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KINEMATIC AND KINETIC TUMBLING TAKE-OFF COMPARISONS OF A SPRING-FLOOR AND AN AIR FLOOR™: A PILOT STUDY

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Research article

Abstract

Tumbling take-offs on floor exercise apparatuses of varying stiffness properties may contribute to apparatus behaviors that lead to increased injury exposure. The purpose of this pilot study was to compare the kinematics, kinetics, and timing performance characteristics of a spring-floor and a spring-floor with an added Air Floor™. Five male international gymnasts performed a forward handspring to forward somersault and a round off, flic flac, backward somersault on a standard spring-floor and a spring-floor with an Air Floor™. Performances were measured via high-speed video kinematics (lower extremity joint angles and positions), electromyography of eight lower extremity muscles, mean peak forces on the feet, and timing. Comparisons of spring-floor types, lower extremity joint angles, lower extremity muscle activations, foot forces, and selected durations were determined. The spring floor with Air Floor™ resulted in longer take-off contact durations than spring-floor alone. Dynamic knee angles may indicate an unexpected and potentially injurious motion of the triceps surae musculotendinous structures. This pilot and hypothesis generating study has suggested future research examining dynamic knee position and angle changes, the role of spring-floor vibration and stiffness in take-offs, and take-off muscle activation alignment with the stiffness of the spring-floor. Pragmatically, there appears to be a convergence of evidence indicating that a slower frequency response of the spring floor may assist tumbling performance and reduce stress and strain in the lower extremity.

Keywords: *Spring-floor, tumbling, take-off, electromyography, foot forces, joint angles.*

INTRODUCTION

Tumbling and floor exercise apparatuses have evolved from dirt, sand, and grass to gymnasium wooden floors, horsehair-filled canvas encased mats, wrestling mats, and various types and thicknesses of polyethylene foam sheets

(Hughes, 1966; Joseph, 1949a, 1949b; Weiker, 1985). Spring-floors, involving metal coil-springs, closed-cell, or combination closed- and open-cell foam pieces under a raised plywood or wood and fiberglass laminate, have been used in international gymnastics competition since at least 1979 (Wilson, Swannell, Millhouse, & Neal, 1986). Prior to spring-floors, a wooden floor apparatus was common with narrow, staggered wooden strips between semi-rigid wooden panels that allowed the wooden surfaces to flex on impact. Spring-floor technology evolved quickly to include metal conical, cylindrical, accommodating compression rate coil-springs (Weller, 2011), and foam blocks of various sizes and designs (Federation Internationale de Gymnastique, 1989; Janssen, 2007; Wilson, Neal, & Swannell, 1989; Wilson et al., 1986). Initially, the height of metal coil-springs or foam blocks was approximately 5cm. Later, the height of the metal springs and foam blocks was increased to approximately 10cm. The matting on the top of the floor exercise apparatus also evolved from approximately 2.5cm to approximately 5cm. A short-pile rugged carpet or other fabric covers the entire 12m x 12m floor exercise area, including a border area serving as an "out of bounds" region (International Gymnastics Federation, 2009).

Investigations of elastic sport surfaces have included gymnastics spring-floors, running tracks, gymnasium floors, and others (Greene & McMahon, 1979; McMahon & Greene, 1978, 1979; Nigg, Yeadon, & Herzog, 1988). Although the initial idea for the spring-floor involved a desire for enhanced safety through reduced landing impact "harshness" (Arampatzis, Bruggemann, & Klapsing, 2000; Nigg, Luethi, Denoth, & Stacoff, 1983; Wilson et al., 1986), the evolution of the gymnastics spring-floor has led to increased elastic behavior with corresponding increases in tumbling height and skill difficulty (Holvoet, Lacouture, & Duboy, 1999; McNeal, Sands, & Shultz, 2007; Paine, 1998). The ultimate outcome of continued increases in elasticity may involve a "revenge effect" (Tenner, 1996) of rapidly increasing skill difficulty exceeding the spring-floor's design characteristics for safety. The increased height of tumbling skills necessitates an increased fall distance and correspondingly greater impact forces (Stefanyshyn & Nigg, 2000). Increasing impact forces (both take-off and landing) may result in exposing the lower extremity to unaccustomed stresses such as those leading to sprains, strains, fractures, and Achilles tendon ruptures (Arndt, Bruggemann, Koebke, & Segesser, 1999; Arndt, Komi, Bruggemann, & Lukkariniemi, 1998; Bieze Foster, 2007; Bruggemann, 1985, 1999).

The elastic characteristics of the modern gymnastics spring-floor requires modification of lower extremity muscle-tendon stiffness characteristics, particularly those muscles and tendons acting on the ankle and knee (Arampatzis & Bruggemann, 1999). Muscle activation and peak force parameters may also vary based on the skills performed (i.e., forward versus backward and twisting versus non-twisting) (Bruggeman, 1987; McNeal et al., 2007). However, in spite of increased elastic characteristics of the spring-floor, injury incidences and rates have continued at a high level (Caine, Lindner, Mandelbaum, & Sands, 1996; Sands, 2000, 2002; Sands, McNeal, Jemni, & Penitente, 2011; Sands, Shultz, & Newman, 1993). Gymnastics training activities have sought to enhance the softness of landings and explosiveness of take-offs that may push lower extremity structures to the edge of their performance envelopes and beyond via repeated execution of high-impact skills (Sands, 2000; Sands et al., 1993).

A relatively recent addition to floor exercise tumbling apparatuses is the "Air Floor™." The Air Floor is a tumbling apparatus formed in long plastic air-filled sections approximately 10cm thick and manufactured in varying widths and lengths. A hand-pump is used to inflate the Air Floor to a desired pressure achieving a selected combination of stiffness and rebound characteristics. The Air Floor section or sections are placed on top of a traditional spring-floor or spring-tumbling-strip and used to augment tumbling skills by modifying both take-off and landing impact properties. The Air Floor is expected to reduce the "harshness" of take-offs and landings, acting elastically like a trampoline, affording the gymnast the ability to perform more skill repetitions and thereby lead to enhanced learning. However, no literature was found supporting or refuting such claims. As such, the Air Floor may be a beneficial training apparatus for floor exercise tumbling skills, allowing the gymnast to perform more repetitions of higher trajectory skills with reduced take-off and impact "harshness."

The purpose of this pilot study was to compare the kinematics, kinetics, and technique timing characteristics while using: 1) a standard spring-floor and 2) a standard spring-floor with an added Air Floor. Specifically, the comparison will involve: 1) lower extremity joint angles, 2) lower extremity muscle activations, 3) peak forces on the plantar surfaces of the feet, and 4) examine the effects of the Air Floor addition to a standard spring-floor on tumbling somersault take-off techniques.

