TABLE 2. Detailed Summary of Clinical Studies Examining Whether Stretching Immediately Before Exercise Improves Performance

Study Acute	Population	Design	Intervention
Stretching no effect			
Pyke[34] (also reported in Table 3 for effects on running)	45 M 15–17 y, random sample from boys' high school	RCT-block design. Blocks based on baseline preintervention scores of outcomes	(1) Strength: 75% effort for pushups, sit-ups, squats (2) Stretch: backward double arm circles, standing trunk turns, standing toe touches
Wiktorsson-Möller et al[31]	8 M participating in moderate fitness programs. Age not reported	Nonrandomized cross-over (includes prepost) with 48 h between each sessions	(1) Warm-up on bicycle for 15 min (2) Warm-up and massage (3) Massage (4) A Warm-up and PNF contract-relax stretch Stretch: isometric contraction for 4–6 s, then relax × 2 s, then passive pain-free stretch × 8 s. Six different movements: ankle dorsiflexion with knee straight and knee bent, hip abduction and extension and flexion, knee flexion. For this article, only stretch and warm-up and stretch alone are compared
Stretching detrimental			
RCT cross-over design			
Little and Williams[29] (also reported in Table 3 for effects on running)	18 M professional soccer players	Nonrandomized cross-over (stretch, then no stretch, then dynamic), 3 conditions tested within 1 week but at least 1 day between tests	All subjects warmed up, then stretched or no stretch, then higher intensity activity, then 2 min rest before testing session (1) Static stretch: right leg 30 s, left leg 30 s (2) No stretch: rest for 1 min (3) Dynamic stretch: right leg 1 s, left leg 1 s, for a total of 30 stretches (60 s total time) Stretching included gastrocnemius, hamstring, quadriceps, hip flexors, gluteals, and hip adductors
Fowles et al[12]	8 M, 4 F College-age recreational athletes	RCT cross-over (includes pre-post) with ≥3 d between sessions	(1) Rest (2) Passive stretch of triceps surae by examiner without pain, restretched every 2 min. Thirteen total stretches for total of 33 min
Church et al[13]	40 F, NCAA Division 1 tennis, rowing, volleyball, jumpers, throwers, sprinters	RCT cross-over (pre-post) with >24 h between sessions	General warm-up 10 exercises for total of 5 min. Then tested, then: (1) None (2) Static stretching (3) PNF stretching (passive stretch-10s contraction, relax with passive stretch) ×3 Muscles stretched were mostly quads and hams. Details of position and duration for static stretch not given

TABLE 2. *(continued)* Detailed Summary of Clinical Studies Examining Whether Stretching Immediately Before Exercise Improves Performance

Outcome	Results	Comments
Counter-movement vertical jump	For vertical jump differences, $P = 0.07$ Vertical jump (cm) Static stretch 39.4 ± 4.5 No stretch 40.4 ± 4.9 Dynamic stretch 40.2 ± 4.5	Jumping mats for jump The order of the sessions was not randomized. If there were a learning effect, one would expect the dynamic stretch superior to no stretch superior to static stretch. If there were a fatigue effect, one would expect the opposite Stretches were only 30 s in this study. Other studies use 30 s repeated for a total of 60 s
Ball throwing (last of 3 trials) Jump height (last of 3 trials) Cycle speed (6 trials, best of last 3 trials)	Actual results for tests not given; only report *F*-test for overall effect as nonsignificant	ROM not measured Because of multiple outcomes, author accepted only $P <$ 0.01 as significant. There were no significant changes but actual results not given
Hams and quads isometric strength, and isokinetic strength at 30 and 180°/s	ROM increased with stretch for all movements (e.g. hip flexion 9° for warm-up and stretch vs. 1° for warm-up alone) Virtually identical strength in hams and quads when comparing warm-up and stretch to warm-up alone (Warm-Up and Stretch / Warm-Up) Hams 30°/s 160 ± 4.8 / 161 ± 5.2 180°/s 137 ± 4.7 / 137 ± 6.4 Isomet 123 ± 5.1 / 126 ± 4.6 Quad 30°/s 215 ± 13.9 / 216 ± 14.5 180°/s 148 ± 8.1 / 145 ± 6.6 Isomet 257 ± 8.9 / 266 ± 8.7	Order of interventions not randomized could result in learning effect. However, this would be expected to improve performance of stretch group, and this did not occur PNF contract-relax stretch actually increases warm-up of muscle. The extra warm-up with this type of stretch may minimize any detrimental effects of the actual stretch itself For note, massage resulted in a decreased force if done without a warm-up
Plantar flexion: Experiment 1: MVC, twitch interpolation and surface EMG at 10° dorsiflexion. Measured pre and post (0, 5, 10, 15, 30, 45, and 60 min) Experiment 2: MVC and EMG at 3 different angles. Hip and knee at 90° so mostly soleus. Measured pre and post (30 and 60 min only)	ROM increased by 6.5° immediately after stretch due to both stretch-relaxation and an increase in stretch tolerance In experiment 1, MVC declined to 72% of prevalue immediately after stretch, and improved to 80% at 5 min, 87% at 15 min, and 91% at 60 min. There were no changes in the control group Experiment 2 had the same qualitative results at each joint angle, and the angle for maximum torque did not change with stretching EMG decreased with stretching. Twitch interpolation suggested a 16% decrease in motor unit activation immediately after stretching, and a 13% decrease 5 min poststretching	No warm-up before stretch Two people excluded because EMG was active on stretch Calculations suggest that 57% of the immediate force decline with stretching was due to loss of motor unit activation. However, motor unit activation had only a minor role in force decline 15 min poststretching
ROM Vertical jump height using Just Jump system (subjects familiar with equipment)	ROM greatest poststatic stretch compared to post-PNF or no stretch Vertical Jump (cm) Control 48.65 ± 8.09 Static stretch 48.06 ± 7.64 PNF stretch 47.18 ± 7.38	Although authors measured pre-post, they only report the post values and not the change values. They do not report baseline scores for each of the groups either Only PNF results significant

