

THE EFFECT OF WARM-UP MODALITIES ON TRAMPOLINE FLIGHT TIME PERFORMANCE

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Abstract. Trampoline flight time is a recent addition to Olympic scoring and was sufficient in weight to displace a formed medal winner from a podium placement at the 2012 Olympics. The aim of our study was to examine different warm-up routines on trampoline flight time.

We examined ten elite, female trampolinists (mean \pm SD: age 19.2 \pm 5.4 y) who performed six different warm-up routines in a randomised, cross-over, counter-balanced manner: (a) static stretching (STAT, control), (b) STAT+10 trampoline bounces, (c) dynamic stretching (DYN), (d) DYN+10 trampoline bounces, (e) DYN+Drop jumps (DYN+DJ) and (f) DYN+isometric mid-thigh pulls (DYN+IP). Data were analysed using general linear models, Dunnett-HSU post-hoc tests vs. Control/STAT and magnitude based inferences vs. control.

Our analysis demonstrated that total flight time following DYN 10 (17.29 \pm 0.52s, 83% likely beneficial, $P < 0.002$) was significantly longer versus STAT (16.59 \pm 0.49 s), with a trend toward significance for DYN (16.97 \pm 0.20 s; 22% likely beneficial, $P = 0.077$). The DYN-IP (14.04 \pm 0.48 s) and DYN-DJ (14.15 \pm 0.66 s) produced the shortest vs. all warm-up forms ($P < 0.005$). To the contrary, the DYN+DJ and DYN+IP conditions were >99% likely to be detrimental to performance. Our results demonstrate a clear improvement in flight times when using a dynamic warm-up coupled with a trampoline specific bouncing task (DYN+10).

Key words: muscle activation, trampoline, bounce height, flight time

Introduction

Scoring for Olympic trampoline competition is based on level of execution, complexity, and total flight time of a ten-skill routine. Specifically, execution scores reflect the presentation of each skill; difficulty scores reflect the complexity of each skill and flight time addresses the total time taken from the initiation of the first skill through the completion of the tenth skill. The inclusion of flight time is a recent addition to the scoring system and can profoundly influence competition outcomes. For example, at the London 2012 Olympics, the athletes who placed 3rd and 4th both performed routines containing a difficulty factor of 14.8 difficulty. However, Athlete A placed 3rd with an

execution score of 24.8 and a flight time of 16.35 sec (total score 55.96), while athlete B placed 4th despite having a higher execution score (25.0), yet a shorter flight time (16.06 sec; total score 55.86). Interestingly, Athlete B was a silver medallist at both the Athens 2004 and Beijing 2008 Olympic Games before the introduction of flight time. The importance of flight time is further demonstrated as the difference between a medallist and non-medallist at the 2012 Olympic Games and 2013 World Championships amounted to only 0.26 sec and 0.68 sec, respectively.

Very few studies have examined trampoline performance. Instead, coaches tend to draw from established routines involving various floor exercises. Mechanically, bouncing is unique, in that it involves repeated, explosive, bilateral explosive hip, knee and ankle joints extensions, coupled with the more isometric stabilization of the upper body. The goal of trampoline bouncing is to depress the landing surface of the trampoline as much as possible in order to maximise the spring recoil and attain the greatest bounce height (Farquharson 2012). Insufficient stability during this phase will dampen the resultant energy transfer during the spring recoil phase and diminish flight time (Farquharson 2012). Though literature suggests the contents of a warm-up can potentially evoke greater contractile responses for muscle contraction, we are unaware of any studies having examined the specific effects of warm-up on trampoline flight time (Tillin and Bishop 2009).

A 'traditional' trampoline warm-up is comprised of a sub-maximal aerobic component followed by a bout of static stretching. However, recent meta-analyses suggest that static stretching does not maximize exercise performance, whereas a dynamic warm-up appears to be a more favourable means of performance enhancement (Sivic et al. 2013; Shrier and McHugh 2012). The primary aim of our study was to compare a dynamically oriented warm-up versus a static stretching routine. We hypothesized that a warm-up consisting of dynamic stretching followed by sport-specific trampolining movements would be most effective for enhancing bounce performance on a trampoline.

