COMPARISON OF BOUNCE CHARACTERISTICS ON THREE TYPES OF TRAMPOLINES

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Abstract

Trampoline use has skyrocketed in recent years in a variety of recreational contexts and among athletes in sports ranging from gymnastics and diving to skiing and snowboarding. The purpose of this study was to examine the bounce characteristics elicited by athletes bouncing on three types of trampolines. Tumbl Trak, Standard, and Super Tramp trampolines were assessed by 10 experienced trampoline and acrobatic athletes (5 males, 5 females). A triaxial accelerometer (250 Hz) characterized the 10 highest controlled bounces on each trampoline and each athlete. Repeated measures ANOVAs showed statistical differences in bounce characteristics: time from bounce start to peak acceleration ($p<.001$, $\eta^2=0.82$), time from peak acceleration to bounce end ($p=.030$, $\eta^2=0.40$), and total bounce time ($p<0.001$, $\eta^2=0.78$, jump height ($p<.001$, $\eta^2=0.95$) peak acceleration ($p=.015$, $\eta^2=0.37$), and flight time ($p<.001$, $\eta^2=0.97$). Average acceleration, force, and allometrically scaled average force were not statistically different ($p>.140$, $\eta^2=0.20$). The stiffest trampoline with the least time values, peak accelerations, and jump heights was the Tumbl Trak, followed by the Standard trampoline, and Super Tramp, respectively. This information may help practitioners and others to understand the bounce behaviors of athletes on these types of trampolines.

Keywords: trampoline, comparison, acceleration, jumping.

INTRODUCTION

Trampolines have been used in various forms from the early 1900s (Horne, 1968). The modern trampoline dates from 1936 and was developed by George Nissen and Larry Griswold (Ladue & Norman, 1954). The characteristics that make a trampoline are a flexible surface (i.e., bed) attached to dozens of springs which are in turn connected to a large round, square, or rectangular metal frame. The trampoline has undergone a number of designs that include different sizes, shapes, beds, and spring configurations for different purposes. Trampoline is an Olympic competitive event (International Gymnastics Federation, 2018).

In spite of the relatively long history of trampolines, there is a paucity of scientific information about the mechanical behavior of the trampoline and the interactions of athletes with these apparatuses. Trampolines are used for recreation (Fisher, 2010), spatial orientation (Heinen, 2011), fitness exercise (Atterbom & MacLean, 1983; Cugusi et al., 2018), gymnastics (Heinen, 2011;

Hondzinksi & Darling, 2001), diving (Kimball, 1999), medical treatment (Giagazoglou et al., 2013; Hahn, Shin, & Lee, 2015; Sahlberg & Strandvik, 2005), and as a competitive event (Esposito & Esposito, 2009; Jensen, Scott, Krustrup, & Mohr, 2013). A recent *New York Times* posting described a new activity called "Gtramp" which involves backyard and other trampoline use arising from skateboard, parkour, and youth social media activities (Kettler, 2018).

Trampolines offer athletes the ability to rise as high as five or more meters in the air with minimal physical effort (Eager, Chapman, & Bondoc, 2012). The flight time of trampoline jumping enhances an athlete's ability to practice difficult skills, gain spatial awareness, and land on a soft trampoline bed. Trampoline beds are assumed to be soft and flexible. However, the "softness" of a trampoline bed represents a flawed understanding (Farquharson, 2012). The energy required to project the athlete high in the air is considerable and on descending and landing the energy from the flight should be absorbed and returned by the athlete's musculoskeletal system and the trampoline bed. Understanding how bouncing on trampolines may affect timing, acceleration, height, and energy exchange is largely unknown with the exception of some physics modeling (Blajer & Czaplicki, 2001; Chen et al., 2016; Yeadon & Hiley, 2017).

A recent study of circus acrobats used a wearable three-dimensional accelerometer to measure accelerations in seven male acrobats during training and show performances. The results revealed that accelerations were statistically greater during training than shows. Moreover, accelerations were classified into categories of magnitude from approximately 1 g to more than 12 g (Barker, Burnstein, & Mercer, 2018). A conference presentation on trampoline measurements showed average peak accelerations of approximately 5 g (49 m/s^2) and flight times ranging from 0.50 s to 0.54 s (Eager et al., 2012). The values from the Eager and colleagues (Eager et al., 2012) measurements are astonishingly low. The corresponding jump height for these values would be approximately 31 cm to 36 cm which is easily attainable in a vertical jump from the floor (Simons & Bradshaw, 2016b). A thesis investigating the relationship between trampoline bouncing and the countermovement vertical jump found no statistically significant relationship (Briggs, 2014). A study by the National Aeronautics and Space Administration (NASA) showed that trampoline bouncing by eight males at four heights with accelerometers on the ankle, forehead, and back resulted in accelerations of 3.0-7.0 g, 3.9-6.0 g, 3.0-5.6 g, respectively (Bhattacharya, McCutcheon, Shvartz, & Greenleaf, 1980).

