational activity for children, however this comes with a potentially increased risk of lower limb strains. The aim of this research was to determine if trampolines of differing stiffness influence lower limb kinematics in children. Fourteen participants grouped based on age; 5-7 and 9-11 years old, each performed twenty bounces on three different trampolines of varying stiffness. Lower limb kinematics were analysed across the ten middle bounces for each trampoline. Findings demonstrated no significant interaction effects across any hip, knee, ankle or foot kinematic variables across the trampolines within both age groups. There were also no significant differences in performance variables across the three trampolines. This study suggests that children do not appear to alter lower limb kinematics in adapting to different trampoline stiffnesses.

KEYWORDS: Trampolines, Joint Angles, Maturation

INTRODUCTION: Domestic trampolines, as a form of exercise, provide many health benefits, including improved cardiovascular function, weight loss, and facilitating the development of proprioceptive skills. However, trampolines are associated with an increased risk of lower limb strains in children (Eager et al. 2012). The most common users of domestic trampolines are children. Bone strength and joint stiffness are known to increase with maturation (Currey & Butler 1975; Shultz et al. 2008). In understanding the relationship between lower limb kinematics and trampoline stiffness, trampolines can be designed to reduce injury potential for the marketed user. Therefore, it is important to determine how trampoline setup can increase injury risk in order to minimise injury potential, whilst also allowing children to benefit from trampoline exercise. Trampoline function is a result of the interaction between Hooke’s law and Newton’s third law of motion, namely between the user and the trampoline bed and spring components (Kraft 2001). Different manufacturers produce trampolines which vary in specification (e.g. size of bed and number of and length of springs). Currently little is known as to how the spring and bed components contribute to the user bounce performance and the associated potential for injury. However, altering the springs stiffness is likely to alter trampoline performance characteristics such as acceleration and jerk.There is a paucity of research around the interaction of trampolines and users. This is indeed surprising given their popularity as a recreational exercise activity.

When used as a training tool, trampolines have been found to increase leg strength through strengthening of knee extensor and flexor muscles (Tillinghast 1966) and increase dynamic stability through an increased hip moment (Aragão et al. 2011). However, this research used a senior adult population (67 years ± 4 years) and mini trampolines (*e.g.* 3.5 foot). Of the few studies which have investigated the trampoline and user interaction, these have almost exclusively involved athletes performing somersaults on competition level performance trampolines (Blajer 2001; Burke, 2015). Previous literature in running has found that surface stiffness influences lower limb kinematics, with an increased initial knee flexion identified prior to foot contact on stiffer surfaces (Dixon et al. 2000). To the authors’ knowledge, no research has investigated biomechanical responses to domestic trampolines. An additional complication relates to the range of users targeted by domestic trampoline manufactures (most commonly 6-10 year olds), and changes in musculoskeletal maturation between these age ranges (Currey & Butler 1975). Therefore, the aim of this study was to investigate how trampoline stiffness influences lower limb kinematics in children.

METHODS: Fourteen participants volunteered for this research and were placed into two groups based on age; 5-7 years old (n=8; mean ± SD, age 6 years 1 month ± 9 months; height 1.18m ± 0.06 m; mass 23.8 kg ± 5.3 kg) and 9-11 years old (n=6; age 10 years 1 month ± 12 months; height; 1.38m ± 0.11m; mass 35.10 kg ± 10.5 kg). Following familiarisation, participants performed twenty bounces on three trampolines of varying specifications (table 1). Participants were instructed to bounce at the maximum height that was able to be maintained throughout the study. For each participant, 29 retro-reflective markers were placed on anatomical landmarks to create a whole body model. Thirteen motion capture cameras (Raptor cameras with Cortex 7.2 software; Motion Analysis Corporation, Santa Rosa, CA) were used to record kinematics sampling at 148.1 Hz.

Table 1: Trampoline specifications relating to the variations in stiffness.