TABLE 2. *(continued)* Detailed Summary of Clinical Studies Examining Whether Stretching Immediately Before Exercise Improves Performance

Study Acute	Population	Design	Intervention
Stretching detrimental			
RCT cross-over design			
Nelson and Kokkonen[14]	11 M, 11 F, college physical education students with no stretching or weight lifting history	RCT cross-over with 24 h between sessions (pre-post only for ROM)	(1) Quiet sitting (2) Ballistic stretch, 1 ×/s, for 15 s. Repeat ×3 with 15 s recovery. All stretches first completed unassisted (×3), and then repeated with assistance (×3) Muscle groups: hip, thigh and calf—sit and reach, lotus, standing calf, standing ½-lotus, standing quad/hip flexor
Kokkonen et al[15]	15 M, 15 F, college-age, untrained physical education students with no stretching or weight lifting history	RCT cross-over with 24 hours between sessions (pre-post only for ROM)	(1) Quiet sitting (2) Twenty min static stretch hip, thigh and calf. Each stretch held 15 s, 15 s recovery, repeated ×3. All stretches first completed unassisted (×3), and then repeated with assistance (×3) Muscle groups: hip, thigh and calf—sit and reach, lotus, standing calf, standing ½-lotus, standing quad/hip flexor
Cornwell et al[16]	10 M, college-age, physically active but not in regular physical training	RCT cross-over with 24 hours between sessions (no pre-post)	All subjects practiced techniques on day 1 to standardize starting positions and kinematics (1) Assisted static stretch: 10 s ×3. Stretches were supine with leg over side of table (quads), prone hip extension, and knee-to-chest (2) Control: quiet sitting ×10 min
Knudson et al[17]	10 M, 10 F, university age, heterogenous activity from moderately active to intercollegiate athletics	RCT cross-over with 1 wk between sessions	Cycle ×3 min, 3 practice jumps (1) Con: rest ×10 min (2) Stretch: stretch 3 × 15 s, standing quad, standing calf, seated hams
Laur et al[18]	16 M, 16 F, 18–35 yo, healthy	RCT, cross-over with 5–7 days between sessions	On day 1, 1 RM tested, then 10 min rest, then protocol. Protocol: 5 min cycle warm-up, then: (1) Con: rest ×3 min (2) Stretch: supine assisted hams stretch, 20 s, repeat ×3 with 10 s rest between
Evetovich et al[19]	10 M, 8 F, college age, recreational athletes (9 including weight training but not competitive)	RCT cross-over with 48 hours between sessions	(1) Control: no activity (2) Stretch: static stretches 30-s hold, repeat ×4, 15 s rest between Muscles: standing biceps stretch, standing pectoralis major stretch, assisted abduction stretch
McNeal and Sands[10,11]	14 F, 7–9 y, competitive gymnasts	RCT, cross-over with 24 hours in between sessions	(1) Static stretch 30 s (2) Control: routine warm-up without stretching Muscles: triceps surae, assisted supine hams stretch, sit-and-reach stretch
Young and Elliott[20]	14 M college-age jump sport athletes (football, field hockey, track and field)	RCT cross-over with 24 hours between sessions	All warmed-up. Then rest ×4 min. Then: (1) Static stretch: 3 × 15 s, 20 s rest (2) PNF contract-relax: total 20 s (3) MVC: 5 s, 30 s rest, repeat ×3 (4) Control (tested after 4 min rest) Stretches included triceps surae, gluteal muscles, quads. Done to the onset of pain

