TABLE 4. Detailed Summary of Clinical Studies Examining Whether Stretching Not Immediately Before Exercise Improves Performance

Study	Population	Design	Intervention
Stretching beneficial			
RCT cross-over design			
Kerrigan et al[35]	30 M, 66 F, ≥65 y without orthopedic problems or history of falling	RCT	Exercises performed 5-min BID for 10 wk Warm-up pre and post: 4 side-steps, 3 front-back steps, un-weighted hip flexion ×4 (1) Stretch: static stretch hip-lunge stretch for hip flexors 30-s, repeat ×4 (2) Control: stretch deltoid, with same warm-up and timing
Wilson et al[36]	Eighteen trained power lifters, no previous stretching, in off-season	RCT pre-post	Eight wk of training Stretch: stretches done mostly as holding at extreme ROM on normal strength training exercises, holding 8–20 s, 2 sets of 6–9 reps. Continue regular off-season strength training. Total time ~10–15 min, performed after regular weight training Control: regular off-season strength training Stretches: decline pushups, dumbell flies, chest stretches, shoulder flexion. Total time
Dintiman[37]	145-M physical education university students	RCT, pre-post	Eight wk training, 5 groups (1) Inactive (2) Sprint (3) Sprint then stretch (4) Sprint then weights (5) Sprint then stretch then weights Sprint training 3 days/wk, began long slow distance type training and then speed work later 8 static stretches, total of 20 min 3×/wk Weights: ¾ squat, heel raise, dead lift, straddle lift

TABLE 4. *(continued)* Detailed Summary of Clinical Studies Examining Whether Stretching Not Immediately Before Exercise Improves Performance

Outcome	Results	Comments
Hip extension in same position as stretch Gait analysis Power from force platform Mean of 6 trials used for gait analysis and power calculations	Hip extension ROM increased in stretch group at rest and during walking At slow walking, hip external extension torque increased from 0.47 to 0.52 in Stretch group but not control ($P < 0.003$). At fast speed, hip external extension unchanged in stretch group but decreased in control Comfortable walking speed (m/s) identical increases in both groups.	Age group and limitations of this group mean that any extrapolation to performance issues in athletes are purely hypothesis-generating Adherence 94%
	Pre / Post Stretch: 1.19 ± 0.18 / 1.23 ± 0.18 Control: 1.19 ± 0.17 / 1.23 ± 0.18	
ROM (best of 3 trials) Musculotendinous stiffness Rebound bench press 1RM Pure concentric bench press 1RM	ROM increased by 13% in stretch group Musculotendinous stiffness during activity decreased only at high loads	Two controls did not return Stretch subjects stretched using weights that could have a strength training effect. However, these were minimal weights compared to regular loads In controls, velocity for rebound bench press did not change, but pure concentric bench press actually decreased. Therefore, stretching seemed to prevent decline in velocity rather than improve velocity Encouragement to perform included by training friends
	Pre / Post Rebound bench press Stretch: 133.3 ± 24.6 / 140.6 ± 24.2 Control: 129.2 ± 14.1 / 129.9 ± 20.4	
	Pure concentric bench press Stretch: 118.3 ± 24.3 / 123.6 ± 25.6 Control: 116.4 ± 12.8 / 117.1 ± 18.5	
	Velocity of contraction and power curve increased in stretch group for rebound bench press only (15.8%; $P = 0.1$). There were no changes in the control group	
ROM Fifty-yd dash with a running start (mean of 3 trials) MVC quads (mean of 3 trials)	ROM increased in all 4 measures for sprint and stretch group only	The author mentions 2 master's theses from 1960 and 1961. These were not available for the current analysis. The authors report that stretching did not affect speed in one, but ankle dorsiflexion jumping height did improve in the other
	Pre / Post Fifty-yd dash Inactive: 6.32 ± 0.43 / 6.29 ± 0.41 Sprint: 6.31 ± 0.37 / 5.98 ± 0.33 Sprint and stretch: 6.42 ± 0.51 / 6.00 ± 0.47 Sprint and weights: 6.52 ± 0.51 / 6.04 ± 0.39 Sprint and stretch and weights: 6.54 ± 0.50 / 6.01 ± 0.35	
	MVC quads Inactive: 590 ± 185 / 597 ± 181 Sprint: 604 ± 182 / 639 ± 181 Sprint and stretch: 607 ± 230 / 636 ± 210 Sprint and weights: 576 ± 196 / 714 ± 188 Sprint and stretch and weights: 587 ± 166 / 742 ± 170	
	Over all groups, order of increases in speed were sprint and weights and stretch > sprint and weights > sprint and stretch > sprint, but only significant differences between sprint and weights and stretch versus sprint alone	

