Internet Journal of Allied Health Sciences and Practice

Volume 22 | Number 1 Article 20

December 2023

A Neuromuscular Training Program Performed on Foam is Accompanied by Improved Balance and Jump Height in Recreational Runners

Katie L. Nixon
University of Michigan, klnixon@umich.edu

Cameron J. Franz
Saginaw Valley State University, cjfranz@svsu.edu

Carson J. Birchmeier
University of Michigan, cjbirchm@svsu.edu

Jeremy L. Knous
Saginaw Valley State University, jknous@svsu.edu

David C. Berry
Saginaw Valley State University, dcberry@svsu.edu

See next page for additional authors

Recommended Citation

Nixon KL, Franz CJ, Birchmeier CJ, Knous JL, Berry DC, Osterhoff KM, et al. A Neuromuscular Training Program Performed on Foam is Accompanied by Improved Balance and Jump Height in Recreational Runners. The Internet Journal of Allied Health Sciences and Practice. 2023 Dec 15;22(1), Article 20.

A Neuromuscular Training Program Performed on Foam is Accompanied by Improved Balance and Jump Height in Recreational Runners

Abstract

Purpose: To assess balance, plyometric performance, and strength of recreational runners completing a neuromuscular training (NMT) program on a novel foam surface. **Methods:** After baseline testing, participants (n=14) completed 22-minute exercise sessions on foam twice weekly for eight weeks, and a post-training testing battery. Testing included lower quarter Y-balance test (LQYBT), dynamic leap and balance test (DLBT), squat jump and countermovement jump tests, and isometric strength testing of the foot and ankle via handheld dynamometry (HHD). Participants were asked to maintain their normal running routines throughout the study period and report any training missed due to injury. **Results:** Participants demonstrated significant (pConclusion: This study supports the use of progressive NMT on foam as a feasible intervention for recreational runners as all participants maintained typical running routines and reported no injuries. While further research is needed to directly inform possible effects of NMT on foam on injury risk and running performance, the improvements in single leg dynamic balance, lower body plyometric performance, and some indices of lower extremity strength in the present study suggest the efficacy of NMT performed on foam.

Author Bio(s)

Katie L. Nixon, BS, is a graduate of the Exercise Science program at Saginaw Valley State University and a student Doctor of Physical Therapy at University of Michigan-Flint in the class of 2026.

Cameron J. Franz is an Exercise Science and Pre-Physical Therapy student at Saginaw Valley State University, University Center, Michigan.

Carson J. Birchmeier, BS, is a graduate of the Exercise Science program at Saginaw Valley State University and a student Doctor of Physical Therapy at University of Michigan-Flint in the class of 2026.

Jeremy L. Knous, PhD, CSCS, is a Professor of Kinesiology and Assistant Dean of the College of Health and Human Services at Saginaw Valley State University, University Center, Michigan. He is also a certified strength and conditioning specialist.

David C. Berry, PhD, MHA, AT, ATC, is a Professor of Kinesiology and the Program Coordinator for Rehabilitation Medicine and Exercise Science at Saginaw Valley State University, University Center, MI. He is also a licensed athletic trainer in the state of Michigan.

Kisha M. Osterhoff, MS, ACSM-EP, is the Humam Performance Lab Coordinator for the Department of Kinesiology at Saginaw Valley State University. She is also a certified exercise physiologist.

Merrick A. Lincoln, PT, DPT, CSCS, is an Associate Professor of Kinesiology at Saginaw Valley State University. He is a certified strength and conditioning specialist and licensed physical therapist in the state of Michigan.

Acknowledgements

This study was funded by an Undergraduate Research Program (UGRP) grant at Saginaw Valley State University. The authors declare no conflicts of interest.

Authors

Katie L. Nixon, Cameron J. Franz, Carson J. Birchmeier, Jeremy L. Knous, David C. Berry, Kisha M. Osterhoff, and Merrick A. Lincoln

The Internet Journal of Allied Health Sciences and Practice
Dedicated to allied health professional practice and education
Vol. 22 No. 1 ISSN 1540-580X

A Neuromuscular Training Program Performed on Foam is Accompanied by Improved Balance and Jump Height in Recreational Runners

Katie L. Nixon[1]
Cameron J. Franz[2]
Carson J. Birchmeier[1]
Jeremy L. Knous[2]
David C. Berry[2]
Kisha M. Osterhoff[2]
Merrick A. Lincoln[2]

1. University of Michigan
2. Saginaw Valley State University

United States

ABSTRACT
Purpose: To assess balance, plyometric performance, and strength of recreational runners completing a neuromuscular training (NMT) program on a novel foam surface. **Methods:** After baseline testing, participants (n=14) completed 22-minute exercise sessions on foam twice weekly for eight weeks, and a post-training testing battery. Testing included lower quarter Y-balance test (LQYBT), dynamic leap and balance test (DLBT), squat jump and countermovement jump tests, and isometric strength testing of the foot and ankle via handheld dynamometry (HHD). Participants were asked to maintain their normal running routines throughout the study period and report any training missed due to injury. **Results:** Participants demonstrated significant ($p<0.05$) improvements in LQYBT composite scores and individual reach directions, DLBT completion time, countermovement jump and squat jump performances, as well as bilateral ankle dorsiflexion strength, and right ankle inversion strength. **Conclusion:** This study supports the use of progressive NMT on foam as a feasible intervention for recreational runners as all participants maintained typical running routines and reported no injuries. While further research is needed to directly inform possible effects of NMT on foam on injury risk and running performance, the improvements in single leg dynamic balance, lower body plyometric performance, and some indices of lower extremity strength in the present study suggest the efficacy of NMT performed on foam.