Methods

We performed an initial sample size estimate based on 95% confidence intervals and achieving a power of level of 0.80. Subsequently, we recruited 12 female elite competitive trampolinists (mean \pm SD: age 19.2 \pm 5.4 years; body mass, 61.3 \pm 13.9 kg; height 161.1 \pm 7.1 cm), who had at least three years of competitive experience at the national level of competition and trained 9.2 \pm 2.1 hours week⁻¹. All participants gave informed consent prior to testing for this study approved by the University of Bath Ethics Committee. An overview of the experimental design is outlined in Figure 1. To initiate the study, each individual participated in an introductory session that outlined the routines and procedures. An individual independent of the study assigned warm-up treatments and all conditions were assigned using a randomised, crossover design, and counter-balanced design.

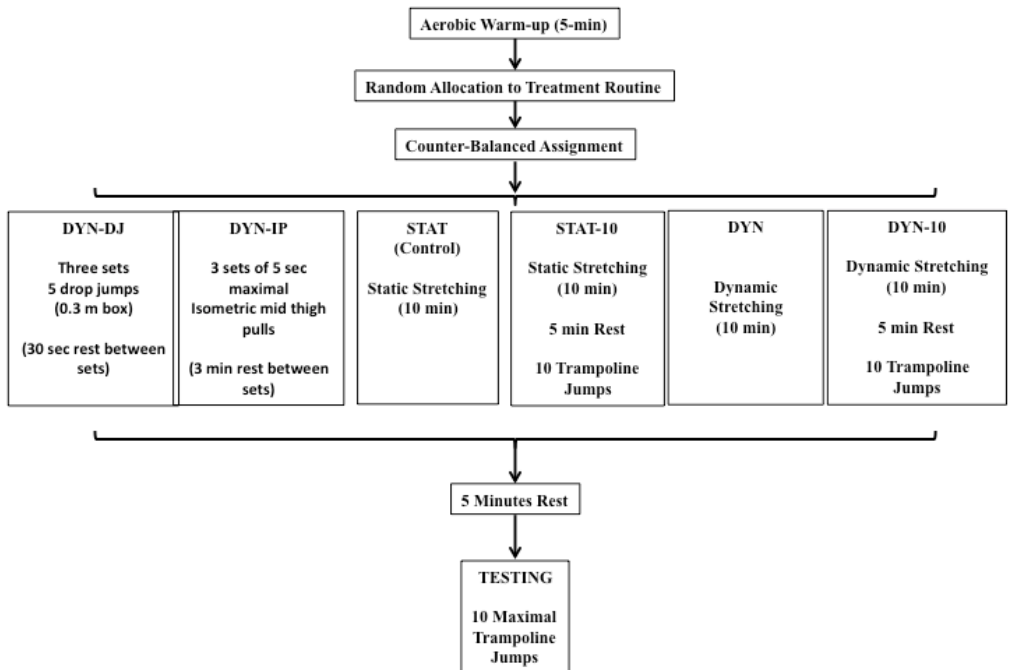


Figure 1. Schematic representation of the study protocol.

Experimental Approach to the Problem

At the beginning of each trial, participants prepared for testing using a standardised 5-min aerobic warm-up comprised of a light jog (2 min), side steps with arm swing (1 min), high knees (30 sec), heel kicks (30 sec), crossover steps (aka, Carioca, 30 sec) and skipping (30 sec). This procedure was then followed by one of six interventions:

(1) **Static stretching (STAT)** – The stretches used in this intervention are identified in Wilson et al. (2010) focusing on the leg adductors, abdominals and torso (Wilson et al. 2010). Each stretch was held for 20 seconds and repeated twice. Each stretch cycle was separated by 10 seconds and the routine lasted approximately 10 minutes.

(2) **Static stretching plus 10 maximal effort trampoline bounces (STAT+10)** – Participants repeated the requirements of intervention #1.