TABLE 2. *(continued)* Detailed Summary of Clinical Studies Examining Whether Stretching Immediately Before Exercise Improves Performance

<table>
<tr><th>Outcome</th><th>Results</th><th>Comments</th></tr>
<tr><td>1 RM* for knee flexion and knee extension after intervention (i.e. not change pre-post)
Standardized protocol used to increase weights for 1 RM; subjects blinded to weights</td><td>Nine percent increase in sit and reach test
Knee flexion: stretch trial had 1 RM 7.5% less than nonstretch trial
Knee extension: stretch trial had 1 RM 5.6% less than nonstretch trial</td><td>All students believed stretching improved strength prior to study
Used graded protocol for 1 RM. Therefore, it is theoretically possible that the outcome was fatigue rather than absolute force. However, the authors did use an accepted protocol for 1 RM measure</td></tr>
<tr><td>1 RM for knee flexion and knee extension after intervention (i.e. not change pre-post)
Standardized protocol used to increase weights for 1 RM; subjects blinded to weights</td><td>Increase in ROM, 16%
Decrease in flexion 1 RM, 7.3% and decrease in extension 1 RM, 8.1%</td><td>Used graded protocol for 1 RM. Therefore, it is theoretically possible that the outcome was fatigue rather than absolute force. However, the authors did use an accepted protocol for 1 RM measure</td></tr>
<tr><td>Static jump height and peak power from semisquat position with hands on hips
CM jump + height and peak power with hands on hips
Not clear if used mean or peak for jump heights</td><td>Static jump decreased by 4.4 ± 1.3% (1.0 ± 0.3 cm) and CM jump by 4.3 ± 1.3% (1.2 ± 0.4 cm)
Peak power decreased by 3.2 ± 0.9% (111.7 ± 31.8 W) in static jump and by 2.2 ± 0.9% (86.7 ± 35.7 W) in CM jump</td><td>ROM not measured
Three jumps were performed, but unclear if mean or best was used in analysis.
Both height and peak power were calculated from vertical velocity at take-off from force-time data
Because jump kinematics standardized, cannot assess if stretching altered kinematics. This could either increase or decrease jumping performance</td></tr>
<tr><td>Mean of 3 trials CM jump velocity with hands on hips
Mean of 3 trials jump kinematics with hands on hips</td><td>Stretch group decreased peak velocity by 3% ($P = 0.13$). 55% decreased velocity (−7.5%), 35% increased velocity (+2.4%), and 10% no change
No change in kinematics</td><td>ROM not measured
The lack of change in kinematics suggests that the results in Cornwell et al[16] were not due to the standardized jumping technique</td></tr>
<tr><td># of repetitions at 60% 1 RM prone hams curl at 3s/rep.
RPE during repetitions</td><td><table><tr><th></th><th>Day 1</th><th>Day2</th></tr><tr><td>Males</td><td></td><td></td></tr><tr><td>Stretch day 1</td><td>14.5 ± 3.0</td><td>17.3 ± 3.0</td></tr><tr><td>Stretch day 2</td><td>15.9 ± 3.1</td><td>17.4 ± 2.9</td></tr><tr><td>Females</td><td></td><td></td></tr><tr><td>Stretch day 1</td><td>15.4 ± 1.8</td><td>16.9 ± 2.7</td></tr><tr><td>Stretch day 2</td><td>14.1 ± 1.9</td><td>15.8 ± 4.3</td></tr></table>RPE not different</td><td>Change in ROM not recorded
1 RM established at first testing session, then 10-min break, but subject may have been affected
Both groups increased the number of repetitions for second session.
Both groups had similar reps for the first session. The results only say that there was a greater increase in the nonstretching group</td></tr>
<tr><td>Forearm flexion isokinetic torque at 30°/s and 270°/s with 2 min rest between. Best of 3 trials analyzed
EMG-surface
MMG‡</td><td>Torque (Nm) slightly decreased with stretching at 30°/s (49.5 ± 4.1 vs. 50.4 ± 4.1) and at 270°/s (20.9 ± 2.5 vs. 23.4 ± 2.5). The changes were significant when the 2 isokinetic velocities were combined
No change in EMG
MMG increased with stretch (decreased stiffness) at 30°/s (93.5 ± 14.4 mV vs. 63.1 ± 10.6 mV) and 270°/s (207.6 ± 35.6 mV vs. 136.4 ± 31.7 mV)</td><td>ROM not measured</td></tr>
<tr><td>Drop jump height§
Ground contact time
Air time
Tested after warm-up</td><td>Jump height decreased by 8.2% (from 0.268 m to 0.246 m)
Air time decreased with stretching 0.44 vs. 0.47 (estimated from figure)
No change ground contact time</td><td>ROM not reported
Not clear if static stretch group also did routine warm-up
Two studies that appeared to use the same subjects (1 less[11] with some overlap in outcomes (ground contact time)</td></tr>
<tr><td>Squat jump
(1) Height
(2) Force
(3) Rate of force
Drop jump height (hands on hips):
subjects told to minimize ground contact time</td><td>MVC intervention group results not reported here as not pertinent to question
Jump height = 36.6 ± 3.4 control; 35.0 ± 4.0 PNF, 35.9 ± 3.7 static
Force = 1.69 ± 0.14 control; 1.64 ± 0.18 PNF; 1.63 ± 0.14 static
Rate of force = 13.6 ± 3.6 control; 13.1 ± 3.6 PNF; 12.8 ± 3.3 static
Drop jump = 188 ± 25 control; 182 ± 22 PNF; 175 ± 20 static</td><td>ROM not measured
Although only the drop jump changes were significant, the stretching group did worse than the control group in all measures</td></tr>
</table>