Keywords: runners, instability training, neuromuscular training, dynamic balance, handheld dynamometry, performance enhancement and prevention

INTRODUCTION

Neuromuscular training (NMT) programs are commonly recommended to improve performance and reduce injury risk among athletes.[1-3] These programs typically include exercises to improve balance, strength, and plyometric performance, and may include activities representative of sport.[3] Evidence suggests a dose-response relationship between NMT participation and reduced injury rates.[1]

Instability training increases the complexity, or technical difficulty, of NMT exercise by placing the athlete on an unstable surface during exercise.[4-8] Various foam materials are commonly used for lower extremity instability training.[5-10] While Airex® (Airex AG, Sins, Aargau, Switzerland) foam pads commonly used in NMT trials, a foam device called Sanddune® (Sanddune Stepper, Indio, California, USA) is commercially available.[8,10] Thicker than Airex® and consisting of two connected foam platforms, the Sanddune® is a novel lower extremity instability device validated for balance training (See Figure 1).[10]

Figure 1. Neuromuscular training exercise performed on foam device

Injuries among runners are common, with prevalence and incidence rates exceeding 40% among trail runners.[11] Coaches and sports medicine professionals, including athletic trainers, exercise physiologists, physicians, and physical therapists, have vested interests in reducing injury risk and improving performance among runners. Neuromuscular training programs have been shown to reduce running-related injury rates, improve running economy, and enhance running performance.[9,12-17] For runners, however, there is a paucity of research on NMT programs performed on unstable surfaces.

This study aimed to assess balance, strength, and plyometric performances of recreational runners completing a neuromuscular training program on the Sanddune® foam pad. We hypothesized NMT performed on the foam device would correspond with improvements in balance, jump performance, and distal lower extremity strength. Moreover, we predicted the foam NMT program would be well-tolerated by recreational runners as evidenced by concurrent running training throughout the NMT program and minimal attrition due to injury.

METHODS

This study used a single group, repeated measures design. Participants completed pre-training testing, 16 twice-weekly supervised NMT sessions, and post-training testing. All participants performed NMT program unshod on the Sanddune®. Standardized outcome measures consisted of tests of balance, jump performance, and isometric strength of the ankle and foot. All procedures were approved by the Institutional Review Board at Saginaw Valley State University.

Participants

All participants were adults recruited at university facilities and through local running clubs via flyers and standardized verbal scripts. Participants were required to identify as "healthy recreational runners," which was operationally defined as those with no known injuries who reported running an average six miles (9.66 kilometers) or more per week for the previous six months. Participants were excluded if they reported major musculoskeletal injury or surgery in the previous six months, reported the use of non-physician prescribed steroids or peptide hormones, were pregnant, reported use of substances known to affect balance or cognition within 24 hours of any session, reported one or more contraindication to exercise on the Physical Activity Readiness Questionnaire (PAR-Q), or failed to attend two NMT exercise sessions per week of the study. Written informed consent was obtained from each participant.

A total of 19 participants were recruited. As five participants failed to attend two training sessions each week, 14 participants completed the study (7 males, 25.4 +/- 8.94 years, 7 females, 25.6 +/- 6.9 years). Additional anthropometric data and self-reported running habits of the participants are detailed in Table 1. Anthropometric assessments were conducted during pre-training and post-training sessions. Assessments included body mass via physician scale (Detecto 337, Detecto/Cardinal, Webb City, Missouri, USA), height via stadiometer (Seca 213, Vogel & Halke, Hamburg, Germany), and body composition via handheld bioelectrical impedance (Body Logic Pro HBF-300, Omron Corporation, Kyoto, Japan). Weekly running was collected via participant self-report. Participants were asked to maintain their normal running routines and report all injuries, which were defined as "any musculoskeletal issue resulting in the loss of one or missed workout."

Table 1. Physical characteristics and self-reported running of participants

	All (n=14)	Female (n=7)	Male (n=7)
	Mean ± SD	Mean ± SD	Mean ± SD
Age (y)	25.5±7.7	25.6±6.9	25.4±8.9
Height (cm)	168.0±9.7	163.0±7.1	173.0±9.9
Body mass (kg), pre-training	71.9±20.5	64.9±9.82	78.9±26.5
Body mass (kg), post-training	71.5±19.4	65.2±9.3	77.8±25.2
Body fat percentage, pre-training	20.3±8.2	25.3±3.8	15.2±8.48
Body fat percentage, post-training	19.8±9.1	25.8±3.2	13.7±9.4
Lean mass percentage, pre-training	79.7±8.2	74.7±3.8	84.8±8.4
Lean mass percentage, post-training	80.3±9.2	74.2±3.2	86.3±9.4
Average running per week (km), pre-training	28.0±18.0	31.5±4.0	24.3±16.3
Average running per week (km), during training	24.7±19.3	26.2±22.8	20.2±14.8

SD, standard deviation

Outcome Measures

Tests described below were administered in identical order at pre-training and post-training sessions under similar laboratory conditions 20°C - 25°C; 13%-56% relative humidity). Each test was administered by the same investigators. Pre-training and post-training testing sessions occurred within one week of initiating and completing the eight-week NMT program, respectively.