Trampoline Stiffness	Spring Number	Spring Length (mm)	Frame Height (mm)	Spring stiffness (N/mm)
Lowest stiffness	64	180	790	4.13 ± 0.14
Medium stiffness	60	140	790	8.09 ± 0.44
Highest stiffness	54	140	760	8.09 ± 0.44

A custom written MATLAB script (R2015a, Mathworks, Natick, MA) was used to analyse all data. Kinematic data were smoothed using a second order, low-pass, Butterworth filter with a cut off frequency of 10 Hz. For each trial, the middle ten consecutive bounces were taken forward for analysis, with the mean used for each individual. Joint kinematics were calculated for the contact phase, with series interpolated to 101 data points for time normalisation, and presented as a percentage of the bounce cycle. Contact was determined as the moment that the right mid-toe, as an average of the 1st and 5th metatarsals, broke the vertical plane of the trampoline frame when moving downwards (0%) and then upwards with take-off (100%). 3D joint angles were calculated for the hip, knee, ankle, and foot. Specifically, the hip joint was determined using vectors of the right acromion-greater trochanter, and greater trochanter-lateral femoral epicondyle. The knee was identified from the greater trochanter to the middle of the medial and lateral femoral epicondyles, while the ankle was determined from the mid-knee to the middle of the medial and lateral malleoli. The foot angle was determined using vectors from the mid-ankle to the second metatarsal head, to the mid-toe. Joint ranges of motion were identified from the local minima to the local maxima during each bounce. Joint angular velocities were also calculated, and local maxima and minima were extracted. Performance was defined using jump height (m), defined using the sternal notch marker, offset against the sternal notch when the participant was standing off the trampoline and bed contact time (s). All data were analysed using SPSS software (Version 26.0. IBM Corp, Armonk, NY). Descriptive results are displayed as mean ± SD and statistical significance was set at 0.05. Once normality was confirmed (Shapiro-Wilks>0.05), a two-by-three (age x stiffness) mixed ANOVA was conducted to investigate the effect of trampoline stiffness, with post-hoc paired t-tests used.

RESULTS:

Table two shows that trampoline stiffness did not affect contact time (p=0.90) across both age groups. The stiffness of the trampoline significantly affects jump height (F(1.6,26.6)=3.1, p<0.01). Jump height was significantly higher on the stiffest trampoline compared to the trampoline of medium stiffness (p<0.01) and low stiffness (p<0.01), where 9-11year olds jumped significantly higher than the 5-7 year olds (p< 0.1). Trampoline stiffness did not affect joint angles; Hip_{RoM} (p=0.48), $Knee_{RoM}$ (p=0.75), $Ankle_{RoM}$ (p=0.95) or $Foot_{RoM}$ (p=0.52) across both age groups. However, knee range of motion was significantly lower in the 5-7 year olds compared to the 9-11 year olds (p=0.01). Trampoline stiffness did not affect maximum or minimum angular velocity across both ages and for all joints; Hip_{ω} (p=0.65; p=0.82 for minimum and maximum ω respectively), $Knee_{\omega}$ (p=0.66;p=0.91), $Ankle_{\omega}$ (p=0.60;p=0.94), or $Foot_{\omega}$ (p=0.91;p=0.85). The minimum angular velocity was significantly larger for the 9-11 year olds at the $Knee_{\omega}$ (p<0.01), $Ankle_{\omega}$ (p=0.04), and $Foot_{\omega}$ (p=0.01). Only maximum $Foot_{\omega}$

(F(1,42)=4.752, p=0.04) had any significant differences across age group, with a significantly large angular velocity in the 5-7 year olds.

Table 2: Lower limb kinematics and performance values across the three trampolines of varying stiffness for children aged 5-7 and 9-11 years.

Variable	Low Stiffness		Medium Stiffness		High Stiffness	
	5-7 years	9-11 years	5-7 years	9-11 years	5-7 years	9-11 years
Hip RoM (°)	16 ± 7	20 ± 8	17 ± 8	19 ± 8	12 ± 4	21 ± 12
Knee RoM (°)	23 ± 8	27 ± 6	22 ± 7	27± 6	18 ± 6	26 ± 9
Ankle RoM (°)	50 ± 9	45 ± 10	51 ± 5	47± 7	52 ± 6	48 ± 5
Foot RoM (°)	13 ± 9	17 ± 6	11 ± 4	20 ± 8	9 ± 3	19 ± 6
Max Hip$_{\omega}$ (°·s^{-1})	137 ± 53	137 ± 78	137 ± 53	137 ± 78	163 ± 42	163 ± 140
Max Knee$_{\omega}$ (°·s^{-1})	273 ± 97	273 ± 101	227 ± 53	227 ± 50	246 ± 82	246 ± 86
Max Ankle$_{\omega}$ (°·s^{-1})	403 ± 136	403 ± 91	394 ± 68	394 ± 83	415 ± 120	415 ± 92
Max Foot$_{\omega}$ (°·s^{-1})	244 ± 107	80 ± 125	208 ± 57	80 ± 97	228 ± 54	81 ± 81
Min Hip$_{\omega}$ (°·s^{-1})	-166 ± 81	-198 ± 95	-166 ± 81	-198 ± 95	-129 ± 77	-218 ± 147
Min Knee$_{\omega}$ (°·s^{-1})	-129 ± 58	-238 ± 132	-126 ± 80	-180 ± 67	-101 ± 23	-208 ± 103
Min Ankle$_{\omega}$ (°·s^{-1})	-364 ± 140	-439 ± 134	-335 ± 134	-380 ± 150	-291 ± 83	-435 ± 128
Min Foot$_{\omega}$ (°·s^{-1})	-153 ± 33	-235 ± 163	-123 ± 37	-188 ± 66	-127 ± 40	-223 ± 75
Max Jump Height (m)	0.65 ± 0.14	0.77 ± 0.19	0.51 ± 0.11	0.71 ± 0.18	0.60 ± 0.14	0.75 ± 0.21
Contact Time (s)	0.38 ± 0.05	0.40 ± 0.07	0.38 ± 0.05	0.43 ± 0.13	0.36 ± 0.07	0.40 ± 0.06