Trampolining has received considerable attention in terms of injury and injury prevention in Australia, Germany, New Zealand, and the U.S. (Ashby, Pointer, Eager, & Day, 2015; Chalmers, Hume, & Wilson, 1994; Hammer, Schwartzbach, & Paulev, 1981; Lewald, 1979; Sandler et al., 2011; Torg & Das, 1984). Moreover, studies of the benefits of trampolining include aerobic fitness, convenience, and balance (Atterbom & MacLean, 1983; Butler, 1969; Da Roza, Brandao, Mascarenhas, Jorge, & Duarte, 2015; Giagazoglou et al., 2013; Guillot & Collet, 2004; Hardy, Mullen, & Martin, 2001; Heitkamp, Horstmann, Mayer, Weller, & Dickhuth, 2001; Katch, Villanacci, & Sady, 1981; Ladue & Norman, 1954). However, analyses of bounce characteristics have seldom been addressed. In addition, there appear to be only a few studies comparing backyard trampolines, mini-trampolines, and full-size or competitive trampolines in terms of injury incidence and rates (Council On Sports & Fitness, 2012; Sands, Hondzinski, Shultz, & George, 1995; Torg & Das, 1985). It is our belief that the lack of information on the characteristics of bouncing on different trampolines has been ignored and merits research.

The Center of Excellence facility of the U.S. Ski and Snowboard Association headquarters is unusual in that there are three different types of trampolines, expert trampolinists (i.e., national team Aerial, Moguls, and Half-Pipe Skiers along with Half-Pipe and Big-Air Snowboard), and expert coaching. Many of these athletes are former gymnasts and trampolinists. Moreover, these athletes regularly perform skills on trampolines that are equal or more difficult than competitive trampolinists. These athletes regularly perform quad-twisting triple somersaults (Aerials) and quadruple somersaults (Big-Air Snowboard). These skills are performed on unpredictable terrain, a variety of weather conditions, and landings on snow.

Trampoline use has skyrocketed in recent years in a variety of recreational contexts and among athletes in sports ranging from gymnastics and diving to skiing and snowboarding (Ashby et al., 2015; Chalmers et al., 1994; Esposito & Esposito, 2009; Fisher, 2010). However, scientific understanding of the behavior of trampolines has not kept pace. Characterizing the interaction of trampoline-related activities and athletes may assist practitioners, scientists, and medical professionals in encouraging or discouraging use of trampoline bouncing for acrobatic athletes and others.

The purpose of this study was to characterize the bounce behaviors elicited by three types of trampolines to determine the relative accelerations, durations, average forces and other factors. In spite of a relatively long history of trampoline use, and the fact that many catastrophic injuries occur in the center of the trampoline bed by highly-trained athletes (Torg, 1985; Torg & Das, 1984), it should be imperative to derive a more complete understanding of the workings of trampoline-athlete interactions while bouncing. We hypothesized that all of the trampoline types would show statistically different bounce characteristics.

METHODS

Participants: Ten experienced trampoline athletes from the U.S. Ski and Snowboard Aerials Team volunteered to participate in this study. The anthropometric information for the athletes was: five males (Mean ± SD; age 22.6 y ± 3.4 y; height 174.0 cm ± 5.0 cm; mass 73.2 kg ± 9.2 kg) and five females (Mean ± SD; age 19.8 y ± 2.8 y; height 160.2 cm ± 5.0 cm; mass 57.9 kg ± 4.8 kg).

Equipment: Bounce accelerations provided by the athletes were obtained from three types of trampolines: Tumbl Trak (bed size = 1.52 m x 11.89 m, solid black bed, Tumbl Trak, Mount Pleasant, MI, USA), a standard competitive trampoline (bed size = 2.14 m x 4.27 m, two-string bed, Rebound Products, Thornhill, Ontario, Canada), Super Tramp (bed size = 3.05 m x 6.10 m, one-string bed, Rebound Products, Thornhill, Ontario, Canada). See Figures 1-3.