Lower Quarter Y-Balance Test

Dynamic single leg balance was tested via Lower Quarter Y-Balance Test (LQYBT). The LYQBT requires the participant to complete maximal lower body reaches in three directions (anterior, posteromedial, and posterolateral) while maintaining balance on the opposite leg.[18] Limb length was measured as the linear distance between the medial malleolus and the anterior superior iliac spine in supine. Three trials in each direction for each foot were collected and the mean reach for each direction was used for analysis. Composite scores were calculated as the sum of the three reach directions divided by three, then multiplied by limb length. Absolute asymmetry was calculated as the absolute value of the difference between right limb and left limb mean reach performances for each of the reach directions. Pliskey et al. (2009) reported excellent intra-rater reliability of LQYBT composite scores (ICC, intraclass correlation coefficient: 0.97 to 0.99).[18]

Dynamic Leap and Balance Test

Dynamic balance was assessed via Dynamic Leap and Balance Test (DLBT) per standard procedures.[19] Briefly, six inch (15.24 centimeter) peripheral targets were arranged on the floor around a central target in the pattern of the Star Excursion Balance Test (SEBT)—two anterior, two anteromedial, two medial, two posteromedial, and two posterior. The two targets in each direction were placed at the 100% and 150% of each participant's SEBT normative reach, respectively.[19] The participant was instructed to leap from dominant foot to non-dominant foot, landing on the closer target, then to immediately leap back to the central target, landing on the dominant limb. Leg dominance was established by asking the participants which leg they would use to kick a ball.[20] After attaining balance for two seconds, the participant repeated the leap to the distant target, landing on the non-dominant limb, then immediately returning to the central target to re-achieve balance on the dominant limb for two seconds. This procedure was repeated for each of the reach directions. Total time to complete the 20 leaps and number of errors testing were recorded. Errors were identified per Balance Error Scoring System criteria, which include touching down non-weightbearing foot, excessive hip abduction, out of testing position for greater than two seconds, and stepping, stumbling, or falling.[19,21] The mean performances for three trials were used for analysis.[19] The same investigator administered all DLBT testing. Test-retest reliability of DLBT was previously reported to be excellent with a sample of healthy college students (ICC: 0.93).[19]

Vertical Jump Tests

Squat jump and countermovement vertical jump performances were measured via switch mat (Just Jump System, Probotics Inc., Huntsville, AL, USA). This device has been validated against jump and reach method and demonstrates excellent within-session reliability (ICC: 0.96).[22,23] Two vertical jump tests were assessed using standard procedures.[23,24] The squat jump test eliminated the stretch shortening contraction from the countermovement. Participants began in a squatted position with a 90-degree knee angle on the switch mat, held position three seconds, then performed a vertical jump with intent for maximum height. For the countermovement jump test, participants began the test standing on the switch mat and performed a rapid quarter squat countermovement, which was immediately followed by vertical jump with intent for maximum height.[23] Participants were required to maintain arms akimbo during squat jump and countermovement tests.[22] Three minutes rest was provided between trials, and the averages of three trials were used for analysis.

Handheld Dynamometry

Isometric strength of the foot and ankle was measured via handheld dynamometry (HHD). Peak isometric force was measured using Lafayette Manual Muscle Testing System (Model-01165, Lafayette Instrument Company, Lafayette IN, USA) for ankle dorsiflexion, plantarflexion, inversion, eversion, flexion of the great toe, and flexion of the four lesser toes using previously described techniques.[25,26] The mean of three trials for each was used for analysis. The same investigator, a physical therapist trained in HHD assessment, administered all tests. Intra-rater reliability for measurements of peak force via HHD for ankle dorsiflexion and plantarflexion have been reported to be good or excellent (ICC > 0.75) and demonstrate moderate agreement (ICC >0.50) with fixed dynamometry.[25] Intra-rater reliability for HHD assessment of inversion-, eversion-, lesser toe flexion peak forces have also been reported to be good or excellent (ICC: 0.81 to 0.94).[26]

Neuromuscular Training Program

The research team developed a NMT program to be performed unshod on the Sanddune® twice weekly for eight weeks (16 sessions). The program included exercises representative of running gait (i.e., stationary running), balance activities, plyometric training, and bodyweight strength exercises. Each phase of the NMT program consisted of the same core exercises; however, complexity was progressed in each phase via introduction of more challenging exercise variations. Members of research team demonstrated each exercise and supervised every NMT session. The NMT program is summarized in Table _.