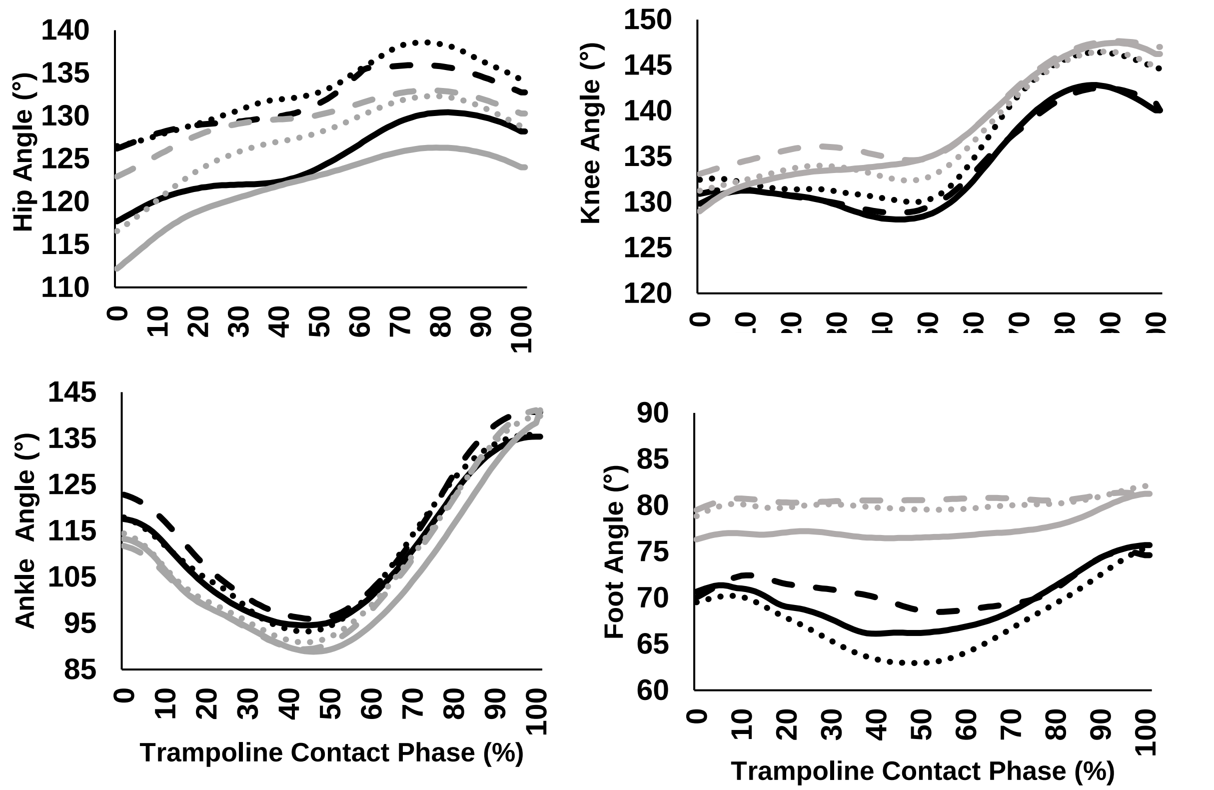

Figure 1. The hip, knee, ankle and foot joint kinematics for the 5-7-year age group (**black**) and 9-11 years (**grey**) age group across the three trampolines; stiffest (dotted line), middle stiffness (dashed line), least stiff (solid line).