METHODS

Subjects: Five male national team gymnasts, including two Olympians, (Mean ± SD, Mass 63.9 ± 3.2 kg; Height 164.6 ± 1.1 cm; 24 ± 2.6 yr) training at the U.S. Olympic Training Center in Colorado Springs, CO, USA volunteered to participate. The athletes were all international level gymnasts who competed in the all-around event consisting of competitive routines on six apparatuses: floor exercise, pommel horse, still rings, vault, parallel bars, and horizontal bar. Data collection preceded all training on each testing day. All data collection and athlete consent and participation followed the requirements of the United States Olympic Committee and data were analyzed retrospectively via approval from the East Tennessee State University Institutional Review Board on the study of human subjects.

Instrumentation and Equipment: Athletes performed a forward handspring to forward layout somersault and a round off, flic flac, backward layout somersault, on a full-size floor exercise area (American Athletic, Inc. Ames, IA. USA). The floor exercise apparatus consisted of a 12 x 12 m square area of 50 wood and fiberglass laminate panels (1.23 x 2.44 x 0.013 m) held together at the edges by metal fasteners. Each panel had 32 cylindrical coil-springs placed evenly in 37 cm squares attached to the under-surface. The metal coil-springs were 10.7 cm in height and 5cm in diameter with 9 coils. Each spring was fastened to the panel undersurface with round plastic socket-like fasteners held with wood screws. The panels and entire floor exercise apparatus area was completely covered by Ethafoam™ matting (416-745 Foam, 0.05 m thick). The matting was covered by a polypropylene backed carpet (60oz weight, 1.7 kg).

A tumbling Air Floor™ (Tumbl Trak, Mount Pleasant, MI, USA) (6.0 x 1.52 x 0.10 m) provided the second tumbling condition. The Air Floor was placed on top of the existing spring-floor. Tumbling elements were performed on the spring-floor alone or on the Air Floor lying atop the spring-floor. The run-up to the Air Floor was performed on the underlying spring-floor. The run-up and tumbling elements were performed within the space of the 12 m side dimension of the spring-floor. Figure 1 shows the spring configuration on the underside of a wood and fiberglass laminate spring-floor panel. Figure 2 shows a side view of a fully inflated Air Floor depicting the inner fiber orientations that hold the Air Floor's shape.

Figure 1. *Spring configuration on the underside of a spring-floor fiberglass wood laminate panel.*

Figure 2. *Side view of an Air Floor segment showing the flexible fibers linking the top and bottom surfaces and ensuring the maintenance of the shape of the Air Floor.*

Muscle activation magnitudes were measured via surface electromyography (sEMG) using a Noraxon™, Telemyo™ telemetered electromyographic system (Noraxon, Inc. Scottsdale, AZ, USA). The sEMG signal was amplified at the transmitter with a gain of 500 and an additional gain of 500 at the receiver, achieving a total gain of 1000 for all channels and sampling at 1000 Hz. Surface-type Noraxon Dual Electrodes™ (Ag/AgCl, 2.0 cm center-to-center spacing, 10 mm diameter detection area, product #272) were adhered unilaterally on the right side muscle bellies of the following muscles: soleus, lateral gastrocnemius, biceps femoris, gluteus maximus, lumbar erector spinae, anterior tibialis, vastus lateralis and peroneus longus. The electrode longitudinal axes were placed parallel to the muscle fiber orientation of each muscle as described by the Noraxon™ MRXP Master Software (Version 1.03.05). Skin preparation consisted of cleaning and rubbing the area with an alcohol-soaked gauze pad, light sanding with fine-grain sand paper, followed by a second cleaning of the skin area with an alcohol-soaked gauze pad. Electrode cables were then attached to the electrodes and taped with elastic tape to the athlete's lower extremity. Cables were connected to a transmitter held in a small belt pack secured around the gymnasts' waist. Data were transmitted to a receiver interfaced to a laptop computer (Dell Latitude D820, Round Rock, TX, USA) using Noraxon™ MRXP Master software (Version 1.03.05). Crosstalk was minimized by placing electrodes in the cross-sectional center of the muscle belly.

On the second test day the athletes were instrumented with a Tekscan™, F-Scan Mobile Research™ system (Version 6.31, South Boston, MA, USA) that recorded forces from the plantar surfaces of the feet via thin (0.15 mm) force and pressure sensitive insoles (Tekscan 3000E). The insole sensors were trimmed with scissors to fit the foot plantar surface of each athlete. The pressure insoles had 960 resistive sensor areas per insole with a pressure range from 345-517 kPa. Each pair of insoles was used once per athlete and test day by taping the insoles to the plantar surfaces of the athlete's feet using elastic tape. Each pressure insole ribbon was connected to a pair of Versa Tek "cuffs" interfaced to a data logger (sampling 500 Hz) worn on a belt fastened securely about the athlete's waist as per manufacturer's instructions. Figure 3 shows an example of the mapping of average peak forces from the soles of the feet during a backward layout somersault take-off.