Instrumentation: Accelerations were obtained from a PASCO Scientific triaxial accelerometer (PASCO Scientific, Roseville, CA, USA PS-3202) attached rigidly to a waist belt that was worn snugly about the waist of the athlete placing the accelerometer posterior to the lumbar spine at approximately the level of lumbar vertebrae L3 to L4 (Simons & Bradshaw, 2016a). Accelerometer placement has varied widely in experiments because of potential threats to stability from skin movement, subcutaneous fat, breathing, tissue inertia and many other factors (Simons & Bradshaw, 2016a). Placement of accelerometers on the upper back has been compared to the lower back among female participants in bilateral hopping and drop landings (Simons & Bradshaw, 2016a, 2016b) with better correlations with drop landings on a force platform arising from an upper back placement and better inter-day reliability arising from a low back placement (Simons & Bradshaw, 2016a, 2016b). Acceleration data were transmitted via Bluetooth to a laptop computer. Data were captured, displayed, and stored using the PASCO Capstone software (PASCO Scientific, Roseville, CA, USA, V1.11.1). The sampling rate was 250 Hz. Calibration was performed using gravitational vertical.

Calibration was ensured by rotating the accelerometer systematically such that one of the three axes of the accelerometers was oriented to the line of gravity approximately 9.806 m/s^2, while the remaining axes measured approximately 0 m/s^2.

Figure 1. Tumbl Trak trampoline.

Figure 2. Standard trampoline.

Procedures: The athletes were fitted with the belt and accelerometer and then asked to perform 10 or more consecutive bounces on each of the three trampolines. The athletes were instructed to bounce as high as they could control. A self-selected number of initial bounces were undertaken and the athlete announced verbally when he or she was bouncing maximally. Sampling was undertaken throughout all bounces similar to previous procedures (Briggs, 2014; Harden & Earnest, 2015). The ten bounces with the highest and most consistent sequence of accelerations were used as the bounce trials to characterize each trampoline's acceleration profile.

Figure 3. Super Tramp trampoline.

Data analysis: Following data capture and storage, PASCO Capstone software was used to extract relevant information from each bounce (Figure 4) (Shanahan, 2004). A bounce was defined as the period from trampoline bed contact to departure. The variables of interest for this study were:

- time from start of a bounce to the peak acceleration,
- time from peak acceleration to the end of the bounce,
- total time of the bounce,
- jump flight time,
- jump height,
- peak acceleration,
- average acceleration,
- average force and allometrically scaled force.

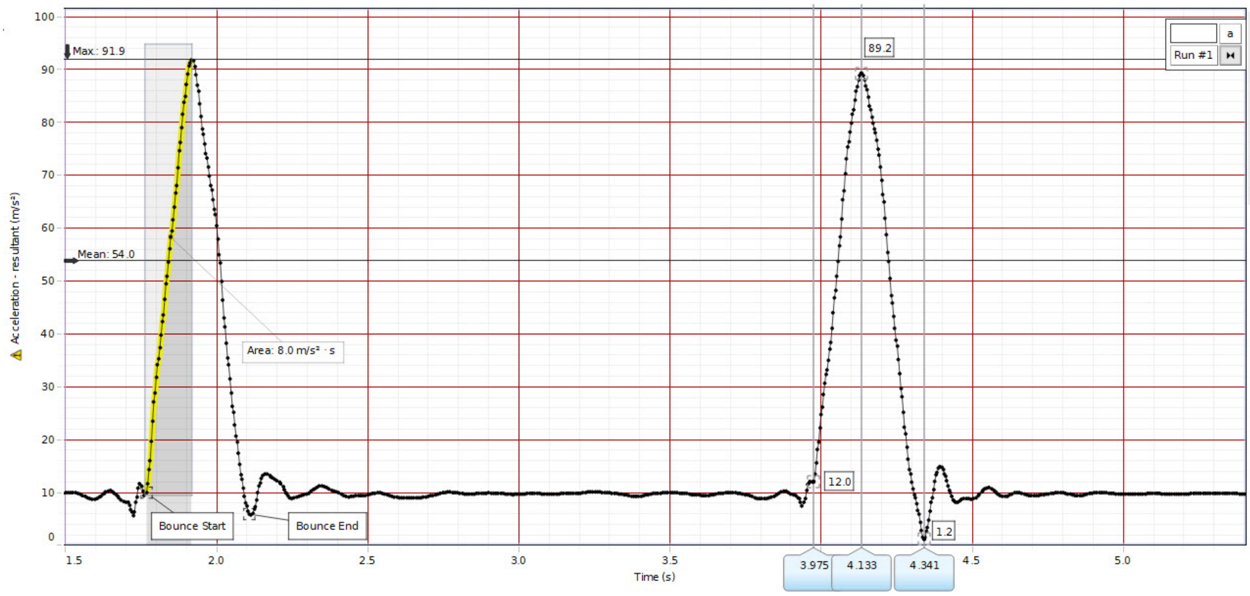

Figure 1. Example of the data and variables that were extracted from the bounce accelerations.