DISCUSSION: The aim of this study was to investigate if domestic trampoline stiffness influences lower limb kinematics in children during bouncing. Analysis of traditional joint kinematic variables identified that participants in both age groups did not significantly alter lower limb joint angles or angular velocity in response to changes in trampoline stiffness. These findings are in contrast to previous research investigating other exercise related impacts, whereby an increased knee flexion prior to foot contact was linked to increasing surface stiffness in running (Dixon et al. 2000). Likely, the changes identified in running were to facilitate absorption of increased forces at impact although there was limited force data to support this. Changes in running terrain (e.g. grass versus concrete) are likely more severe than stiffness alterations in a trampoline configuration with around a 10% change in spring quantity. Previous literature has also shown that increasing the spring number by four springs to change stiffness of mini-trampolines has no effect on bounce performance (Kersting et al. 2017). Here, however a significant difference in jump height across the three trampoline types was found. Indeed, in the current research, it could be that small alterations in force dissipation throughout the kinematic chain accommodate changes in stiffness, but are not visible at the level of analysis demonstrated here. This is supported by Aragão et al. (2011), demonstrating that individuals increase dynamic stability through increasing net hip moment contributions. In this regard, the lower limb morphology is likley too complex to identify inividual joint alterations using simple, traditional methods of mechanics. Interestingly, the foot kinematics visually show subtle differences between the two age groups (figure 1). As a general trend, the younger age group approach trampoline contact in greater plantar-flexion, and undergo a greater range of motion, suggesting that the older children are able to maintain a stiffer joint configuration throughout contact which may warrant further investigation.

CONCLUSION: Children do not appear to adapt their lower limb kinematics in response to changing trampoline stiffness. However, alterations in external and internal force loading, and segmental interactions, may alter to allow for adaptations in stiffness. Further work is required to understand how the risk of injury is reduced and how the body mitigates changes in stiffness.

REFERENCES

Aragão, F.A., Karamanidis, K., Vaz, M.A. & Arampatzis, A. (2011). Mini-trampoline exercise related to mechanisms of dynamic stability improves the ability to regain balance in elderly. Journal of Electromyography and Kinesiology 21 (3): 512-518. https://doi.org/10.1016/j.jelekin.2011.01.003.

Blajer, W. & Czaplicki, A. (2001). Modeling and inverse simulation of somersaults on the trampoline. Journal of Biomechanics, 34(12), 1619-1629.

Burke, D., Yeadon, F. & Hiley, M. (2015). Optimum technique for maximising forward somersault rotation in trampolining. In 33rd International Conference on Biomechanics in Sports, 122-125.

Currey, J. & Butler, G. (1975). The mechanical properties of bone tissue in children. Journal of Bone and Joint Surgery, 57(6), 810-814. https://doi.org/10.2106/00004623-197557060-00015.

Dixon, S.J., Collop, A.C. & Batt, M.E. (2000). Surface effects on ground reaction forces and lower extremity kinematics in running. Medicine and Science in Sports and Exercise 32(11), 1919-1926. https://doi.org/10.1097/00005768-200011000-00016.

Eager, D., Scarrott, C., Nixon, J. & Alexander, K. (2012). Survey of injury sources for a trampoline with equipment hazards designed out. Journal of Paediatrics and Child Health 48(7), 577-581. https://doi.org/10.1111/j.1440-1754.2012.02426.x.

Kersting, U., Brandi, A., Rosendal, A., Hansen, J., Kristensen, M., Gregersen, M., (2017). The potential effect of mini-trampoline stiffness on take-off behaviour of gymnasts- A methodological study. 35th Conference of the International Society of Biomechanics in Sport.

Kraft, M. (2001). A simple approximation for the vertical spring force of the trampoline jumping cloth. Technical University Braunschweig.

Shultz, S.J., Nguyen, A.D. & Schmitz, R.J. (2008). Differences in lower extremity anatomical and postural characteristics in males and females between maturation groups. Journal of Orthopaedic and Sports Physical Therapy 38(3), 137-149. https://doi.org/10.2519/jospt.2008.2645.

Tillinghast, J. (1966). The effects of a trampoline class on cardiovascular fitness, leg power, vertical jumping height and leg strength. Texas Technological College.