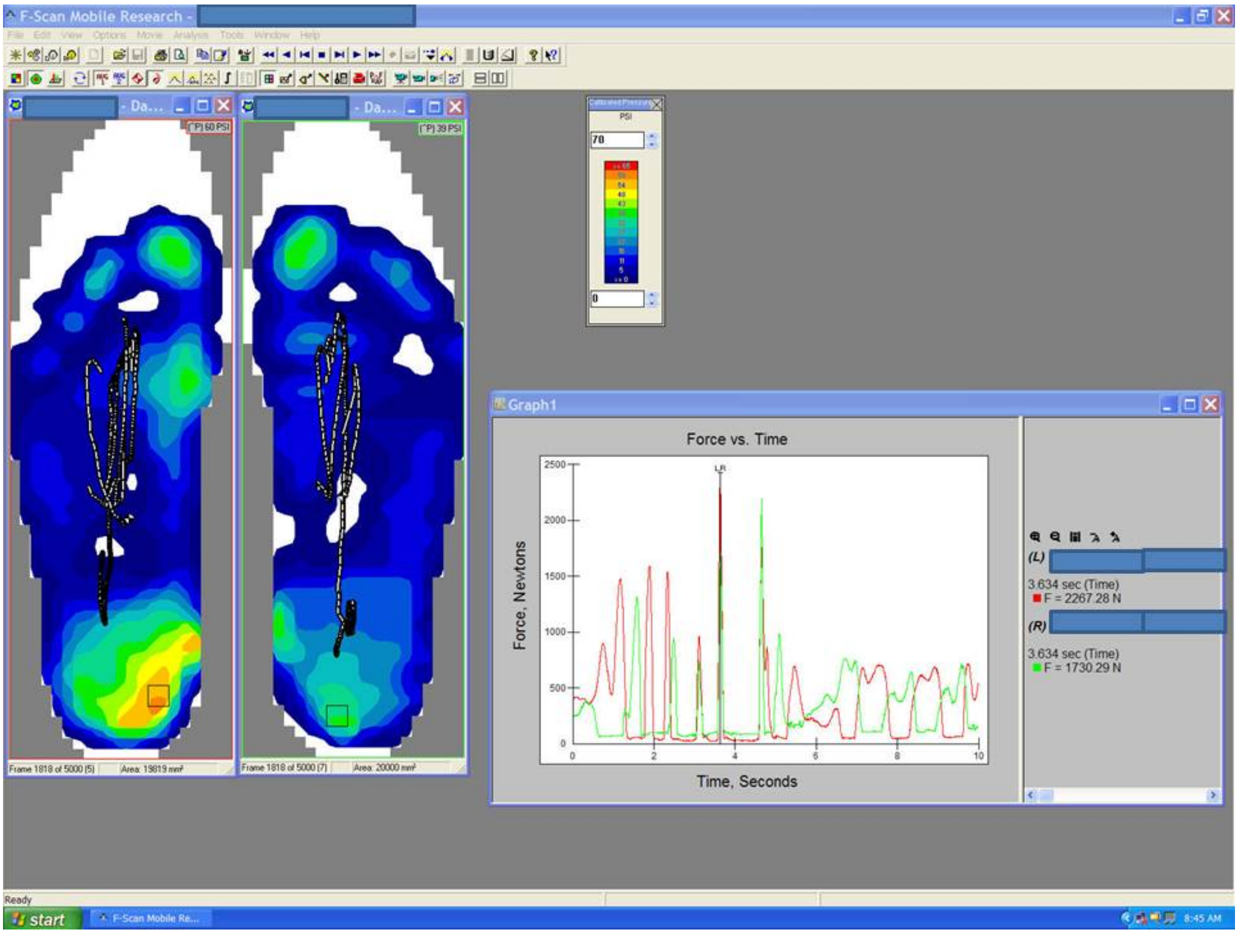

Figure 3. *Example of a computer screen image showing a backward layout somersault take-off. Force "maps" for each foot plantar surface are shown on the left, and the total force data on each plantar surface is shown on the line graph on the right. The black line near the long-axis center of the plantar force map (left) is the center of pressure of the foot derived from the total forces on each foot plantar surfaces across the entire tumbling pass. Note that the non-colored areas indicate the trimming of the sensors to fit the athlete's feet.*

Videography and Kinematics: A high-speed color-video camera (Photron^{TM}, Model 1280, Photron USA, San Diego, CA, USA) was placed perpendicular to the sagittal plane of motion. Video images were captured by Photron^{TM} software at 500 Hz (FASTCAM, Version 2.4.3.2, Photron, San Diego, CA USA). Two-dimensional kinematics of joint angles (ankle, knee, hip, and torso), during the take-off phase of the somersaults, were obtained from the lower extremity using PEAK Motus^{TM} software (Peak Performance Technologies, Motus Version 9.0, Centennial, CO, USA). Two-dimensional calibration was performed using a rectangular calibration frame (1.00 x 1.10 m) following manufacturer's instructions. Tumbling direction was fixed so that the gymnast had his left side nearest the camera during backward somersault take-offs and his right side during forward somersault take-offs. Circular (2 cm) reflective markers were placed bilaterally on the 5th metatarsals, lateral malleoli, lateral knees at the joint line, lateral hips at the greater trochanter, and lateral torso at level of the xiphoid process and on the 12th rib at the inferior-lateral angles. Digitizing of the side of the athlete's lower extremity began 10 video fields prior to foot contact and ended 10 video fields following foot departure. Relative joint angles were identified for lower extremity positions at toe contact with the floor surface, at the midpoint of the take-off foot contact duration, and at toe departure. The angles were derived as follows (Figures 4 and 5): hip - vertex at the hip joint and the two end points were the torso center and the knee and knee - vertex at the knee and the two end-points were the hip and ankle. A quintic spline algorithm was used to smooth the digitized marker trajectory data (Woltring, 1985).

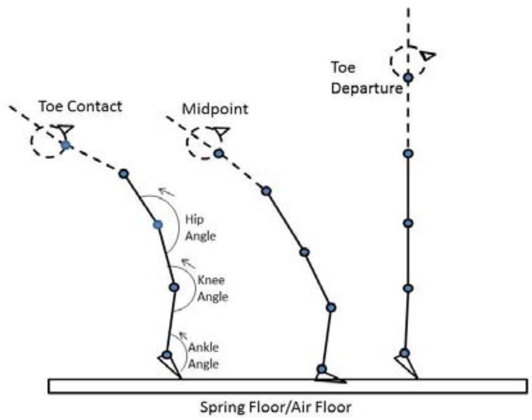

Figure 4. *Layout forward somersault take-off with lower extremity contact positions, joint angle positions, and joint angle directions. Dotted segments indicate non-digitized and non-analyzed segments.*

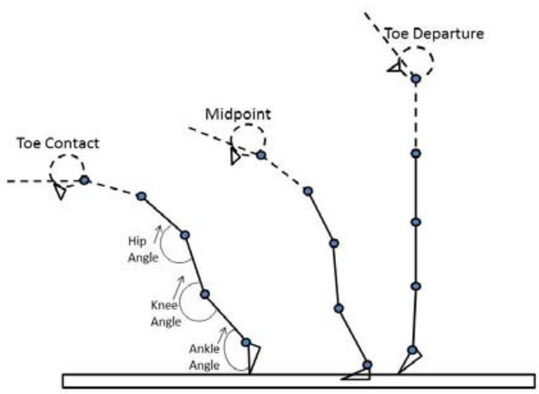

Figure 5. *Layout backward somersault take-off showing lower extremitycontact positions, joint angle positions, and joint angle directions. Dotted segments indicate non-digitized and non-analyzed segments.*

Procedures: The athletes reported to the U.S. Olympic Training Center gymnastics training facility on two separate days. Two days were required because of the added weight of the instruments and the inherent interference of the cables of the two instruments (sEMG and foot plantar surface forces).

The athletes performed a self-selected warm-up prior to testing. Following the warm-up, the athletes were instrumented with either the sEMG or foot plantar force systems and performed two or more familiarization tumbling passes on the spring-floor or the spring-floor with the additional Air Floor. Two data collection trials of a round off, flic flac, layout backward somersault, and two trials of a forward handspring to forward layout somersault were performed on each tumbling surface. The trials were randomly assigned by athlete, floor-type, and instrumentation.