(3) **Dynamic stretching (DYN)** – This intervention targeted the same muscle groups as intervention #1, but used dynamic movements instead. This procedure included: anterior/posterior and medial/lateral leg swings (×10 swings each leg), forward lunges with torso rotation (×5 each leg), forward lunge to standing leg head to knee bend (×5 each leg), side lunge (×5 each leg), “inch worm,” where participants started in a piked, prone position, with hands and feet on the ground and then walked their hands forward as far as possible and then walked them back (×5), standing torso rotation (×10) and downward dog calf pump. This procedure was repeated twice and lasted approximately 10 minutes.

(4) **Dynamic stretching plus 10 maximal effort trampoline bounces (DYN+10)** – Participants repeated the requirements of intervention #3, followed by 5 minutes rest before completing 10 maximal effort bounces on the trampoline starting from stand-still.

(5) **Dynamic stretching plus drop bounces (DYN+DJ)** - Participants repeated the requirements of intervention #3, followed by 5 minutes rest before completing three sets of drop jumps (×5) from a 0.3 m box to the floor, with 30 seconds rest between each set. Participants were instructed to 'react as fast as possible to immediately jump as high as possible' according to instructions from previous research (Bomfim Lima et al. 2011). Hands were placed on the iliac crest throughout each bounce.

(6) **Dynamic stretching plus isometric mid-thigh pull (DYN-IP)** - Participants repeated the requirements of intervention #3, followed by 5 minutes rest before completing three 5 seconds maximal isometric mid-thigh pulls separated by 3 minutes rest. Trials were performed on an isometric dynamometer. Hip and knee angles were measured using a two-prong goniometer and were set at 155–165° (15–25 flexion) and 135–145 (35–45 flexion), respectively. These joint angles were based on previously published protocols purporting to correspond to the position whereby the highest forces can be generated (Garhammer 1980; Kawamori et al. 2006; Stone et al. 2003).

Performance Test and Data Collection

Performance was determined by measuring the total time from initiation of the first bounce, from a standstill position, to the completion of the 10th maximal effort bounce. Bounces were performed on a competition standard (Eurotramp, Baden Wuerttemberg, Germany). Flight time was measured using a Sony 900 E Video Camera sampling at 600 Hz. The line of the camera was positioned perpendicular to the length of the trampoline to allow view of the whole trampoline and the participants' feet during full depression of the trampoline bed. Instructions given to the participants were to 'bounce as high as possible, with as much effort as possible for every bounce.' Technique was not standardised, per se, but instead participants were encouraged to bounce as they usually would during training and competition.

Statistical Analysis

The primary outcome for our study was total flight time. Secondary outcomes included total time for the first five bounces and second five bounces of the trampolining routine. As a tertiary/exploratory measure we examined the slope of the time, bounce relationship, reasoning that a more efficient warm-up routine would enable participants to gain height more quickly. Thus, a steeper slope would denote a faster rate of ascent. We used a general linear model to examine flight intervals by warm-up style for all treatments versus a control condition (STAT). Statistical significance between the STAT condition and the five dynamic warm-up treatments were examined using a Dunnett-Hsu post-hoc assessment with the STAT condition as the referent comparison group. All data were analysed using the SPSS (Version 21.0; SPSS Inc., Chicago, USA).

Consistent with CONSORT recommendation, we used the STAT condition as a covariate in our analyses, as well as the participants, given the age of our participants and potential issues regarding maturation and physical development. Further, despite power calculations to determine our requisite sample size, we performed a bootstrap analysis of our data using 1,000 imputations in order to improve the accuracy of confidence intervals surrounding our various analyses. Readers should note that bootstrapping has no effect on the mean value for each variable,

but only serves to refine the confidence intervals associated with each measure. We further examined our data for an order effect due to the number of treatment conditions used in our protocol. Lastly, we performed a magnitude of effect analysis as proposed by Batterham et al (2006) to evaluate the practical aspects of our findings (3). Significance was set at an alpha of 0.05 and all data are presented as mean ± SD and 95% confidence intervals as appropriate.

