LOWER LIMB JOINT COORDINATION STRATEGIES OF 5-7 AND 9-11-YEAR-OLD CHILDREN ON DOMESTIC TRAMPOLINES OF DIFFERENT STIFFNESSES

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The aim of this research was to assess differences in lower limb coordination in two developing age groups during trampoline bouncing, and if alterations in trampoline stiffness influence coordination strategies in children. Eighteen participants were recruited and grouped based on age; 5-7 and 9-11 years old. Each participant performed twenty bounces on two different trampolines of high and low stiffness. Lower limb kinematics were recorded using 3D motion capture and analysed across ten middle bounces for each trampoline. Findings demonstrated that the two different age groups employed different coordination strategies, with some changes with different trampoline stiffnesses. This information could be useful for trampoline manufacturers to modify trampolines for age-specific trampoline use.

KEYWORDS: Kinematics, vector coding, joint coupling.

INTRODUCTION: Domestic trampolines are a globally popular recreational activity for children. Trampoline use, as a form of exercise, carries a wide range of physiological health benefits, including the facilitation of proprioception development and neuromuscular coordination through repetitive, cyclical bouncing. These benefits are achieved with relatively low impacts if used correctly. However, trampolines have also been associated with an increased risk of lower limb strains in children (Eager et al. 2012). Bone strength and joint stiffness increase with maturation (Shultz et al. 2008), therefore different age groups may have different requirements in terms of both trampoline product design but also the purchase of age specific products. Therefore, modifications to trampoline designs could be helpful if targeting specific age requirements. Altering spring properties in circular domestic trampolines is likely to influence trampoline stiffness at impact and used in industry. However, little is still known about children of different age groups interacting with different stiffnesses of commercially available trampolines. Research investigating performance trampolines does exist, however, young, pre-pubescent children are vastly different to elite athletes, and indeed adults, with less advanced musculoskeletal systems. Therefore, children may have different needs in regards to trampoline stiffness to aid in the prevention of both acute, and long-term, chronic injury.

The lower limb joints and associated musculature plays different roles in jumping actions. Effective coordination of the whole lower limb kinematic chain is required for explosive, dynamic activities such as jumping (Jacobs et al., 1996). Indeed, research separating the downward and upward phases of the countermovement jump prior to take off has shown that different joint coordination patterns are required for each phase (Vidal et a., 2017). The knee, namely the powerful vasti group, is important for effective vertical jumping but also braking in landing. The contributions of the knee can be coupled to the ankle via the bi-articular gastrocnemius, pulling on the compliant Achilles tendon to facilitate plantarflexion in both braking in landing and propulsion (Jacobs et al., 1996; Lichtwark and Wilson, 2006). Peculiarly, the foot is often neglected in the biomechanical assessments of the whole lower limb in propulsion, assumed to function as a rigid body, even though its contributions to propulsion are clear (Welte et al., 2018). The interaction between these joints is not currently known in domestic trampoline use, nor have has lower limb joint coordination been assessed with reference to age and trampoline stiffness. Therefore, the aim of this study was to investigate lower limb joint coordination in domestic trampoline use, and how these may differ with trampoline age and also changes in stiffness.

METHODS: Eighteen participants volunteered and were placed into two groups based on age; 5-7 years old (n=10; mean ± SD, age 6 years ± 1 year; height 1.21 m ± 0.08 m; mass 24.7 kg ± 5.3 kg) and 9-11 years old (n=8; age 10 years 4 months ± 13 months; height; 1.43 m ± 0.06 m; mass 35.70 kg ± 7.75 kg). Following familiarisation, participants performed twenty bounces on two trampolines of different stiffnesses (table 1). For each participant, 29 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 differing bounce stiffness.