Surface electromyography (sEMG) was assessed using the Noraxon™ MRXP Master software (Version 1.03.05). For the entire take-off period, sEMG processing included full-wave rectification of the raw voltage (µV) signal. The sEMG voltage was integrated to produce an integrated EMG (iEMG, µV·s) and used for further data analysis. All iEMG data were scaled by conversion to percentages of the maximum iEMG for each muscle. Onset and termination of iEMG were determined as the first sample in which the iEMG voltage signal rose to a level greater than 200% above noise or visual inspection of the signal indicated that the take-off muscle activation had begun in spite of the intermediate iEMG signal never dropping below 200% above the signal threshold (McKinley & Smith, 1983). The termination of the iEMG muscle activation signal was the first sample in which the iEMG signal voltage descended below the 200% of voltage signal threshold or visual inspection of the signal indicated that the take-off muscle activation had declined from take-off activation in spite of the intermediate iEMG signal never dropping below the 200% signal threshold.

Calibration of the foot plantar forces device was performed via the single-leg stance method prior to data collection as defined by the instrument manufacturer's software. The foot plantar surface forces were obtained by software (Tekscan™, F-Scan Mobile Research™ system, Version 6.31, South Boston, MA, USA) (Figure 3). An individual sample of peak forces of the entire foot plantar surface was selected and the mean peak force value for all plantar force sensors for each foot was calculated and used for further data reduction and analyses. Peak force was defined as the peak average force across the entire plantar surface of each foot during each type of somersault take-off. The average peak forces were obtained as an included function of the TekScan software.

Analysis: As a pilot study, this was a hypothesis generating investigation. As such, this study was statistically underpowered and, although traditional statistics were used, the primary objective of the study was descriptive searching for promising aspects of performance that could lead to a greater understanding of the gymnast to spring-floor and Air Floor tumbling take-off interactions. Reliability statistics along with hypothesis tests, confidence intervals, statistical power, and effect size estimates were determined (Ellis, 2010). Three repeated measures ANOVAs were calculated for each type of tumbling take-off (6 total). Three angles were extracted from kinematic contact position data and analyzed via a 2 (floor-types) by 3 angles (hip, knee, ankle) x 3 lower extremity floor contact positions (toe contact, midpoint, and toe departure) factorial ANOVA with repeated measures on all dimensions. The iEMG data, previously converted to percentages of the maximum iEMG for each muscle were analyzed with 2 (floor-type) by 2 (take-off-type) by 8 (muscles) repeated measures ANOVAs. A 2 (floor-type) by 2 (left and right feet) repeated measures factorial ANOVA was calculated on mean peak foot plantar surface forces. Total contact times were assessed by a 2 (floor-type) by 2 (tumbling skills) repeated measures ANOVA. Due to the exploratory nature of this study, each analysis was conducted at $\alpha \leq 0.05$ (Huberty & Morris, 1989). All data were statistically analyzed with IBM SPSS Statistics, Version 19.0, Armonk, NY, USA.

RESULTS

Reliability: Two trials of both tumbling take-offs on both floor-types were assessed. Three joint angles were obtained with regard to floor-type, skill, and take-off positions with intraclass correlations across all conditions ranging from r = 0.90 to r = 0.99, and with relative technical errors of measurement ranging from 0.7% to 7.5%. Intraclass correlations for total foot contact times across all conditions ranged from r = 0.96 to r = 0.99, with relative technical errors of measurement ranging from 3% to 5.2%. Muscle activations intraclass correlations were obtained from the muscle iEMG values across all conditions and ranged from r = 0.86 to r = 0.99, with technical errors of measurement ranging from 4% to 47%. The gluteus maximus and biceps femoris muscles activations accounted for the majority of the large variability of measurement. Technical errors of measurement for muscle activations ranged from 3% to 32% when the gluteus maximus and biceps femoris iEMGs were excluded. Mean peak foot plantar force values showed intraclass correlations across all conditions that ranged from r = 0.98 to r = 0.99, with technical errors of measurement ranging from 5.1% to 15.5% (Hopkins, 2000a, 2000b).

Joint Angle Comparisons

The forward handspring to forward layout somersault take-off joint angles did not show a statistical main effect for spring-floor-type ($F_{(1,4)} = 0.5$, $p = 0.52$, $\eta^2_{partial} = 0.11$, power = 0.09). The floor-type by joint angle interaction ($F_{(2,8)} = 0.93$, $p = 0.43$, $\eta^2_{partial} = 0.19$, power = 0.16) and floor-type by lower extremity floor contact positions interaction ($F_{(2,8)} = 1.56$, $p = .27$, $\eta^2_{partial} = 0.28$, power = 0.24) were not statistically significant. Joint angles and lower extremity floor contact positions were statistically different (joint angle: $F_{(2,8)} = 70.3$, $p < 0.001$, $\eta^2_{partial} = 0.95$, power = 1.0;

lower extremity floor contact position, $F_{(2,8)} = 24.2$, $p < 0.001$, $\eta^2_{partial} = 0.86$, power = 0.99). The joint angle by lower extremity floor contact positions interaction ($F_{(4,16)} = 143.83$, $p < 0.001$, $\eta^2_{partial} = 0.97$, power = 1.0) and the spring-floor-type by joint angle by lower extremity floor contact position interaction ($F_{(4,16)} = 3.72$, $p = 0.025$, $\eta^2_{partial} = 0.48$, power = 0.77) were statistically significant. Figure 6 shows the results of the spring-floor-type, lower extremity floor contact position, and joint angle comparisons for the forward handspring to forward layout somersault.

Forward Somersault Take-off Joint Angles (Degrees)

Floor-Type	Lower Extremity Position	Variable	Mean	SD
Spring Floor	Toe Contact	Hip	165.04	6.18
		Knee	218.00	4.78
		Ankle	227.60	9.25
	Midpoint	Hip	191.85	6.56
		Knee	213.90	4.93
		Ankle	242.12	7.27
	Toe Departure	Hip	202.71	9.06
		Knee	180.05	7.11
		Ankle	207.28	10.68
Air Floor	Toe Contact	Hip	166.69	5.57
		Knee	221.23	5.40
		Ankle	228.91	6.82
	Midpoint	Hip	191.18	6.72
		Knee	214.50	8.01
		Ankle	247.66	6.27
	Toe Departure	Hip	199.36	8.22
		Knee	184.23	10.14
		Ankle	204.39	13.52