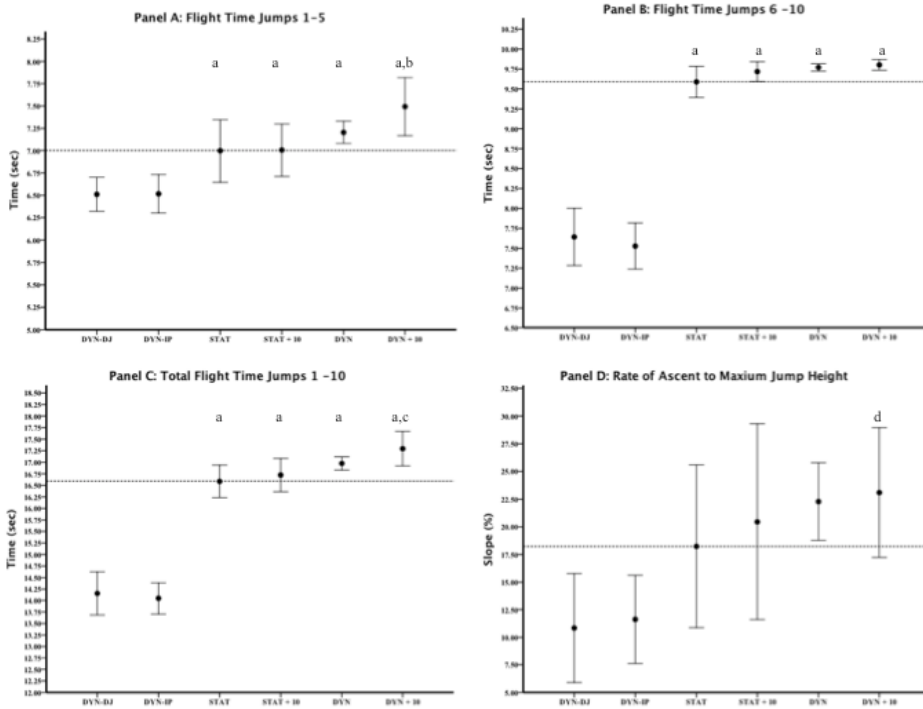
Results

During the study period two participants withdrew from the study for personal reasons. Herein, we present the findings for ten individuals, which satisfies our initial power and sample size estimates. Overall, we observed no significant statistical effects for age (P = 0.112) or testing order (P = 0.90). We did observe, however, a significant statistical effect for warm-up treatments and total flight time, the first five bounces, the second five bounces and the slope of the time-bounce height relationship (all, P<0.001). We have presented our findings for all differences in flight time versus the STAT condition in Table 1. Specific post-hoc comparisons are presented below and shown in Figure 2.

Table 1. Magnitude of warm-up style treatment effects for flight time components of trampolining

Measure	Control	Treatment	Sign.	Diff.	95% CI		Magnitude Based Inference (%)		
					Lower	Upper	Beneficial	Trivial	Harmful
1	2	3	4	5	6	7	8	9	10
Total Flight Time (sec)	STAT	DJ	0.001	-2.43*	2.00	2.86	0.01	0.37	99.62
		IP	0.001	-2.54*	2.11	2.97	0.01	0.34	99.65
		STAT+10	0.528	0.14	-0.57	0.30	5.45	94.27	0.28
		DYN	0.077	0.39	-0.82	0.04	20.19	79.81	0.00
		DYN+10	0.002	0.71*	-1.14	-0.28	83.15	16.85	0.00
Flight Time Bounces 1-5 (sec)	STAT	DJ	0.005	-0.49*	0.16	0.82	0.00	53.37	46.63
		IP	0.005	-0.48*	0.15	0.81	0.00	54.87	45.13
		STAT+10	0.961	0.008	-0.34	0.32	0.17	99.71	0.13
		DYN					42.00	58.00	0.00
		DYN+10	0.004	0.50*	-0.83	-0.17	50.00	50.00	0.00
Flight Time Bounces 6-10 (sec)	STAT	DJ	0.001	-1.95*	1.68	2.21	0.00	0.51	99.49
		IP	0.001	-2.06*	1.80	2.32	0.00	0.51	99.49
		STAT+10	0.326	0.13	-0.39	0.13	0.00	0.60	99.40