The multiple trials (i.e., bounces) were displayed using the Capstone software and a cursor was passed through the data to acquire the timing of the start of the bounce, time of the end of the bounce, peak acceleration time and peak acceleration value. Resultant accelerations were used for all analyses. The trials data were assessed for reliability via trends across trials (Henry, 1950, 1967). The means of the trend-free trials were calculated for each athlete collapsing the ten trials per trampoline-type to a single mean value which was later used for magnitude-based inference and hypothesis testing (Henry, 1950, 1967; Hopkins, Hawley, & Burke, 1999). The large number of performance trials (10 per athlete per trampoline-type) led to using Cronbach's alpha procedures to calculate an intraclass correlation coefficient (ICC) – alpha (Atkinson & Nevill, 1998). Additionally, one-way repeated measures ANOVAs were calculated across the ten trials along with coefficients of variation (CV) for each variable obtained from each trampoline-type (Table 1). Nine variables showed extremely high ICCs while also indicating some statistical differences across trials (Table 1). Closer inspection of these data showed no consistent pattern of variability such as increasing values indicative of learning or decreasing values indicative of fatigue. Therefore, because the ICCs were extremely high, CVs were low or modest, a reluctance to discard data (Henry, 1950), and no apparent pattern of variations across trials, all data were retained and means were calculated utilizing all ten trials for each athlete and each trampoline-type.

Our initial assessment involved calculating reliability and trends across trials values and coefficients of variation with sex as a group factor. After reliability assessments, multiple 9 (variables) by 2 (sexes) by 3 (trampoline-types) repeated measures ANOVAs (RMANOVA) were calculated. The data showed that there were no main effect statistical differences attributable to sex (all $p > 0.05$). Following these uniform results, the data were collapsed across sex and further analyses involved multiple (9 variables) one-way RMANOVAs. All data were analyzed using IBM SPSS software (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY:

IBM Corp). Effect size estimates were calculated as partial eta^2 (η^2) values: ≤ 0.02 = small, 0.02 to 0.13 = medium, 0.13 to 0.26 = large (Cohen, 1988).

Table 1
Trials Reliability.

Variable	Trampoline	Chronbach's Standardized Item Alpha	RMAnova $F_{(9,81)}$	p	Coefficient of Variation Mean (SD)
Time Start to Peak	Tumbl Trak	.96	1.15	.34	18.88 (1.18)
	Standard	.97	1.69	.11	11.82 (11.09)
	Super Tramp	.96	0.50	.87	9.76 (0.76)
Time Peak to End	Tumbl Trak	.99	0.91	.53	10.16 (4.96)
	Standard	.97	1.17	.32	10.93 (5.47)
	Super Tramp	.96	1.06	.37	11.46 (6.26)
Total Time	Tumbl Trak	.98	0.68	.73	11.33 (3.73)
	Standard	.96	1.06	.40	10.13 (2.79)
	Super Tramp	.94	0.72	.79	8.97 (2.87)
Flight Time	Tumbl Trak	.99	0.50	.85	4.10 (2.52)
	Standard	.98	4.47	<.001	3.42 (1.97)
	Super Tramp	.99	0.95	.48	2.71 (1.02)
Jump Height	Tumbl Trak	.99	0.50	.85	8.13 (4.92)
	Standard	.99	4.95	<.001	6.82 (5.40)
	Super Tramp	.99	0.88	.54	5.39 (2.02)
Peak Acceleration	Tumbl Trak	.97	1.55	.14	8.14 (4.92)
	Standard	.99	7.97	<.001	6.83 (3.91)
	Super Tramp	.99	2.72	.008	5.40 (2.02)
Average Acceleration	Tumbl Trak	.97	3.12	.003	6.11 (2.07)
	Standard	.98	1.13	.36	5.24 (2.52)
	Super Tramp	.99	2.64	.010	3.80 (2.14)
Average Force	Tumbl Trak	.99	3.40	.001	6.12 (2.07)
	Standard	.98	1.23	.29	5.24 (2.52)
	Super Tramp	.99	2.48	.015	4.01 (2.26)
Average Force Allometrically Scaled	Tumbl Trak	.97	3.12	.003	6.11 (2.07)
	Standard	.98	1.13	.36	5.23 (2.52)
	Super Tramp	.99	2.64	.01	4.01 (2.26)

RESULTS

Table 2
One-way Repeated Measures ANOVA.