Table 2. Neuromuscular training program for recreational runners

Exercise	Exercise Volume (sets*reps; total duration including rest interval when applicable)	First 2 Weeks: Description of initial exercise	Weeks 3-5: Description of exercise progression	Weeks 6-8: Description of exercise progression
Stationary running	60 seconds continuous. Participants instructed to gradually increase cadence	Participant performs reciprocal gait-like arm and leg movements in place by alternating stance legs with no double limb support.	Exercise technique not changed.	Exercise technique not changed.
Stationary running with heel kicks	30 seconds continuous. Participants instructed to gradually increase cadence	Participant performs “Stationary running” with exaggerated non-weightbearing knee flexion.	Exercise technique not changed.	Exercise technique not changed.
Stationary running with high knees	30 seconds continuous. Participants instructed to gradually increase cadence	Participant performs “Stationary running” with exaggerated non-weightbearing hip flexion.	Exercise technique not changed.	Exercise technique not changed.
Runner’s single leg balance	2 sets*15 repetitions per leg; 120 seconds total	Participant stands atop foam on one leg and performs slow motion running gait-like reciprocal movement of opposite leg and arms.	Add overhead reach. Technique as previously described with addition of overhead reach with stance side arm.	Add heel raise. Technique as previously described with addition of stance leg heel raise.
Single leg hip hinge	2 sets*10 repetitions per leg; 120 seconds total	With arms abducted, participant stands on right leg with slight bend the in knee, flex stance hip, then return to standing.	Technique as previously performed but with hands atop head rather than arms abducted.	Technique as previously described but with arms outstretched overhead and addition of non-weightbearing hip and knee flexion upon return to standing.
Single leg balance with 3-direction lower extremity reach	1 set*6 repetitions per leg; 120 seconds total	Participant stands on right leg and reaches other leg forward, then back and to the inside of stance leg, then back and to the outside of stance leg. This is one repetition.	Exercise technique not changed.	Technique as previously described but balance is maintained on forefoot throughout.

Exercise	Exercise Volume (sets*reps; total duration including rest interval when applicable)	First 2 Weeks: Description of initial exercise	Weeks 3-5: Description of exercise progression	Weeks 6-8: Description of exercise progression
Vertical jump in place	4 sets*5 repetitions per leg; 120 seconds total	With hands on hips, participant squats, pauses for 2 seconds, then performs a vertical jump with maximum intent for height by rapidly extending both legs (i.e., squat jump).	Technique as previously described but eliminate 2 second pause at bottom position (i.e., countermovement vertical jump). Volume increased to 4 sets*7 repetitions.	Technique as previously described but participant uses rapid arm swing to enhance jump performance.
Pogo in place	4 sets*15 repetitions; 120 seconds total	Participant performs an ankle-dominant, double leg vertical projection of body. Forefoot landing is used to initiate subsequent repetition. Hands on hips throughout.	Technique as previously described but performed unilaterally, first on right, then on left. Volume reduced to 2 sets*15 repetitions per leg to allow completion in allocated 120 seconds.	Technique as previous but uses rapid arm swing to enhance jump performance.
Vertical hop in place	2 sets*5 repetitions per leg; 120 seconds total	Standing on one leg with hands on hips, participant performs single leg squat, pauses for 2 seconds in bottom position, then performs a vertical hop with maximum intent for height by rapidly extending stance leg (i.e., squat hop).	Technique as previously described but eliminate 2 second pause at bottom position (i.e., countermovement vertical hop). Volume increased to 4 sets*7 repetitions.	Technique as previous but uses rapid arm swing to enhance hop performance.
Deep squat	2 sets*8 repetitions; 60 seconds total	The participant stands with one foot on each platform of the foam device and squats as deep as possible with hands behind head (i.e., palms on occiput).	Technique as previously described but perform deep squat with arms outstretched overhead (i.e., overhead deep squat).	Technique as previously described but return halfway to standing, descend to bottom of squat again before standing upright to complete the repetition (i.e., 1.5 rep overhead deep squat).
Single leg squat progression	3 sets*8 repetitions per leg; 180 seconds total	Standing on one foot atop foam device, opposite leg extended behind body with forefoot on the floor, the participant performs a	Technique as previously described but the participant maintains opposite leg behind the body without contacting the	Standing on one foot atop foam device with opposite leg in front of the body, the participant performs a single leg squat (i.e., pistol squat).

Exercise	Exercise Volume (sets*reps; total duration including rest interval when applicable)	First 2 Weeks: Description of initial exercise	Weeks 3-5: Description of exercise progression	Weeks 6-8: Description of exercise progression
		single leg squat by lowering the body and returning to upright with minimal weight through the rear foot (i.e., single leg squat with rear foot support).	floor (i.e., skater squat).	
Bent knee heel raise	2 sets*24 repetitions per leg; 240 seconds total	Standing with front of both feet supported on the edge of the foam device, the participant performs heel raises with knees maintained in 45 to 60 degrees of flexion throughout.	Technique as previously described but performed unilaterally (i.e., unilateral bent knee heel raise). Volume reduced to 2 sets*12 repetitions per leg to allow completion in allocated 240 seconds.	Technique as previously described but performed by raising body halfway through ankle plantarflexion range of motion, returning to bottom position, then returning to full plantarflexion to complete repetition (i.e., 1.5 rep unilateral bent knee heel raise).

Stationary running exercises with gradually increasing cadence served as the dynamic warmup for the NMT program, as stationary running is known to increase oxygen consumption and neuromuscular activity in the lower limbs.[27] Poor balance is associated with higher injury risk in runners.[2,11] Therefore, balance exercises were included in the NMT program to promote stability and lower extremity control.[2,12] Plyometric training consisting of jumping and hopping exercises have shown benefits relevant to runners including improved running economy, improved running performance, and reduced muscular soreness following distance running.[9,14,28] Plyometrics with double leg takeoffs and landings (i.e., "jumps") and plyometrics with single leg takeoffs and same-side landings (i.e., "hops) were included in the NMT program. While traditional strength training programs with external weights have shown to improve running economy and performance, the present training program included exclusively bodyweight exercises.[15,16] Use of bodyweight exercise is consistent with many effective NMT programs.[6,12,17] Moreover, beneficial effects of strength training are known to occur among runners regardless of resistance mode used.[16] Strength training for the foot musculature has been shown to promote resilience to injury.[13] Although no specific foot exercises were included in the NMT, the research team hypothesized performance of exercises unshod on the foam device would train intrinsic foot musculature.