Trampoline	Trampoline Size (as sold in ft)	Spring Number	Spring Length (mm)	Spring stiffness (N/mm)
Lowest stiffness	10	64	180	4.13 ± 0.14
Highest stiffness	10	54	140	8.09 ± 0.44

A custom written MATLAB script (R2017b, 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 used for analysis, with means determined for each individual. Joint kinematics were calculated for the downward phase from contact phase to maximum bed deflection ($Phase_{Down}$), and then the upward phase from maximum bed deflection to take off ($Phase_{Up}$). Kinematic time series data were interpolated for both the $Phase_{Down}$ and $Phase_{Up}$ to allow for comparisons. 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 (0%), maximum bed deflection was the point of maximal vertical mid-toe displacement (100%), and take-off (200%). 3D joint angles were calculated for the knee, ankle, and foot. Specifically, the knee joint was determined from the greater trochanter to the middle of the medial and lateral femoral epicondyles (mid-knee) to the middle of the medial and lateral malleoli (mid-ankle), while the ankle joint was determined from the mid-knee, to mid-ankle, to the mid-toe. The foot angle was determined using vectors from the mid-ankle to the second metatarsal head, to the mid-toe.

A modified vector coding technique (Needham et al., 2014) was used to determine joint coupling of the knee-ankle and ankle-foot, for both $Phase_{Down}$ and $Phase_{Up}$. The coupling angle can then be used to identify instantaneous spatial relationships between joints as a percentage frequency of each phase. These are classified using the angle between two consecutive data points relative to the horizontal throughout an angle-angle time series (Needham et al., 2014). Four unique coordination patterns, which identify how the joints are interacting during skill execution: 1) anti-phase, 2) in-phase, 3) proximal joint phase, and 4) distal joint phase. If the coordination is *anti-phase* then both joints are moving in opposite directions (e.g. knee extension with ankle dorsiflexion). Conversely *in-phase* means that in that instant both joints are moving in the same direction (i.e. simultaneous extension). When coupling angles shown to be in the proximal or distal category, there is no simultaneous movement in the distal or proximal joint, respectively. Bounce performance was defined using jump height (m), defined using the sternal notch marker, and bed contact time (s). Bounce performance variables were analysed using a two-by-two (age group x trampoline) analysis of variance (ANOVA) to investigate the performance outcome of trampoline stiffness in IBM SPSS software (Version 26.0. Armonk, NY: IBM Corp). Alpha priori was set at $p \leq 0.05$.

RESULTS: There were no significant interaction effects of bounce height or contact time across group and trampoline stiffnesses ($p>0.05$). Table 2 highlights different coordination patterns, while figure 1 displays the kinematic joint angle coupling plots.