Variable	F	df	p	Effect Size $\eta^2_{partial}$	Power
Time Start to Peak	43.10	2,18	<.001	0.82	1.00
Time Peak to End	6.00	1.17,10.49	.030	0.40	.64
Total Time	31.35	1.27,11.40	<.001	0.78	1.00
Flight Time	248.72	1.38,12.41	<.001	0.97	1.00
Jump Height	159.65	1.27,11.43	<.001	0.95	1.00
Peak Acceleration	5.34	2,18	.015	0.37	.77
Average Acceleration	2.20	2,18	.140	0.20	.39
Average Force	2.19	2,18	.140	0.20	.39
Average Force Allometrically Scaled	2.20	2,18	.140	0.20	.39

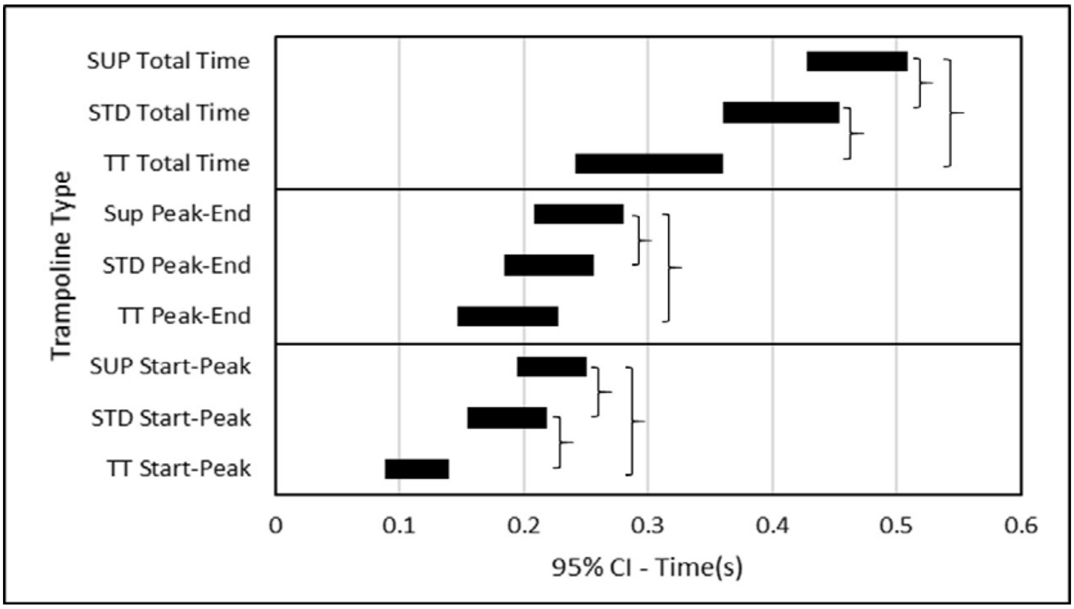

Figure 5. 95% Confidence intervals for time variables on all trampolines. Pairwise statistical differences (p<.05) are shown via brackets. SUP = Super Tramp, STD = Standard Trampoline, TT = Tumbl Trak.

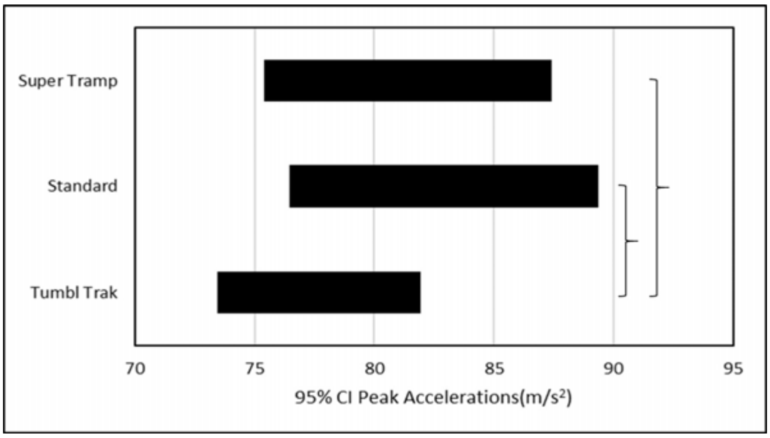

Figure 6. 95% Confidence intervals for peak accelerations on all trampolines. Pairwise statistical differences ($p<.05$) are shown via brackets.