Statistical Analysis

A sample size of 15 participants was determined a priori using G*Power 3 to achieve 0.80 power with an alpha level of 0.05 and 0.80 effect size.[29] Descriptive statistics were analyzed as means and standard deviations. Difference scores were screened for outliers and verified to be normally distributed. Paired t-tests were conducted to compare pre-training and post-training measurements. All statistical analyses were performed with SPSS 28.0 (IBM Corporation, Armonk, NY) with alpha set at ≤0.05 for all analyses. Normality assumption was satisfied per Shapiro-Wilk test and homogeneity of variance was assessed via plot analysis. Effects sizes were calculated as Hedges' g, which expresses differences relative to variability with correction for small samples.[30,31] Effect sizes were interpreted using the following scale [< 0.20 (very small); 0.20 < 0.50 (small), 0.50 < 0.80 (moderate); 0.80 < 1.20 (large); 1.20 < 2.00 (very large)].[32] Effect size analysis included a 95% confidence interval. Only participants who completed all sixteen sessions of training were included in the analyses.

RESULTS

Of 19 participants enrolled, 14 completed the NMT program and post-training testing. The remaining five participants failed to meet the twice weekly attendance requirement due to personal scheduling difficulties. Importantly, no injuries were reported throughout the study. Participants demonstrated improved LQYBT composite scores for right (p = <.001) and left (p = <.001) composite scores.

Significant increases were demonstrated in all LQYBT reach measurements except right anterior reach score (*p* = .066) (See Table 3). DLBT completion time improved (*p* = .005), however, the number of DLBT errors failed to reach statistical significance (*p* = .067) (See Table 4). Squat jump (SJ) (*p* = <.001) and countermovement jump (CJ) (*p* = <.001, 95% CI = -1.87, -.522) scores significantly increased (See Table 5). Ankle dorsiflexion (right: *p* = <.001, left: *p* = .001) and right ankle inversion (*p* = .016) strength also significantly improved. No other changes in isometric strength reached statistical significance (See Table 6).

Table 3. Lower Quarter Y-balance Test pre-training and post-training performances

	Pre-training Mean ± SD	Post-training Mean ± SD	p-value (2 sided)	ES [ES 95% CI]
R Composite Score	90.0±11.0	96.0±9.2	<.001*	1.2 [.5,1.9]
L Composite Score	92.6±11.8	98.7±10.7	<.001*	1.4 [.7, 2.2]
R Anterior Reach (cm)	64.2±8.0	68.0±11.2	.066	.5 [0, 1.0]
L Anterior Reach (cm)	65.3±8.6	71.5±13.3	.022*	.7 [.1, 1.2,]
R Posteromedial Reach (cm)	104.3±14.9	111.6±10.3	.001*	1.1 [.4, 1.7]
L Posteromedial Reach (cm)	109.7±15.6	114.9±10.5	.007*	.8 [.2, 1.4]
R Posterolateral Reach (cm)	101.1±12.9	108.3±9.8	<.001*	1.3 [.6, 2.0]
L Posterolateral Reach (cm)	102.9±13.3	109.6±11.7	<.001*	1.5 [.7, 2.3]
Anterior Absolute Asymmetry	3.8±3.0	3.3±4.5	.736	.1 [-.4, .6]
Posteromedial Absolute Asymmetry	5.0±2.8	3.4±1.8	.079	.5 [-.1, 1.0]
Posterolateral Absolute Asymmetry	3.5±2.2	4.1±3.2	.573	-.1 [-.6, .4]

R, right; L, left; SD, standard deviation; ES, Hedges' g effect size;
ES 95% CI, 95% confidence interval of Hedges' g effect size (ES -1.96*standard error to ES +1.96*standard error)
* Significant difference between pre-test and post-test (p<0.05)

Table 4. Dynamic Leap and Balance Test pre-training and post-training performances

	Pre-training Mean ± SD	Post-training Mean ± SD	p-value (2 sided)	ES [ES 95% CI]
Completion Time (s)	33.1±3.2	29.4±3.6	.005*	.8 [.2, 1.4]
Errors	2.9±1.8	2.1±1.8	.1	.4 [.1, .9]

SD, standard deviation; ES, Hedges' g effect size;
ES 95% CI, 95% confidence interval of Hedges' g effect size (ES -1.96*standard error to ES +1.96*standard error)
* Difference between pre-test and post-test (p<0.05)

Table 5. Jump performance pre-training and post-training performances

	Pre-training Mean ± Standard Deviation	Post-training Mean ± Standard Deviation	p-value (2 sided)	ES [ES 95% CI]
Squat Jump Height (cm)	38.4±7.5	41.7±8.1	<.001*	1.1 [.5, 1.8]
Countermovement Jump Height (cm)	39.6±8.3	42.9±7.8	<.001*	1.2 [.5, 1.9]

SD, standard deviation; ES, Hedges' g effect size;
ES 95% CI, 95% confidence interval of Hedges' g effect size (ES -1.96*standard error to ES +1.96*standard error)
* Difference between pre-test and post-test (p<0.05)