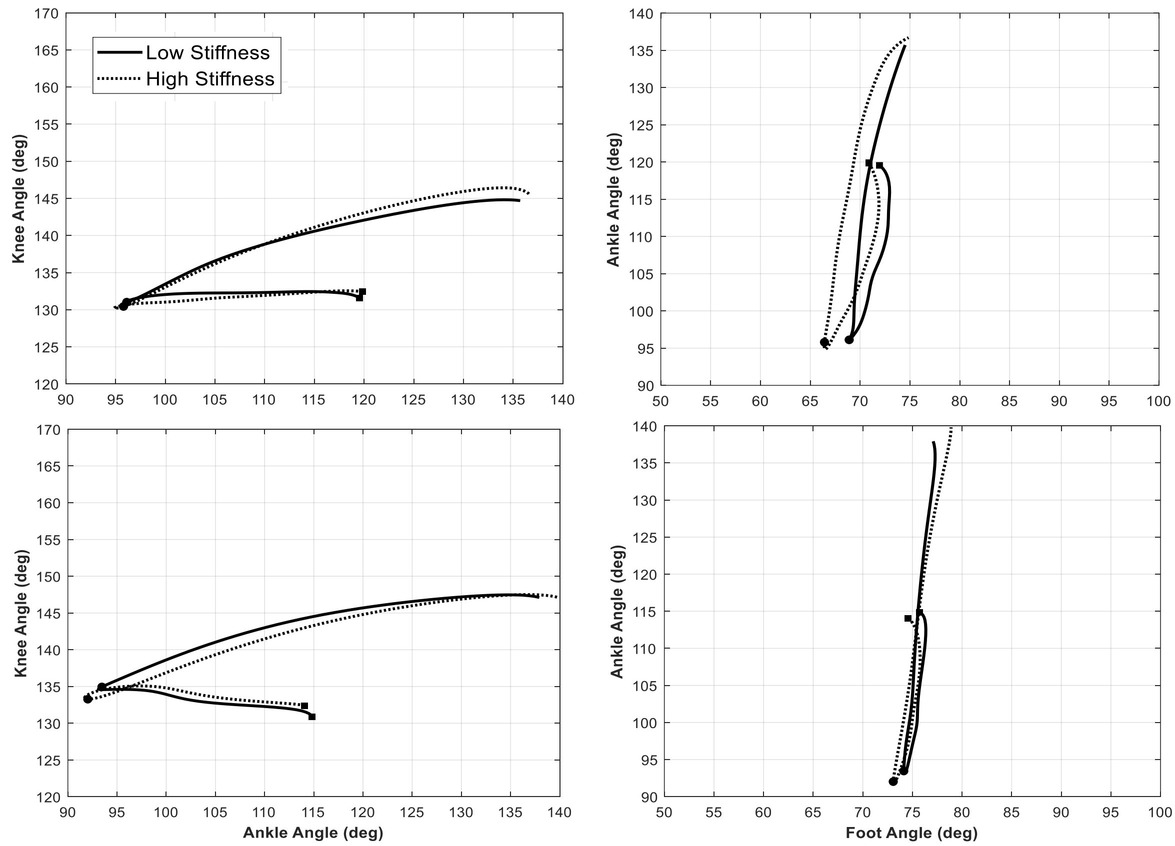
During the $Phase_{Down}$, the knee-ankle joint coupling was predominantly in-phase for both groups, with both joints undergoing simultaneous flexion during impact. Accompanying this the younger age group were more knee dominant (younger, 21 and 22%; older, 12 and 13% for low and high stiffness respectively), while in contrast the 9-11 years age group used a more ankle dominant strategy (younger, 12 and 17%; older, 20 and 21%). In contrast, in the ankle-foot coupling the 5-7 year-old age group used an ankle dominant strategy for the majority of the movement (younger, 42 and 62%; older, 1 and 8%), while the older group appeared to use a predominantly anti-phase movement (younger, 28 and 26%; older, 98 and 67%).

During $Phase_{Up}$ both age groups predominantly used in-phase knee-ankle coupling (younger, 50 and 45%; older, 46 and 50%) in coordinated extension. Both groups displayed a large percentage of knee dominant motion (younger, 41 and 43%; older 50 and 40%). As stiffness increased the 5-7 year-olds increased this knee dominancy, while the 9-11 year-olds increase in-phase extension. The ankle-foot coupling was predominantly anti-phase in both groups, however, the younger age group also showed significant ankle dominancy.

Table 2. Modified vector coding coupling frequency bins (%) for the downward ($Push_{Down}$) and upward bounce phase ($Push_{Up}$) for the knee-ankle and ankle-foot joint couplings. Presented for low and high stiffness trampolines for 5-7 and 9-11-year-old age groups.

	Low Stiffness		High Stiffness	
Phase $Phase_{Down}$	5-7 Years	9-11 Years	5-7 Years	9-11 Years
Knee	22 ± 15	12 ± 7	21 ± 11	13 ± 6
Ankle	12 ± 14	20 ± 18	17 ± 14	21 ± 16
In-Phase	57 ± 12	60 ± 24	51 ± 20	59 ± 20
Anti-Phase	7 ± 6	7 ± 7	9 ± 10	5 ± 4
Ankle	42 ± 23	1 ± 25	62 ± 27	8 ± 24
Foot	7 ± 7	0 ± 6	4 ± 16	19 ± 8
In-Phase	9 ± 3	0 ± 2	5 ± 3	3 ± 1
Anti-Phase	28 ± 23	98 ± 27	26 ± 28	67 ± 28
$Phase_{Up}$				
Knee	41 ± 10	50 ± 16	43 ± 12	40 ± 21
Ankle	4 ± 5	0 ± 5	4 ± 6	0 ± 4
In-Phase	50 ± 14	46 ± 21	45 ± 12	50 ± 29
Anti-Phase	1 ± 1	0 ± 2	2 ± 3	0 ± 0
Ankle	13 ± 16	0 ± 10	36 ± 22	5 ± 21
Foot	0 ± 4	0 ± 3	0 ± 6	0 ± 2
In-Phase	12 ± 4	0 ± 2	0 ± 8	0 ± 1
Anti-Phase	75 ± 18	100 ± 11	64 ± 22	95 ± 20