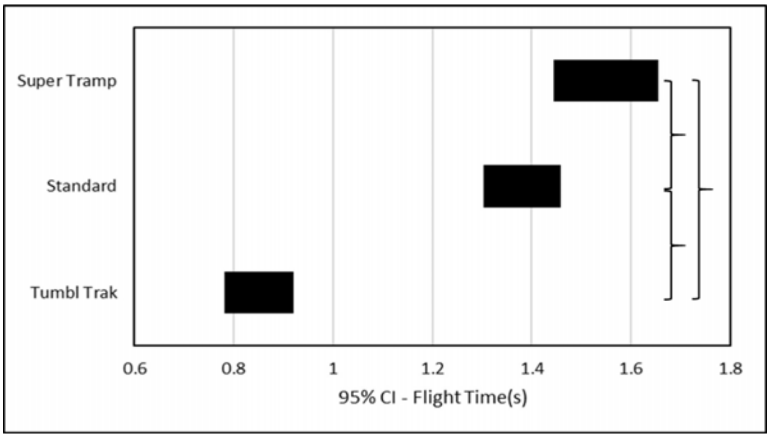

Figure 7. 95% Confidence intervals for flight times on all trampolines. Pairwise statistical differences ($p<.05$) are shown via brackets.

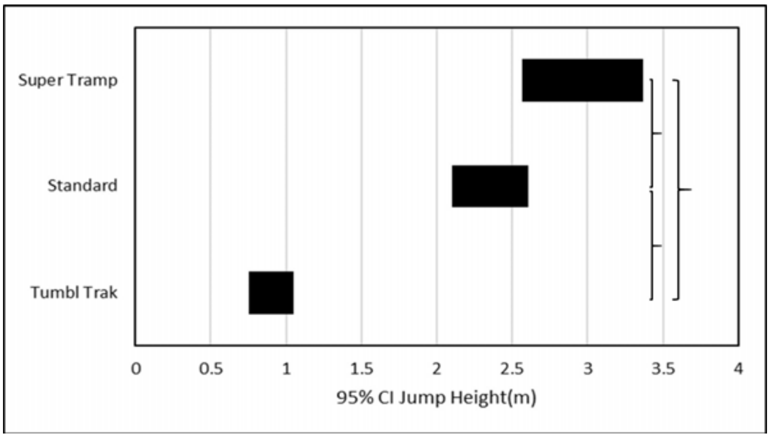

Figure 8. 95% Confidence intervals for jump height on all trampolines. Pairwise statistical differences ($p<.05$) are shown via brackets.

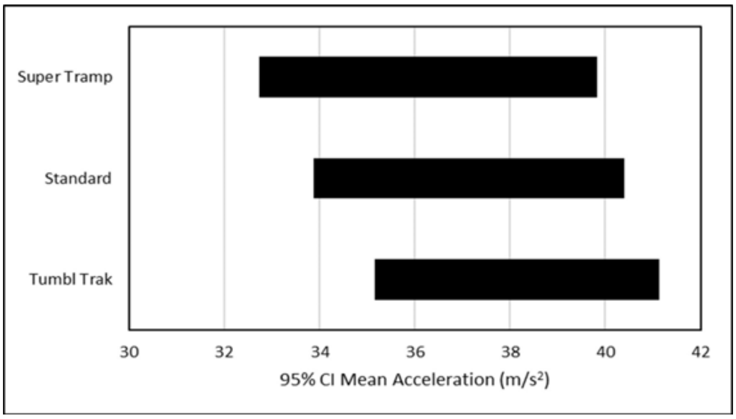

Figure 9. 95% Confidence intervals for mean acceleration on all trampolines. None of the pairwise comparisons were statistically different (all p>.05).