Table 6. Isometric strength pre-training and post-training performances

	Pre-training Mean ± SD	Post-training Mean ± SD	p-value (2 sided)	ES [ES 95% CI]
R Ankle Dorsiflexion (N)	191.0±48.2	226.3±46.8	<.001*	1.3 [.6, 2.0]
L Ankle Dorsiflexion (N)	205.3±53.2	228.8±45.0	.001*	1.0 [.4, 1.6
R Ankle Inversion (N)	200.0±49.5	215.8±58.5	.016*	.7 [.1, 1.2]
L Ankle Inversion (N)	209.3±57.1	221.8±54.1	.1	.5 [.1, 1.0]
R Ankle Eversion (N)	218.9±56.9	239.2±106.0	.4	.2 [.3, .7]
L Ankle Eversion (N)	220.0±70.0	224.0±61.0	.6	.1 [.4, .6]
R Ankle Plantarflexion (N)	424.1±95.6	433.1±108.0	.6	.1 [.4, .6]
L Ankle Plantarflexion (N)	395.9±82.6	431.1±104.0	.1	.4 [.1, .9]
R Great Toe Flexion (N)	179.9±72.7	197.0±63.4	.1	.5 [0, 1.0]
L Great Toe Flexion (N)	175.3±64.3	181.9±55.7	.4	.2 [.3, .7]
R Lesser Toe Flexion (N)	147.8±46.1	162.8±46.7	.1	.4 [.1, .9]
L Lesser Toe Flexion (N)	143.0±53.7	152.1±63.6	.5	.2 [.3, .7]

R, right; L, left; SD, standard deviation; ES, Hedges' g effect size;
ES 95% CI, 95% confidence interval of Hedges' g effect size (ES -1.96*standard error to ES +1.96*standard error)
* Difference between pre-test and post-test (p<0.05)

DISCUSSION

This study aimed to assess dynamic balance, vertical jump, and distal lower extremity strength among recreational runners completing an eight-week NMT on a novel foam surface. Key findings include improved LQYBT composite scores with large to very large effect sizes without change in performance asymmetry between limbs, faster DLBT completion times with large effect size, greater jump performances on squat jump and countermovement tests with large effect sizes, and increased ankle dorsiflexion strength with large effect sizes.

The sole previous study involving the Sanddune® foam device assessed the effects of a NMT program on the among community-dwelling adults.[10] Alotaibi & Moffat reported a six-week (12 session) balance exercise program performed on Sanddune® foam improved static balance and dynamic balance similarly to training on Airex® foam.[10] Notably, the training program in the previous study consisted of exclusively balance exercises, while the present NMT program consisted of balance-, plyometric-, and bodyweight strength training exercises.[10] To assess dynamic balance, Alotaibi & Moffat used the SEBT, which is closely related to LQYBT but not interchangeable.[18,20] Despite methodological differences, dynamic balance improvement in the present study appears consistent previous findings, albeit with interlimb asymmetry findings presenting an exception. Alotaibi & Moffat reported improved asymmetry between right and left limbs, while the asymmetry scores failed to improve in any reach direction in the present study.

The relevance of interlimb dynamic balance asymmetry is equivocal. Among male high school runners, LQYBT asymmetry has been associated with a five-times elevated rate of running-related injury; however, this relationship was not shown among female runners.[33] Moreover, it is not known whether intervention addressing dynamic balance asymmetry mitigates injury risk.[34] Targeted NMT including disproportionate training volume for the affected limb may be needed to rectify dynamic balance asymmetry among otherwise healthy runners.

Tests such as SEBT, LQYBT, and DLBT assess dynamic balance and neuromuscular control.[18,19,34] These features are thought to be related to injury risk among runners.[2] However, the relationship between dynamic balance test results and injury risk remains unclear.[34] Although no injuries were reported in the present study, larger studies are needed to directly inform the effects of unstable surface training on injury rates.

Increased ankle joint complex movement velocities and elevated myoelectric activity have been documented during single leg stance on foam.[7] Following completion of the present NMT program, which consisted primarily of single leg exercises, participants experienced improved dorsiflexion strength bilaterally, improved right inversion strength, and showed a trend toward increased left inversion strength. However, other indices of foot and ankle strength failed to improve, including plantarflexion, which was directly trained by several exercises. Since the plantar flexors are primary muscles of running, it is possible bodyweight exercise on the instability device failed to impart an adequate training stimulus to the runners in the study.[35]

Indices of foot strength also failed to improve during the present study. However, the findings are in alignment with the effects of foot training program for runners.[36] Despite hypertrophy of foot intrinsic musculature following the eight-week training program, toe flexion strength failed to increase. [36] Altogether, the use of external loads, in conjunction with or independent from instability training, may be needed for robust enhancement of ankle and foot strength among trained runners.[5,8]

Limitations

There are limitations to the present study. First, the sample of participants was heterogeneous regarding age, sex, body composition, and weekly running mileage. Although recreational runners tend to be a heterogenous group, the small sample size precluded stratification of participants to assess for subgroup trends. Notably, scheduling difficulties resulted in the loss of five participants, which placed the number of participants completing the trial at n=14, just below the apriori target of n=15. This feature may increase the risk of type II error.[37] Finally, the present study design did not include a control group. Therefore, noted improvements in dynamic balance, jump ability, and strength cannot be solely ascribed to the NMT, as time, testing effects, and other factors may have affected outcomes. In addition to addressing limitations of the present study, future research should assess possible effects of NMT performed on Sanddune® on running metrics such as running economy, running kinematics, and time trial performance.