Figure 1. Knee-ankle and ankle-foot angles for the 5-7 year-old (top row) and 9-11 year-old (bottom row) age groups for two low stiffness (solid line), high stiffness (dotted line) trampolines. Squares denote contact, and circles maximal downward vertical displacement.



DISCUSSION: This research sought to investigate lower limb joint coordination patterns with domestic trampoline use, and how these may differ with age and trampoline stiffness.

The large $Phase_{Down}$ in-phase flexion, along with knee dominant coordination, are similar to Vidal et al. (2017) during the downward phase of countermovement jumps in an adult population. In-phase and knee dominant downward movement is an important strategies for controlled jump preparation, using powerful musculature (Jacobs et al., 1996; Lichtwark and Wilson, 2006). However, adults in Vidal et al. (2017) showed predominantly knee dominancy, and very little ankle dominancy. The in-phase joint coupling strategies in this research are likely more useful for absorbing and controlling impact during repetitive trampoline bouncing. Further, alongside knee dominancy, both age groups showed greater ankle dominancy with increasing stiffnesses (table 2). This may be due to greater ankle contribution being possible on a softer medium of trampoline bed relative to the floor, allowing for more efficient use of the powerful Achilles tendon during $Phase_{Down}$ compared to adults in countermovement jumping. Future work should incorporate the analysis of segmental accelerations and force distribution to confirm the contributions of the joints to control and attenuate forces and accelerations at impact. In the ankle-foot coupling, the 5-7 age group used ankle dominancy for the majority of $Phase_{Down}$ while the older group used predominantly anti-phase coupling. The 9-11 year-olds coupled the two joints, attenuating the landing. This could indicate a greater utilisation of the stretch shortening cycle with the foot and ankle stretching shared soft tissue structures, such as the Achilles tendon and plantar fascia (Lichtwark and Wilson, 2006). The larger ankle dominancy in the 5-7 year olds, relative to the older 9-11 year olds, seemingly supports this notion. With increasing stiffness, the younger children increased this ankle dominancy, while the older children increased foot dominancy (0 to 19%), suggesting use of the spring foot mechanisms (Welte et al., 2018). Combined, these findings highlight different landing strategies across stages of maturation.

The in-phase coupling of both groups during the $Phase_{Up}$ is useful for propulsion. Second to this the knee dominant coupling shows the powerful vasti contribution (Vidal et al., 2017). Both groups showed the similar effective jumping strategies. As stiffness increased, however, the 5-7 year-old group increased knee dominancy while the 9-11 year-old group coordinate both joints further. This highlights that the older age group more effectively move joints in simultaneous extension. Similarities exist with greater knee-ankle in-phase coupling during the upward phase in countermovement jumps with adults (Vidal et al., 2017) suggesting that a reliance on a single joint may reduce with maturation. Supporting this notion further, the 5-7 year-olds also demonstrated some, albeit moderate, anti-phase (1 and 2%) and ankle dominant patterns (4% in both stiffnesses) while the older age group remained at 0%. The ankle-foot coupling during the $Phase_{Up}$ remained predominantly anti-phase for both groups. The foot flexes while the ankle plantarflexes with push-off. This is an effective strategt for jumping motion. Once again, however, the younger age group show more individual joint strategies with greater ankle dominancy, potentially highlighting a less developed strategy.

CONCLUSION: Different coordination strategies occur with age and changing stiffness during domestic trampoline use. Stiffness appears to influence coordination strategies less than age, with maturation associated with more coordinated, and less single joint dominant movement. These findings can be incorporated in age-specific trampoline manufacture and use.

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