	1	2	3	4	5	6	7	8	9	10
			DYN	0.17	0.18	-0.44	0.08	0.54	99.46	0.00
			DYN+10	0.108	0.21	-0.47	0.05	49.03	50.97	0.00
								possibly	possibly	most unlikely
Slope of Ascent (%)	STAT	DJ	0.0560	-7.39	-0.19	14.97	0.97	6.94	92.09	
								very unlikely	unlikely	likely
			IP	0.0860	-6.61	-0.97	14.19	1.87	7.80	90.33
			STAT+10	0.5600	2.22	-9.80	5.36	65.78	8.17	26.04
								possibly	unlikely	possibly
			DYN	0.2890	4.05	-11.63	3.53	81.89	5.83	12.28
			DYN+10	0.2040	4.86	-12.44	2.72	87.55	4.52	7.93
								likely	very unlikely	unlikely



^a Represents significance vs. DJ and IP (P < 0.005).
^b Represents significance vs. STAT and STAT+10 (P < 0.004).
^c Represents significance vs. STAT and STAT+10 (P < 0.01).
^d Represents significance vs. DJ and IP (P < 0.05).

Figure 2. Data represent difference in flight time vs. control condition (i.e., STAT) of the trampoline routine. Panel A represents the bounces 1–5. Panel B represents bounces 6–10. Panel C represents total flight time. Panel D represents the slope of the height, time relationship for bounces 1–5. Data represent mean ±95 CI

Primary Outcomes. We observed significantly lower total flight time for the DYN+DJ and DYN+IP warm-up conditions as compared to all other treatment conditions (all, $P < 0.001$). While no statistical differences were noted between the STAT+10 and DYN conditions versus the STAT condition, we did observe that the DYN+10 treatment produced a longer flight time than the STAT ($P = 0.002$), STAT+10 ($P=0.01$), DYN+DJ ($P < 0.001$) and DYN+IP ($P < 0.001$) warm-up conditions. When using the magnitude of effects approach, we found that the DJ (99.62%) and IP (99.65%) conditions were most likely to be detrimental to performance. While the DYN+10 was 83.15% likely to be beneficial, the performance surrounding the DYN condition was found to be unlikely (20.19%) beneficial and likely trivial to the STAT condition.

Secondary Outcomes. For our analysis of the first five bounces, we observed no significant statistical effects for any warm-up routine versus the STAT condition, though the DYN+10 ($P = 0.06$), DYN+DJ ($P = 0.07$) and DYN+IP ($P = 0.07$) did approach statistical significance. The DYN+10 warm-up routine did produce longer flight times over the first five bounces compared to the DYN+DJ and DYN+IP routines ($P < 0.001$).

For the second five bounces, we observed significantly lower flight times for the DYN+DJ ($P < 0.001$) and DYN+IP ($P < 0.001$) warm-up routines versus the STAT warm-up. While no statistical differences were noted between the STAT+10 and DYN conditions versus STAT, we did observe that the DYN+10 treatment produced longer flight times than the DYN+DJ and DYN+IP warm-up conditions (all, $P < 0.001$).

Tertiary/Exploratory Outcomes. Our examination of slope of ascent relationship showed the STAT (21.6%), STAT+10 (19.7%), DYN (23.3%) and the DYN+10 (22.4%) to have the steepest slopes and, therefore, fastest rates of ascent compared to the DYN+DJ and DYN+IP warm-up routines. While no statistical differences were noted between the STAT, STAT+10, DYN and DYN+10 treatments, all four were significantly greater than the DYN+DJ and DYN+IP warm-up conditions (all, $P < 0.001$). When examining the magnitude of effects for the rate of ascent, we found the DYN+DJ (92.09%) and DYN+IP (90.33%) likely to be detrimental to performance, whereas the DYN (81.89%) and DYN+10 (87.55%) were likely to be beneficial to performance.