Runners report barriers to performing NMT, including lack of time, lack of knowledge, and the perception that the NMT exercises contribute to overtraining.[38-40] Supervision and novelty of training are reported to be facilitators and motivators for performance of NMT among recreational runners.[38,39] Therefore, a challenge for strength and conditioning professionals is to develop and deploy efficient and engaging NMT programs that do not interfere with running-specific training. Although additional studies are needed to elucidate the direct performance and injury-risk related effects of the program, neuromuscular training on foam may represent suitably time-efficient and undeniably novel method of training for recreational runners.

CONCLUSION

Recreational runners training on a novel foam surface demonstrated improvements in balance and vertical jump performance. Across the eight-week study, total NMT time was under six hours (352 minutes) per runner and was completed concurrently with the runners' normal running workouts. Although the present sample was small, no adverse events or injuries were reported. These findings suggest a supervised NMT program on foam may be a practical and time-efficient neuromuscular training method for runners.

Acknowledgements: This study was funded by an Undergraduate Research Program (UGRP) Grant at Saginaw Valley State University. The authors declare no conflicts of interest.

REFERENCES

1. Emery CA, Pasanen K. Current trends in sport injury prevention. *Best Prac Res Clin Rheumatol*. 2019 33(1):3-15. [PMID 31431273]
2. Vincent HK, Brownstein M, Vincent KR. Injury prevention, safe training techniques, rehabilitation, and return to sport in trail runners. *Arthrosc Sports Med Rehabil*. 2022;4(1):151-162. [PMID 35141547]
3. Hübscher M, Zech A, Pfeifer K, Hänsel F, Vogt L, Banzer W. Neuromuscular training for sports injury prevention: a systematic review. *Med Sci Sports Exer*. 2010;42(3):413-421. [PMID 19952811]
4. La Scala Teixeira CV, Evangelista AL, Pereira PE, et al. Complexity: a novel load progression strategy in strength training. *Front Physiol*. 2019 Jul 3;10:839:1-5. [PMID 31354510]
5. Behm DG, Anderson KG. The role of instability with resistance training. *J Strength Cond Res*. 2006;20(3):716-722. [PMID 16937988]
6. Blasco JM, Tolsada C, Beltrán M, et al. Instability training, assessing the impact of level of difficulty on balance: a randomized clinical trial. *Gait Posture*. 2019;70:116-121. [PMID 30849606]
7. Strøm M, Thorborg K, Bandholm T, et al. Ankle joint control during single-legged balance using common balance training devices–implications for rehabilitation strategies. *Int J Sports Physl Ther*. 2016;11(3):388-399. [PMID 27274425]
8. Kibele A, Classen C, Muehlbauer T, Granacher U, Behm DG. Metastability in plyometric training on unstable surfaces: a pilot study. *BMC Sports Sci Med Rehabil*. 2014;6(1):30. [PMID 25089202]
9. Lännerström J, Nilsson LC, Cardinale DA, Bjorklund G, Larsen FJ. Effects of plyometric training on soft and hard surfaces for improving running economy. *J Hum Kinet*. 2021;79:187-196. [PMID 34400998]
10. Alotaibi HM, Moffat M. Effect of balance training using different compliant surfaces on performance of one leg stance test and star excursion balance test. *Intl J Phys Med Rehabil*. 2019;7(4):1-9.
11. Kakouris N, Yener N, Fong DT. A systematic review of running-related musculoskeletal injuries in runners. *J Sport Health Sci*. 2021;10(5):513-522. [PMID 33862272]
12. Mendez-Rebolledo G, Figueroa-Ureta R, Moya-Mura F, et al. The protective effect of neuromuscular training on the medial tibial stress syndrome in youth female track-and-field athletes: a clinical trial and cohort study. *J Sport Rehabil*. 2021;30:1019-1027. [PMID 33883301]
13. Taddei UT, Matias AB, Duarte M, Sacco IC. Foot core training to prevent running-related injuries: a survival analysis of a single-blind, randomized controlled trial. *American J Sports Med*. 2020;48(14):3610-3619. [PMID 33156692]
14. Lum D, Barbosa TM, Aziz AR, Balasekaran G. Effects of isometric strength and plyometric training on running performance: a randomized controlled study. *Res Q Exer Sport*. 2023;94(1):263-271. [PMID 35323106]
15. Eihara Y, Takao K, Sugiyama T, et al. Heavy resistance training versus plyometric training for improving running economy and running time trial performance: a systematic review and meta-analysis. *Sports Med Open*. 2022;8(1):138. [PMID 36370207]
16. Balsalobre-Fernández C, Santos-Concejero J, Grivas GV. Effects of strength training on running economy in highly trained runners: a systematic review with meta-analysis of controlled trials. *J Strength Cond Res*. 2016;30(8):2361-2368. [PMID 26694507]
17. Patoz A, Lussiana T, Breine B, et al. Concurrent endurance training with either plyometric or dynamic body-weight training both improve running economy with minimal or no changes in running biomechanics. *Sports Biomech*. Published online April 16, 2023. doi: 10.1080/14763141.2023.2200403 [PMID 37062901]
18. Plisky PG, Butler PP, Kiesel RJ , Underwood KB, Elkins, B. The reliability of an instrumented device for measuring components of the star excursion balance test. *N Am J Sports Phys Ther*. 2009;4(2):92-99. [PMID 21509114]
19. Jaffri AH, Newman TM, Smith BI, Miller SJ. The dynamic leap and balance test (DLBT): A test-retest reliability study. I*nt J Sports Phys Ther*. 2017;12(4):512-519. [PMID 28900556]
20. Fullam K, Caulfield B, Coughlan GF, Delahunt E. Kinematic analysis of selected reach directions of the star excursion balance test compared with the Y-balance test. *J Sport Rehabil*, 2014;23(1):27-35. [PMID 23945793]
21. Finnoff JT, Peterson VJ, Hollman JH, Smith J. Intrarater and interrater reliability of the Balance Error Scoring System (BESS). *PM&R*. 2009;1(1):50-54. [PMID: 19627872]
22. Leard JS, Cirillo MA, Katsnelson E, et al. (2007). Validity of two alternative systems for measuring vertical jump height. *J Strength Condi Res.* 2007;21(4):1296-1299. [PMID: 18076265]