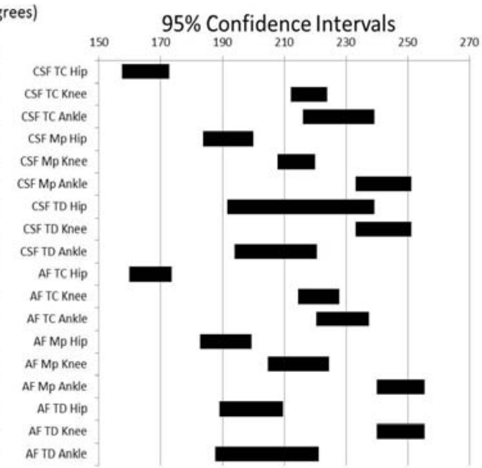

Figure 6. *Forward layout somersault take-off joint angle comparisons.*

Backward Somersault Take-off Joint Angles (Degrees)

Floor-Type	Lower Extremity Position	Variable	Mean	SD
Spring Floor	Toe Contact	Hip	165.04	6.18
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		Ankle	207.28	10.68
Air Floor	Toe Contact	Hip	166.69	5.57
		Knee	221.23	5.40
		Ankle	228.91	6.82
	Midpoint	Hip	191.18	6.72
		Knee	214.50	8.01
		Ankle	247.66	6.27
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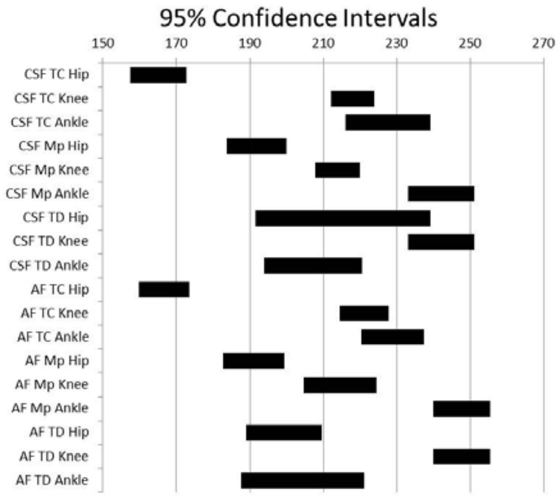


Figure 7. *Backward layout somersault take-off joint angle comparisons.*

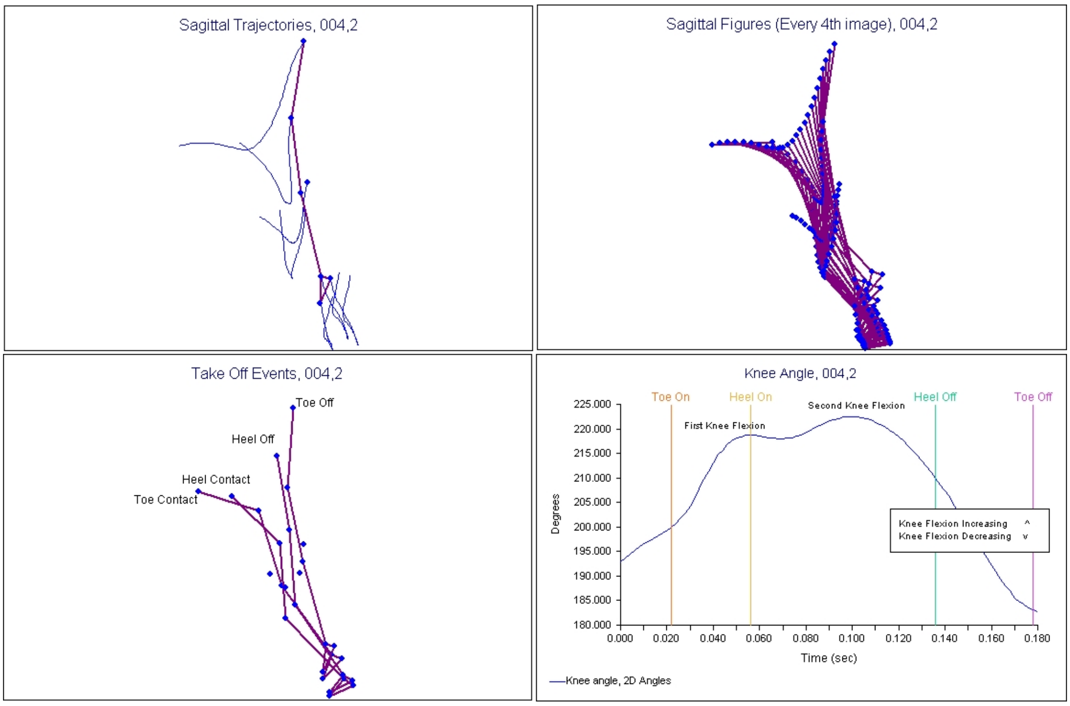


Figure 8. *Kinematic marker trajectories during the layout backward somersault take-off. Moving clockwise from the top-left image panel: 1) all digitized marker trajectories shown for the duration of the take-off, note the abrupt change in knee position: 2) every fourth video field from the 500 fields/s video to ensure that separate images can be displayed, 3) changes in knee angles during the period from toe contact, heel on, heel off, and toe departure, 4) individual digitized images of the four contact positions. Note the distinct two periods of knee flexion in the lower right panel.*

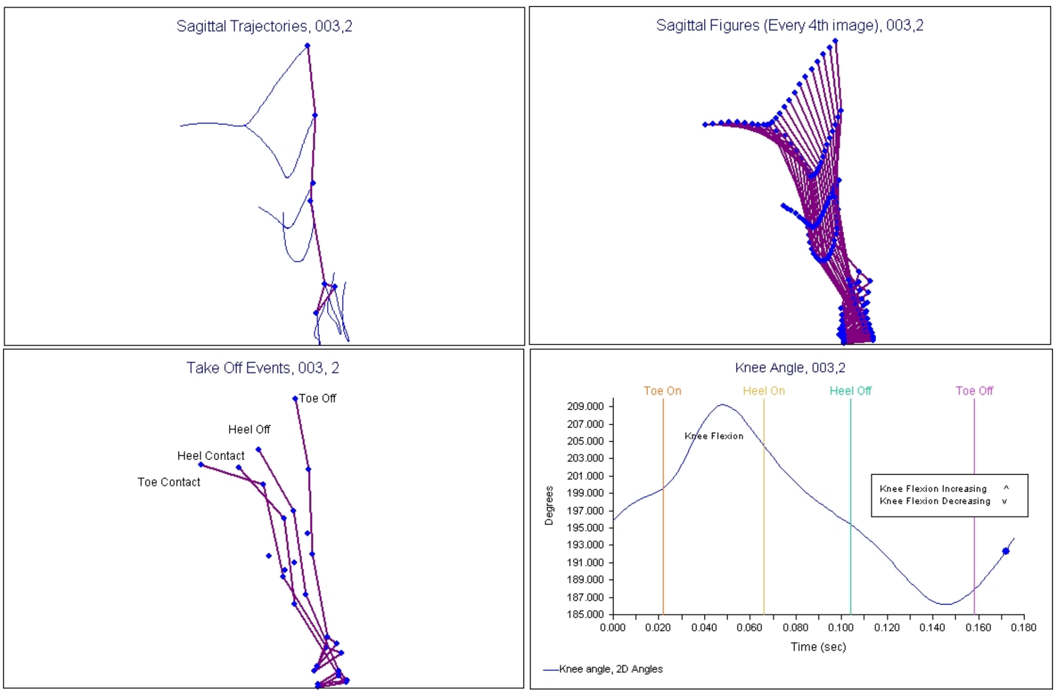


Figure 9. *Kinematic marker trajectories. Note that the lower right panel shows only a single knee flexion period.*