TABLE 4. *(continued)* Detailed Summary of Clinical Studies Examining Whether Stretching Not Immediately Before Exercise Improves Performance

Study	Population	Design	Intervention
Hunter and Marshall[38]	50 M, recreational sports (mostly basketball and volleyball), no resistive training, no stretching or plyometrics	RCT, pre-post	Ten wk training, 4 groups: power, stretch, power and stretch, control Power: dead lift, squat, plyometrics, weighted CM jumps, 2×/wk Stretching: 1 supervised session/wk and 3 unsupervised session/wk. Included hamstrings, quadriceps, hip (extension, adduction, abduction), plantarflexors. Stretch until mild discomfort, 20-s repeat ×3 at start, and gradually increase duration to 60 s over training period. After the fourth wk, contract-relax 10 s stretching added Power and stretch: as above, combine programs Control: no change in activity
Handel et al[30]	16-M athletes (swimmers, runners, soccer), in 20s	Right-left comparison, pre-post	Warm-up ×2 min. Then stretch only 1 side Stretch: contract-relax 10-s contraction, 1–2 s relax, 10–15 s stretch, repeat ×8 (2 quad and 2 hams). 3 days/wk ×8 wk
Pre-post			
Worrell et al[39]	10 M, 9 F university students with tight hamstrings	Pre-post, right-left comparison	Three wk training 5 days/wk with hamstring static stretching 1 side and hamstring PNF stretching the other side Static: standing hamstring 15–20 s hold, 15 s rest, repeat ×4 PNF: 5 s hamstring contraction then 5 s quadriceps contraction, repeated ×4
Hortobagyi et al[40]	12 M, active high	Pre-post	Seven wk of training. Static stretches 3×/wk after warm-up (not defined). Stretches were for quadriceps, hip flexors and hip extensors. Each stretch held 10 s and repeated twice

TABLE 4. *(continued)* Detailed Summary of Clinical Studies Examining Whether Stretching Not Immediately Before Exercise Improves Performance

Outcome	Results	Comments
ROM after 5-min cycle warm-up Drop jump: at 30, 60 and 90 cm with hands on hips. Minimize ground contact time CM jump Best of 3 trials used, and jump height calculated from force platform data Muscle stiffness	ROM: hamstrings increase 29° stretch vs. 6° control; quadriceps increase 10° stretch vs. 0° control CM jump Control: 37.0 ± 5.7 Pre; 36.7 ± 5.7 Post Stretch: 35.1 ± 5.4 Pre; 36.4 ± 5.9 Post Power: 36.6 ± 4.8 Pre; 39.5 ± 6.0 Post Power and stretch: 38.5 ± 5.3 Pre; 43.4 ± 6.2 Post For drop jumps, no statistically significant differences. Also, mean of stretch group not consistently better than mean of control group Stiffness changes not consistent	Lost to follow-up: 1 power and stretch, 1 control, 4 power and 4 stretch Order of jumps not randomized
Measures at both 4 and 8 wk, after 5 min warm-up with no stretching ROM with hip flexed and extended Isometric force at 108° (flex), 83°, 58°, 33°, 8° (ext) Eccentric isokinetic torque at 60°/s and 120°/s Concentric isokinetic torque at 60°/s, 120°/s, 180°/s and 240°/s Surface EMG Used mean of the best ⅗ trials	ROM increased by ~3–4° at 4 wk and 6° at 8-wk Absolute Torque Change at 0–8 wks Eccentric: Extensors / Flexors 60°/s: 55.9 ± 43.7 / 25.8 ± 22.7 120°/S: 49.7 ± 44.8 / 29.4 ± 26.7 Isometric: 22.1 ± 40.9 / 19.1 ± 19.7 Concentric 60°/s: 15.5 ± 3.0 / 13.5 ± 10.0 120°/s: 0.9 ± 17.6 / 5.4 ± 18.1 180°/s: 6.0 ± 9.6 / 9.0 ± 6.0 240°/s: 2.6 ± 12.9 / 10.3 ± 10.6 EMG increased in eccentric torque only. No changes in unstretched leg At high velocities, maximum torque occurred at position of greater stretch	Authors note that contract-relax stretches involve isometric training Authors observed 0.8 cm ± 1.1 cm increase in thigh circumference after 8 wk. They suggest this is comparable to other isometric programs
Warm-up prior to testing with progressive resistance ROM: active knee extension Hamstring concentric and eccentric isokinetic torque at 60 and 120°/s	ROM hamstrings increased 8° static, 9.5° PNF but not significantly different Authors combined 2 modes of stretching for analysis 60°/s concentric: 115.8 ± 37.0 Pre; 118.7 ± 37.7 Post 60°/s eccentric: 110.1 ± 37.0 Pre; 119.5 ± 43.4 Post 120°/s concentric: 112.3 ± 35.3 Pre; 124.9 ± 40.3 Post 120°/s eccentric: 111.7 ± 39.1 Pre; 126.7 ± 41.3 Post	No control group to compare no stretching Changes in torque refer to both PNF and static groups because ROM was the same, but PNF group involves isometric contractions as part of training
ROM: front-rear splits, side splits, distance shoulder-patella during leg-to-chest movement MVC at 130° (180° = extension) Fast isometric contraction (FIC), relaxation time ($T_{1/2}$) Maximal stride frequency during 10s run-on-spot Speed of contraction at 0, 25, 50, 75, 100, and 125 kg Used best of 3 trials	ROM increased (e.g., symphysis pubis-floor distance decreased from 36.3 ± 3.3 to 28.3 ± 4.1) MVC: 113.3 Pre; 117.4 Post $T_{1/2}$: 0.16 Pre; 0.11 Post Max stride freq: 3.75 Pre; 4.09 Post FIC: 935 Pre; 1092 Post Contraction speed 0 kg: 515 Pre; 610 Post 25 kg: 380 Pre; 475 Post 50 kg: 360 Pre; 400 Post 75 kg: 440 Pre; 450 Post 100 kg: 340 Pre; 350 Post 125 kg: 320 Pre; 340 Post	This study was done in active high school students with no control group. One would expect to see increases in strength and speed in this age group over this duration if they were performing any type of strength or sport-specific training MVC was tested at 130°. The studies on the effects of acute stretches suggest performance decrements only occur closer to terminal extension