23. McMahon JJ, Jones PA, Comfort P. A correction equation for jump height measured using the just jump system. *Int J Sports Physiol Perform*. 2016;11:555-557. [PMID: 26390168]
24. González-Ravé JM, Machado L, Navarro-Valdivielso F, Vilas-Boas JP. Acute effects of heavy-load exercises, stretching exercises, and heavy-load plus stretching exercises on squat jump and countermovement jump performance. *J Strength Condi Res*. 2009;23(2):472-479. [PMID: 19209075]
25. Mentiplay BF, Perraton LG, Bower KJ, et al. Assessment of lower limb muscle strength and power using hand-held and fixed dynamometry: a reliability and validity study. *PloS One*. 2015;10(10):e0140822. [PMID: 26509265]
26. Spink MJ, Fotoohabadi MR, Menz HB. Foot and ankle strength assessment using hand-held dynamometry: reliability and age-related differences. *Gerontol*. 2010;56(6):525-532. [PMID: 19955706]
27. Alberton CL, Pinto SS, da Silva Azenha NA, et al. Kinesiological analysis of stationary running performed in aquatic and dry land environments. *J Hum Kinet*. 2015;49(1):5-14. [PMID: 26839601]
28. Lundstrom CJ, Russell HC, O'Donnell KJ, Ingraham SJ. Core and plyometric training for recreational marathon runners: effects on training variables, injury, and muscle damage. *Sport Sci Health*. 2019;15:167-174.
29. Faul F, Erdfelder E, Lang AG, Buchner A. G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Beh Res Methods*. 2007;39(2):175-191. [PMID: 17695343]
30. Hedges LV. Distribution theory for Glass's estimator of effect size and related estimators. *J Educat Stat*. 1981;6(2):107-128.
31. Borenstein M. Effect sizes for continuous data. In: Cooper H, Hedges L, Valentine J, eds. *The Handbook of Research Synthesis and Meta-analysis.* 2nd ed. Russell Sage Foundation; 2009:221-236.
32. Sawilowsky S. New effect size rules of thumb. *J Modern Appl Stat Methods*. 2009;*8*(2):597–599.
33. Ruffe NJ, Sorce SR, Rosenthal MD, Rauh MJ. Lower quarter-and upper quarter Y balance tests as predictors of running-related injuries in high school cross-country runners. *Int J Sports Phys Ther*. 2019 Sep;14(5):695-706. [PMID: 31598407]
34. Plisky P, Schwartkopf-Phifer K, Huebner B, Garner MB, Bullock G. Systematic review and meta-analysis of the Y-balance test lower quarter: reliability, discrimination validity, and predictive validity. *Int J Sports Phys Ther.* 2021;16(5):1190-1209. [PMID: 34631241]
35. Wahl MJ, Behm DG. Not all instability devices enhance muscle activation in highly resistance-trained individuals. *J Strength Cond Res*. 2008;22(4):1360-1370. [PMID: 18545166]
36. Taddei UT, Matias AB, Ribeiro FI, et al. Effects of a therapeutic foot exercise program on injury incidence, foot functionality and biomechanics in long-distance runners: feasibility study for a randomized controlled trial. *Phys Ther Sport*. 2018;34:216-226. [PMID 30388670]
37. Button KS, Ioannidis JP, Mokrysz C, et al. Power failure: why small sample size undermines the reliability of neuroscience. *Nat Rev Neurosci*. 2013;14(5):365-376. [PMID: 23571845]
38. Linton L, Barr M, Valentin S. Prehabilitation for recreational runners: motivators, influencers, and barriers to injury prevention strategies for running-related injury. *J Sport Rehabil*. 2022;31(5):544-553. [PMID: 35135901]
39. Fokkema T, de Vos RJ, Bierma-Zeinstra SM, van Middelkoop M. Opinions, barriers, and facilitators of injury prevention in recreational runners. *J Orthop Sports Phys Ther*. 2019;49(10):736-742. [PMID: 31443623]
40. Saragiotto BT, Yamato TP, Lopes AD. What do recreational runners think about risk factors for running injuries? A descriptive study of their beliefs and opinions. *J Orthop Sports Phys Ther*. 2014;44(10):733-738. [PMID: 25155860]