The round-off, flic flac, to layout backward somersault take-off angles did not show a statistically significant main effect for floor-type ($F_{(1,4)} = 0.45$, $p = 0.54$, $\eta^2_{partial} = 0.10$, power = 0.08), floor-type by joint angle interaction ($F_{(2,8)} = 15.22$, $p = 0.08$, power = 0.49), floor-type by lower extremity floor contact position ($F_{(2,8)} = 2.12$, $p = 0.18$, $\eta^2_{partial} = 0.35$, power = 0.31), and floor-type by joint angle by lower extremity floor contact position ($F_{(4,16)} = 1.38$, $p = 0.28$, $\eta^2_{partial} = 0.26$, power = 0.33). Statistically significant main effects included joint angle ($F_{(2,8)} = 200.81$, $p < 0.001$, $\eta^2_{partial} = 0.98$, power = 1.0) and lower extremity floor contact position ($F_{(2,8)} = 120.59$, $p < 0.001$, $\eta^2_{partial} = 0.97$, power = 1.0). A statistically significant interaction was observed only for joint angle by lower extremity floor contact position ($F_{(4,16)} = 230.15$, $p < 0.001$, $\eta^2_{partial} = 0.98$ power = 1.0), accompanied by a large effect size. Figure 7 shows the results of the spring-floor-type, lower extremity floor contact position, and joint angle comparisons for the backward flic flac to backward layout somersault.

Knee Angles During Take-off

In keeping with the pilot and hypothesis generating nature of this study, it can be noted that knee angles changed dynamically throughout the entire backward somersault take-off period. Fifteen of the twenty spring-floor trials showed two brief knee flexion periods (Figure 8). Nine of the twenty Air Floor trials showed a similar knee angle pattern as the spring-floor trials, during backward somersault take-offs. Figure 9 shows an example of a layout backward somersault take-off with a single knee flexion period. Both knee flexion examples in Figures 6 and 7 came from the spring-floor trials. The forward handspring to forward layout somersault knee angles showed no unusual pattern with an unremarkable smooth knee angle motion change through the take-off period.

Electromyographic Comparisons

The scaled muscle activation comparisons for the forward handspring to forward layout somersault take-off showed statistical significance only in terms of muscle activations within the skill. Scaled muscle activations main effects for floor-types were not statistically different ($F_{(1,4)} = 0.1$, $p = 0.77$, $\eta^2_{partial} = 0.02$, power =0.06), nor was the floor-type by scaled muscle interaction ($F_{(7,28)} = 1.08$, $p = 0.40$, $\eta^2_{partial} = 0.21$, power = 0.38). The main effect for scaled muscle activation was statistically significant ($F_{(7,28)} = 2.51$, $p = 0.04$, $\eta^2_{partial} = 0.39$, power = 0.78). Figure 10 shows the electromyographic data for the forward layout somersault take-off.

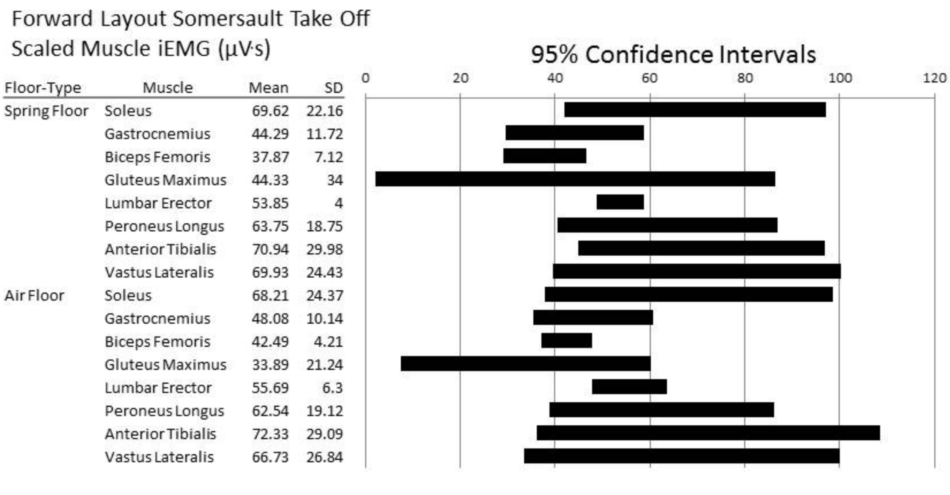
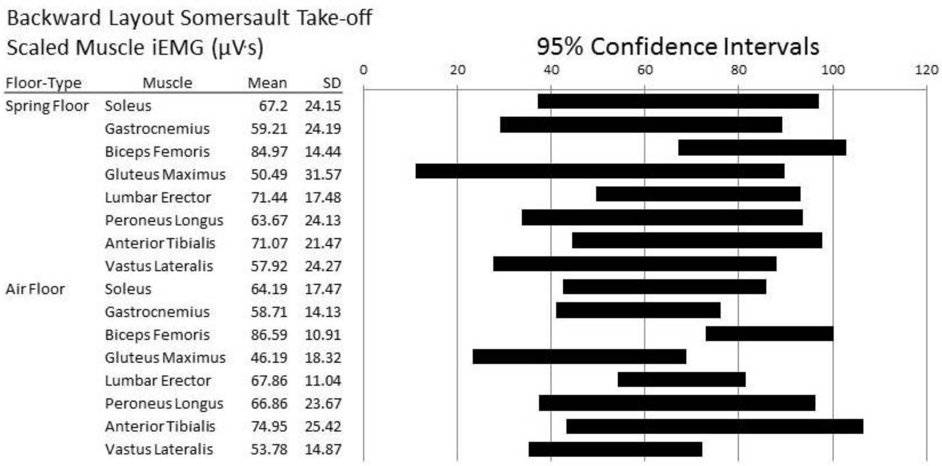
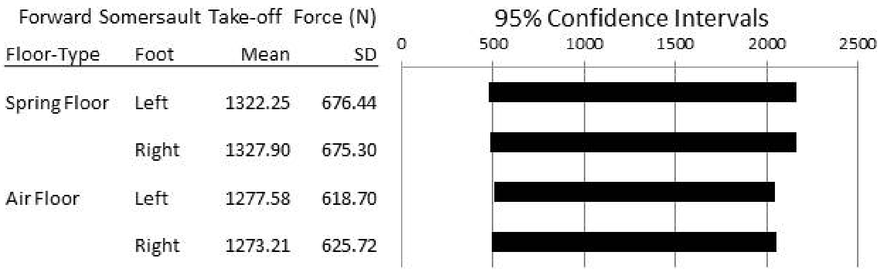