Discussion

The primary aim of our study was to examine the efficacy of different warm-up routines inclusive of a dynamic warm-up versus total flight time during trampolining. Given the importance of the flight time component and the absence of literature examining any potential for performance enhancement associated with warm-up activities, our study is timely and novel to the sport of trampoline and potentially, Olympic competition. Our major finding shows that a DYN+10 warm-up produce longer flight times than a STAT, STAT+10, DYN+DJ or DYN+IP. We further show that a warm-up of DYN+10 and DYN appears to produce a faster rate of ascent to maximal bounce height within the first five bounces. This observation is supported by a steep slope relationship between time and bounce height. These latter findings suggest a potential efficiency component to a warm-up routine that enables trampolinists to gain height faster and maintain height for a longer period of time, thus allowing the athlete more time to perform their respective routine. While the DYN+10 was statistically significant to all treatment groups except the DYN group, it should be noted that DYN was only significantly different versus the DYN+DJ and DYN+IP treatment conditions. Specifically, the difference total flight time difference versus the STAT was 0.39 sec (95% CI, -0.82, 0.043) for DYN and 0.71 sec (95%, 0.27, 1.14) for DYN+10.

The use of DYN stretching in favour of STAT stretching has become increasingly more popular across sport. For example, our results agree with several studies showing a reduction in vertical jump performance from 4–6%

relative to the volume and duration of the protocol examined (Bradley et al. 2007; Wallmann et al. 2005; Fletcher and Monte-Colombo 2010; Robbins and Scheuermann 2008). These effects are on par with the difference between our STAT and DYN+10 treatment differences (i.e., 4.2%). In brief, a DYN warm-up has been shown to enhance neuromuscular function, decrease the inhibition of antagonist muscles, enhances motor unit excitability, improves nerve impulse transmission and promotes stiffness to the muscle tendon unit (Bishop 2003; Yamaguchi et al. 2007). Collectively, these effects result in a balance of force and velocity that facilitates the rate of force development in subsequent muscular contractions. Trampolining poses a challenge to such a warm-up routine as it recruits large muscles groups across the whole body that must be able to stabilize and perform "recoil" type activity. Sekir et al. (2010) showed that this type of activity can translate into a 6.8% and 8.4% increase concentric torque output, respectively and a 14.1% and 14.5% increase in eccentric torque output of hamstrings and quadriceps, following six minutes of DYN in women (Sekir et al. 2010). Hough et al. (2009) also observed heightened electromyographic activity resulting in greater vertical jump height following seven minutes of DYN during jump performance. (Hough et al. 2009). Nonetheless, not all findings are unanimous, as some research has reported no effect for using DYN (Samson et al. 2012; Unick et al. 2005; Behm et al. 2004; Gossen and Sale 2000; Jensen and Ebben 2003; Scott and Docherty 2004).

The apparent discrepancy of findings can be explained by a number of factors including intensity, volume and type of conditioning contraction used, duration of rest periods between and following conditioning contraction, type of performance measure used and individual characteristics (training experience, muscle fibre content). The interaction of these factors determines the ratio of potentiation and fatigue, thus determining whether performance is enhanced due to muscle potentiation or diminished due to muscle fatigue (MacIntosh and Rassier 2002). Accordingly, the 'optimal window' for performance improvement would be at the point whereby fatigue has subsided yet potentiation still exists (Robbins 2005). Due to the explosive nature of trampoline jumping, acute performance may be maximised when preceded by a warm-up including an optimal stretching technique and post-activation potentiation inducing activity that emulates the whole body nature of trampolining. In our study, we used a series of side steps with arm swing, high knees, heel kicks, carioca and skipping to target whole body muscle activation. Regardless, DYN does not appear to be deleterious, but does appear to reduce performance when combined as DYN+DJ and DYN+IP.