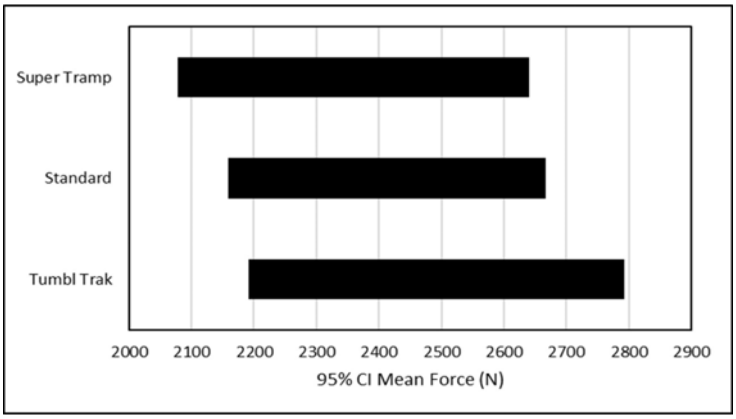

Figure 10. 95% Confidence intervals for mean force values on all trampolines. None of the pairwise comparisons were statistically different (all p>.05).

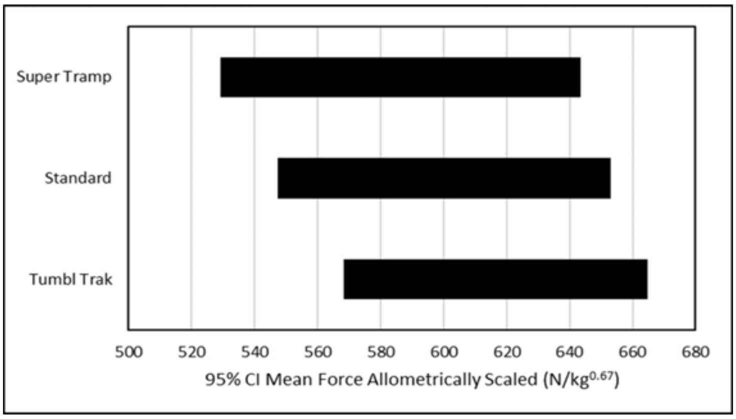

Figure 11. 95% Confidence intervals for mean force allometrically scaled on all trampolines. None of the pairwise comparisons were statistically different (all p>.05).

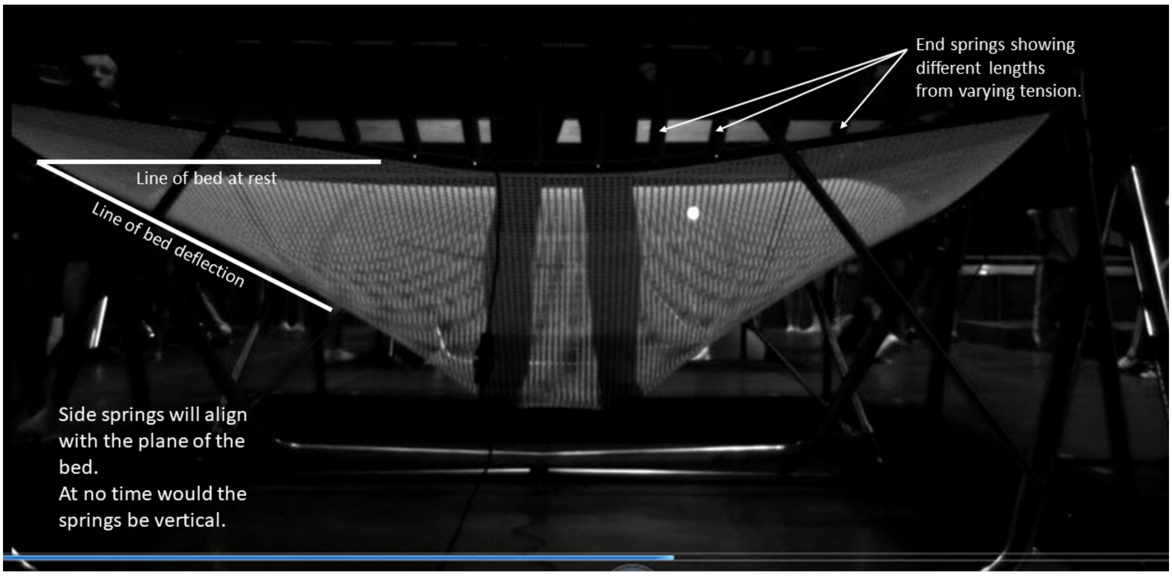

Figure 12. Frame grab from video of bouncing on a Standard trampoline. The string-bed allows a limited view of the legs of the athlete, in this case at the lowest position of the depression of the trampoline.