Figure 10. *Forward layout somersault take-off scaled iEMG comparisons.*



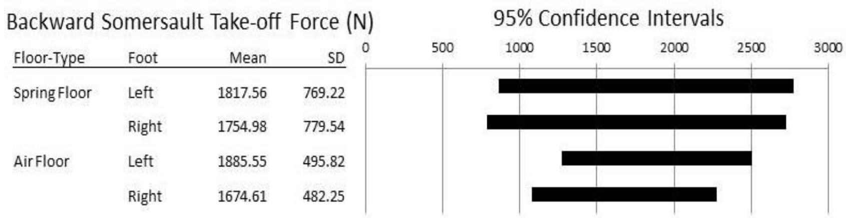
Floor-Type	Muscle	Mean	SD
Spring Floor	Soleus	67.2	24.15
	Gastrocnemius	59.21	24.19
	Biceps Femoris	84.97	14.44
	Gluteus Maximus	50.49	31.57
	Lumbar Erector	71.44	17.48
	Peroneus Longus	63.67	24.13
	Anterior Tibialis	71.07	21.47
	Vastus Lateralis	57.92	24.27
Air Floor	Soleus	64.19	17.47
	Gastrocnemius	58.71	14.13
	Biceps Femoris	86.59	10.91
	Gluteus Maximus	46.19	18.32
	Lumbar Erector	67.86	11.04
	Peroneus Longus	66.86	23.67
	Anterior Tibialis	74.95	25.42
	Vastus Lateralis	53.78	14.87

Figure 11. *Backward layout somersault take-off scaled iEMG comparisons.*



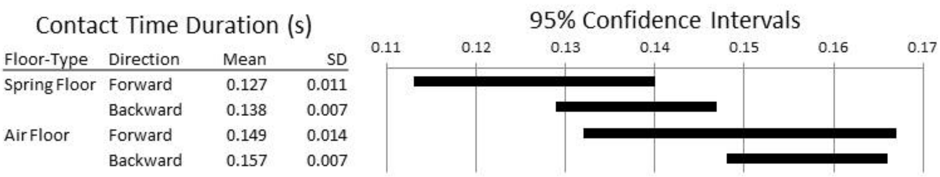
Floor-Type	Foot	Mean	SD
Spring Floor	Left	1322.25	676.44
	Right	1327.90	675.30
Air Floor	Left	1277.58	618.70
	Right	1273.21	625.72

Figure 12. *Forward layout somersault take-off feet plantar surfaces force comparisons.*



Floor-Type	Foot	Mean	SD
Spring Floor	Left	1817.56	769.22
	Right	1754.98	779.54
Air Floor	Left	1885.55	495.82
	Right	1674.61	482.25

Figure 13. *Backward layout somersault take-off feet plantar surfaces force comparisons.*



Floor-Type	Direction	Mean	SD
Spring Floor	Forward	0.127	0.011
	Backward	0.138	0.007
Air Floor	Forward	0.149	0.014
	Backward	0.157	0.007

Figure 14. *Take-off total foot contact time durations by somersault direction*

Scaled muscle activation comparisons for the backward layout somersault take-off on both floor-types showed no statistically significant differences on any dimension. The floor-type main effect was ($F_{(1,4)} = 0.86$, $p = 0.78$, $\eta^2_{partial} = 0.02$, power = 0.06), the scaled muscle activations was ($F_{(7,28)} = 1.82$, $p = 0.12$, $\eta^2_{partial} = 0.31$, power 0.62), and the floor-type by scaled muscle activation was ($F_{(7,28)} = 0.31$, $p = 0.94$, $\eta^2_{partial} = 0.07$, power = 0.13). Figure 11 shows the electromyographic data for the backward layout somersault take-off.

Feet Plantar Surfaces Force Comparisons

The handspring to layout forward somersault take-offs were not statistically different in measures of mean peak foot plantar surface forces (floor-type: $F_{(1,4)} = 1.86$, p = 0.24, $\eta^2_{partial} = 0.32$, power = 0.19; left versus right foot: $F_{(1,4)} = 0.007$, p = 0.94, $\eta^2_{partial} = 0.002$, power = 0.05; floor-type by mean peak foot plantar surface forces interaction: $F_{(1,4)} = 0.95$, p = 0.39, $\eta^2_{partial} = 0.19$, power = 0.12). Figure 12 shows the forces on the foot plantar surfaces comparisons.

Similarly, the round off, flic flac, to layout backward somersault take-offs were not statistically different in measures of mean foot plantar surface peak forces (floor-type: $F_{(1,4)} = 0.001$, p = 0.97, p = 0.39, $\eta^2_{partial} < 0.001$, power = 0.05; Foot: $F_{(1,4)} = 2.32$, p = 0.20, $\eta^2_{partial} = 0.37$, power = 0.22; floor-type by foot interaction: $F_{(1,4)} = 2.74$, p = 0.17, $\eta^2_{partial} = 0.41$, power = 0.25). Figure 13 shows the foot plantar surface force comparisons.

Take-off Floor Contact Durations Comparisons

Floor contact durations statistically differed by floor-type ($F_{(1,4)} = 44.19$, p = 0.003, $\eta^2_{partial} = 0.92$, power = 1.0). The forward or backward tumbling take-off direction contact times did not reach statistical significance ($F_{(1,4)} = 3.84$, p = 0.12, $\eta^2_{partial} = 0.49$, power 0.33) nor did the floor-type by tumbling take-off direction interaction ($F_{(1,4)} = 1.18$, p = 0.34, $\eta^2_{partial} = 0.23$, power 0.14). Figure 14 shows the foot contact durations comparisons.

DISCUSSION

This is a pilot study, attempting to discern the relative promise of future analyses of the gymnasts' interactions with these types of tumbling floors. As such, there were modest, but not surprising, statistical differences in some comparisons with an overall judgment indicating that the Air Floor probably "feels" softer and slower than the spring-floor alone. Beyond the take-off contact durations and probable decreased stiffness of the Air Floor, take-off techniques do not appear to be distorted by the Air Floor. The Air Floor may be a welcome addition to gymnastics tumbling training based on a reduced harshness of take-offs.