Adding to the effects noted for DYN, our study demonstrates that incorporating DYN and a sport specific routine into the warm-up routine can further facilitate performance, which may be subsequent to a greater degree of post-activation potentiation. Post-activation potentiation refers to the phenomena by which muscular performance characteristics are dictated by their contractile history and is dependent on the content of preceding activity (Robbins and Scheuermann 2008). In brief, post-activation potential is a product of greater phosphorylation of myosin light chains due to the increased calcium sensitivity and the subsequent increase in cross-bridge cycling (Judge 2009). Greater recruitment of higher order motor units occurs due to greater synaptic excitation within the spinal cord that is usually induced by a maximal or near maximal intensity voluntary conditioning contraction (Tillin and Bishop 2009). A variety of contraction types have been examined (Chiu et al. 2003; French et al. 2003; Kilduff et al. 2007; Saez Saez de Villarreal et al. 2007). The results from our study suggest that a DYN and DYN+10 routine,

incorporating whole body movements, improves flight time performance in trampolining dramatically more so than combining DYN with DJ, which generally focuses on one muscle group, or IP which employs a whole body isometric contraction (Figure 2).

A primary strength of our study is that we used young, elite levels trampolinists to perform our study. However, these athletes compete below the Olympic level so we are not able to generalize our results respective to Olympic athletes, nor can we opine on the effectiveness of our routine in men. A potential limitation to our study is the relatively small sample size. However, our study meets the qualifications of our pre-study power assessment, employs an extensive number of familiarization trials, was administered using a randomized, counter-balanced procedure and enhanced by the bootstrapping of our analysis. In addition, our analysis procedures used the STAT condition as a covariate to minimize potential variance. Our study is potentially limited by the absence of a power/work assessment associated with trampoline bouncing. While these measures are theoretically possible based on spring tension and trampoline bed depression, it should be noted that a competition trampoline contains 100 steel springs, all of which may vary in tension. The major strength of our study is that we have shown for the first time in the sport of trampoline that DYN+10 and DYN warm-up routine effectively increase flight time by ~23% versus a DYN+DJ and DYN+IP, and ~4% versus STAT. However, the difference noted for mean flight time (~2%, $P = 0.14$) is enough of a difference to displace an Olympic athlete from a podium finish as previously illustrated. Our findings are further supported by the large partial eta squared values observed in our study for total flight time (0.897), the first five bounces (0.512) and second five bounces (0.931). Lastly, when using a magnitude of effect analysis, we found the DYN+10 group to demonstrate the highest likelihood for performance enhancing effect followed closely by the DYN warm-up condition. Some caution is warranted, however, as athletes may respond differently to various warm-up conditions.

For the first time, we present data demonstrating that warm-up can positively or negatively affect the flight time characteristics of trampoline performance. The information gathered from this study can be used to aid competitive performance by allowing the athlete to reduce the number of jumps necessary to gain the appropriate height required to execute their routine. Our sub-analyses further suggest that these same types of routines allow trampoline athletes to gain height more quickly, thus allowing them more time to focus on their routines. In contrast, trampoline athletes' should avoid undertaking plyometric or isometric exercise following a DYN warm-up sequence prior to performing on the trampoline, as it appears to diminish performance. The current scoring for competitive trampolining contains a component solely based on flight time. We have demonstrated for the first time in our study that a dynamic warm-up procedure as described above, either alone or inclusive of ten sport specific bounces, produce longer flight times during trampoline performance. While this may seem intuitive on some level, when a dynamic warm-up is combined with isometric or drop jumping activity, trampoline performance is substantially decreased. While the subtle difference between a DYN+10 and STAT warm-up appears to be small, our attempt to enhance our analysis using a magnitude based effects model suggests that this difference is "likely" to be effective vs. STAT training, unlikely to be "trivial" and "most unlikely" to be harmful. However, coaches should assess athletes individually and make subsequent warm-up recommendations accordingly.

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