TABLE 4. *(continued)* Detailed Summary of Clinical Studies Examining Whether Stretching Not Immediately Before Exercise Improves Performance

Study	Population	Design	Intervention
Stretching no effect			
Nelson et al[41]	16 M, 16 F college students, trained (run 30 min/d 5 d/wk, accustomed to treadmill) but not regular stretchers	RCT pre-post changes, stratified on gender	Static stretches ×10 wks. Hold 15 s, repeat ×3 (includes both assisted and unassisted), 15 different exercises. Stretching lasted ~40 min, 3 d/wk Stretches were sit and reach, quads and triceps surae
Godges et al[42]	25 M college recreational athletes with tight hip flexors on Thomas test. Intensity of outcome required fitness in upper 20% of age and gender-matched population values	RCT, pre-post	Three wk of training (1) Control group (2) Static stretch of hip flexors for 2 min (<15% body weight) and rest ×2-min, repeat ×3, 2×/wk (3) Leg lowering exercise 5 min BID

TABLE 4. *(continued)* Detailed Summary of Clinical Studies Examining Whether Stretching Not Immediately Before Exercise Improves Performance

Outcome	Results	Comments
Sit and reach	ROM increased 9% on sit and reach test, no change in control	Only measured sit and reach and hip rotation for ROM. Authors state that these are major predictors of running economy in cross-sectional research studies
Running economy at 70% VO_2 peak (6 mph 2% grade for males, 5 mph at 2% grade for females)	Virtually identical running economy pre-post (results only given in figure)	
VO_{2peak}	VO_{2peak} unchanged	
ROM	Leg-lowering group results not reported as not pertinent to this study's question	Used same program as with the effects from acute stretching.[32] However, whereas the authors found improvements in economy of motion with an acute bout of stretching, there was no difference with 3 wk of training
Walking economy at 108 m/min at 108 m/min	ROM hip extension increased only in stretching group	
Running economy at 200 m/min		
Trunk performance (same as training motion)		

	Pre	Post
Walking economy		
Stretch	17.9 ± 1.317.8 ± 0.9	
Control	17.9 ± 1.2	16.4 ± 2.2
Running economy		
Stretch	39.5 ± 1.7	38.7 ± 1.7
Control	39.3 ± 2.8	38.0 ± 2.7