Reliability values across the tumbling pass trials were uniformly high based on intraclass correlations. Electromyography data were the most variable demonstrating high technical errors of measurement for some muscles across trials. The mean peak foot plantar surface force measures also showed modestly high, technical errors of measurement across trials, again indicating that some intra-individual performance variability was observed.

The kinematic analyses showed primarily that the lower extremity joint angles during take-off in the forward handspring to forward layout somersault may have resulted in some floor-type technique dependencies based on the statistically significant spring-floor-type by joint angle by lower extremity floor contact position interaction. Inspection of the confidence intervals and effect size indicators may indicate that the reason for the significant three-way interaction lies primarily with the obvious joint angle differences required by the take-off skill performance and selected body position time-points at the different contact positions, as opposed to a factor specific joint angle differences caused by the spring floor-types.

The backward somersault take-off presented a more puzzling and perhaps important variation in take-off technique both within and between floor-types. A more thorough investigation of the dynamic changes in knee angles and positions during the backward somersault take-off opens a line of questions regarding what would cause a gymnast to flex his knees twice during what is primarily a rapid jump that follows a flic flac and leads to a somersault.

The two knee flexions in the lower extremity during a single jump may be the result of several mechanisms, acting individually or in concert:

- the spring-floors may have produced an intermediate vibration of such magnitude that the gymnasts' knees are forcefully "re-flexed" due to an asynchronous or intermediate timed recoil,
- the spring-floors' stiffness may be out of sync and/or inappropriate for the natural stiffness of the gymnasts' lower extremity muscles,
- and/or the gymnasts' second knee flexion may not contribute to the rebound-type jump of the gymnast but rather contribute to enhancing the rotational momentum of the backward somersault.

A statistical difference in muscle activations was found in the forward layout somersault take-off for muscle-by-muscle comparisons, while the backward layout somersault showed no statistical differences on any dimension. However, the effect size estimates for the forward layout somersault scaled muscle iEMG values and the floor-type by scaled muscle iEMG values interaction indicated a modest effect. The variability of performance variables may have influenced traditional statistical analysis because of the small sample size and pilot-nature of this study. The backward layout somersault showed a modest effect size for the scaled muscle iEMG values only. Consulting Figures 10 and 11, the 95% Confidence Intervals provide a visual distinction between the two directions of take-offs, and to a lesser extent, the potential influences from the floor-types. Figures 10 and 11 also appear to show that the backward layout somersault take-offs elicit more muscle involvement and at higher levels than the forward layout somersault take-offs via the 95% Confidence Intervals (McNeal et al., 2007). Drop jumps onto two types of spring-floors from 0.22 m and 0.42 m showed no statistical differences between floor-types, while a statistical difference was evident between the EMG data from the gastrocnemius and rectus femoris muscles (Gormley, 1982).

Mean peak foot plantar surface forces were not statistically different in any of the comparisons. As expected, the overall peak force values were obtained during the backward layout somersault take-offs (Figures 12 and 13). The mean peak plantar surface forces in this study ranged from 1273 N to 1885 N, well below the maximal peak forces of 5000 N documented as the maximal permissible force limit of floor impacts (Wilson et al., 1986). The greater backward somersault take-off forces is supported by McNeal and colleagues' investigation of muscle activation comparisons (McNeal et al., 2007). A non-statistically significant trend was noted in the forward handspring to forward layout somersault take-off with the spring-floor exhibiting greater forces. In the backward layout somersault, the non-statistically significant trends were mixed. Effect sizes for these comparisons may indicate potential floor-type and left/right foot effects that were probably overwhelmed in the analysis because of variability and the small sample in this pilot study. Of particular anecdotal interest (the gymnasts did not perform twisting somersaults in this study), but requiring more investigation, was the 100% correspondence of greater plantar surfaces forces arising from the foot opposite to the gymnast's preferred twist direction. In other words, if the gymnast twists to the left, he demonstrated relatively higher mean peak forces on the right foot plantar surface. Again, foot plantar forces dependence on twist direction was supported by bilateral EMG comparisons by McNeal and colleagues (McNeal et al., 2007).

Spring-floor contact durations were greater in this study than those of McNeal and colleagues (McNeal et al., 2007), while comparing almost identically to the floor contact durations provided in a spring-floor comparison study of cylindrical springs with conical springs (114 ms to 120 ms) (Gormley, 1982). The 115 ms contact time for the forward layout somersault take-off and 117 ms contact time for the backward layout somersault take-off may have occurred because of the increased size and mass of the male tumblers contrasting with the McNeal and colleagues (2007) findings. However, the Air Floor take-offs were statistically longer in this study than those of McNeal and colleagues (2007), 149 ms for forward somersault take-offs and 157 ms for backward somersault take-offs. Both studies and surfaces followed the same trend that backward somersault take-offs required slightly more time than forward somersault take-offs.

The premise that spring-floors are too stiff has been proposed by Paine (1998) in a bioengineering doctoral dissertation based on frequency analysis of the backward somersault take-off from a round off and flic flac. An earlier study using drop weight tests found that two types of spring-floors demonstrated stiffness values approximately 2.3 to 2.4 times the stiffness of lower extremity muscles in running and jumping activities (Gormley, 1982). Paine (1998) also determined that by reducing the fundamental frequency of the spring-floor of that era by half, take-off velocities were enhanced. In short, by "softening" the floor Paine was able to achieve a more comfortable and effective backward somersault tumbling take-off. A study of layout backward somersault flight trajectory distance on a spring-floor versus a foam block floor among U.S female national team members showed that the foam block floor resulted in longer flight trajectories from take-off to landing (Sands & George, 1988). The investigators speculated that the reason for the lengthened trajectory distance was because of the reduced stiffness of the foam block floor thus allowing the gymnast to prolong her foot contact phase and depart from the floor surface with slightly more rearward horizontal velocity.

CONCLUSION

This initial comparison of two types of tumbling surfaces showed that while there are some modest differences in the surfaces, there does not appear to be deleterious effects on tumbling take-off technique. The Air Floor, as expected, appears to be a softer surface permitting less harshness in both directions of take-offs. A limitation of this study was the inability to measure the pressure of the inflated Air Floor. However, practitioners are unable to measure the inflation pressure and rely exclusively on the "feel" of the surface's stiffness to gauge pressure level.

There appears to be a consensus among scientists and practitioners that softer take-off and landing surfaces may contribute to injury prevention. If this is true, the Air Floor has many of the indicators of decreased impact harshness and may allow gymnasts to perform more repetitions with less lower extremity stressors than the spring-floor alone. However, one should be cautioned that a potential revenge effect could occur in that a feeling of decreased harshness may lead to over training via too high volume of repetitions of difficult skills.

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