DISCUSSION

Hypotheses were supported for all "non-average" variables and all variables showed large effect sizes. The Tumbl Trak trampoline showed a larger number of differences from the Standard and Super Tramp apparatuses. The Tumbl Trak is designed to encourage horizontally directed tumbling skills more than vertical cyclic bouncing, but Tumbl Trak trampolines are commonly used for teaching stationary jumps and saltos (Sands, 2002). The larger trampolines were able to propel the athletes higher and with greater accelerations than the Tumbl Trak. The Super Tramp was capable of propelling the athletes the highest and with the greatest flight times. Flight times were mirrored by longer bed contact times.

Our data indicated greater peak accelerations, flight times, and trampoline bed contact times than most previous studies. A similar study involving three trampoline types (unidentified manufacturers) showed lower peak accelerations although the instructions to the athletes were not specified and may have been less aggressive than the instructions in this study (Eager et al., 2012). The Eager and colleagues (Eager et al., 2012) study involved three trampolines with different spring mechanisms and designs which may have influenced the bounce characteristics they observed. Given the unknown nature of the trampolines, and the varying dimensions of the trampolines in the present study, comparisons are difficult. The size of the trampoline, arrangement of springs, and fabric of the bed are likely to interact with bounce characteristics (Kraft, 2001).

A study contesting the existing mechanical models of trampoline bouncing showed that the normal application of a vertical ideal spring model based on Hooke's Law is not correct because of the horizontal orientation of the trampoline springs and bed, the involvement of a subset of the total springs, and the weight of the athlete (Kraft, 2001). In fact, the springs of a modern trampoline act at varying angles to the body of the bouncer rather than co-vertical (Kraft, 2001). Figure 12 shows an athlete's bounce at the lowest position of trampoline bed depression. Differential tension on the springs visible near the top of the image is shown by the middle springs' greater elongation than those farther from the middle. The side springs (not visible) follow the line of the string-bed as shown by the white bed area visible through the net-like structure of the strings. Note that at no time are the springs oriented vertically in line with the bouncer's body or the line of gravity. Typical Hooke's Law models of trampoline bouncing indicate a sinusoidal acceleration result that is lower in magnitude (approximately 10 m/s^2) than that obtained by Kraft's model and experimentation (Kraft, 2001). The alternative model developed by Kraft showed that heavier athletes will always have longer contact times with the trampoline bed when controlled for the distance of descent of the preceding flight and depth of the depression of the trampoline bed (Kraft, 2001). The study by Eager and colleagues (Eager et al., 2012) used a vertical spring model.

The present study recorded flight times corresponding with peak accelerations ranging from slightly less than 0.8 s to greater than 1.6 s. However, the relationship between bed contact time and height of flight can be nonlinear with height of the previous jump, weight of the athlete, musculoskeletal skill application, and nature of the trampoline can all interact to effect bounce characteristics (Glitsch & Henrichs, 1993; Kraft, 2001). For example, higher flights can be achieved following shorter trampoline bed contact times (Briggs, 2014; Glitsch & Henrichs, 1993; Kraft, 2001).

Given that all terrestrial animals vary muscle stiffness while running and jumping to compensate for the characteristics of landing and take-off surfaces, trampoline bouncing is likely to invoke the same mechanisms. Perception, skill, and prior knowledge of the stiffness of the landing surface has been shown to influence motor control strategies of the lower extremity (Ferris & Farley, 1997; McNitt-Gray, 1991a, 1991b; McNitt-Gray, 1993; McNitt-Gray, 1999; Moritz & Farley, 2004). McNitt-Gray demonstrated the importance of individual motor control strategies when handling a drop landing (McNitt-Gray, 2000). Leg muscle stiffness is varied when jumping on sprung surfaces to compensate for the nature of the surface (Arampatzis, Bruggemann, & Klapsing, 2001). Children also show similar adaptations to an elastic jumping surface by varying their lower extremity muscular stiffness (Arabatzi, 2018). Based on athlete feedback, the three trampolines, in order of stiffness would be Tumbl Trak, Standard, and Super Tramp.

CONCLUSIONS

Measured differences were observed in the acceleration behavior of three types of trampolines and the interactions of the trampolines with male and female athlete bouncers. Peak acceleration values were statistically different while average accelerations were not. The Tumbl Trak trampoline was the stiffest with the lowest accelerations and flight times. The Standard trampoline showed middling acceleration and related behaviors while the Super Tramp showed the greatest. This information may prove useful when prescribing trampoline training and rehabilitation protocols for athletes and others who use trampolines. Those with compromised motor control skills may be at more risk when bouncing than healthy and experienced athletes. Future research should expand on these findings along with the influence muscle stiffness and motor control.

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