TABLE 2. *(continued)* Detailed Summary of Clinical Studies Examining Whether Stretching Immediately Before Exercise Improves Performance

Study Acute	Population	Design	Intervention
Stretching detrimental			
RCT cross-over design			
Young and Behm[21]	13 M and 4 F, age 26 ± 8.5 y with weight-training or power sport experience	RCT cross-over with 6–72 h between sessions	All warmed-up. Then rest ×4 min. Then: (1) Control walk ×3 min, 5 squats, 5 heels raises (2) Jog ×4 min (3) Stretch: 30 s per stretch ×2 (4) Run and stretch: jog and then stretch using parameters of groups 2 and 3 (5) Run and stretch and jump: jog and stretch as in group 4, then 3 jumps 80% maximum effort, then 4 jumps 100% maximum effort Stretches included gastrocnemius and soleus wall stretches, assisted prone quads stretch, assisted prone hip extension stretch. Done to the onset of pain
Pre-post design			
Behm et al[22]	12 M, university students, excluded individuals who could not recruit >80% of quads (based on ITT[‖])	Pre-post testing for all 12 subjects Nonrandomized cross-over trial for 6 subjects, with 1 wk between sessions	Five-min cycle warm-up (1) Con: rest ×3 min (for cross-over) (2) Stretch all groups: 45 s, rest 15 s, repeat ×5 Muscle groups: standing quads, hurdler quads, kneeling hip extension, assisted prone quads
Nelson et al[23]	25 M, 30 F, college physical education students	Pre-post	Unassisted standing heel-buttock quad warm-up stretch, followed by assisted (1) standing heel-buttock quad stretch and (2) prone heel-buttock quad stretch. Each stretch static, held 30 s, rest ×20 s, repeat stretch
Nelson et al[24]	10 M, 5 W, college physical education students	Pre-post	Unassisted standing heel-buttock quad warm-up stretch, followed by assisted (1) standing heel-buttock quad stretch and (2) prone heel-buttock quad stretch. Each stretch static, held 30 s, rest ×20 s, repeat stretch
Cornwell et al[25]	10 M, age 22.5 ± 1.8 (SD) y	Pre-post	Two days for subjects to familiarize with testing procedures Static stretches of gastroc and soleus. 30 s hold, repeat ×3
Avela et al[26]	20 M, 21–44 y	Quasi cross-over: pre-post with opposite leg as control	Stretched leg: dynamic stretch of triceps surae, knee 120°, ankle 90°, warmed with heat lamp. Stretch by 10°, hold 0.2 s, repeated ×60 min Control: no stretch

TABLE 2. *(continued)* Detailed Summary of Clinical Studies Examining Whether Stretching Immediately Before Exercise Improves Performance

Outcome	Results	Comments
Concentric jump (1) Height (2) Peak force (3) Rate of force Drop jump (0.3 m) height (hands on hips): subjects told to minimize ground contact time EMG-surface	Jump height (cm) = 29.3 ± 3.7 control; 28.3 ± 3.5 stretch; 30.2 ± 3.7 run; 29.2 ± 3.2 run/stretch Peak Force (bw) = 1.80 ± 0.29 control; 1.88 ± 0.28 stretch; 1.73 ± 0.25 run; 1.83 ± 0.26 run/stretch Rate of force (kN/s) = 15.0 ± 4.3 control; 17.8 ± 7.1 stretch; 14.6 ± 5.3 run; 15.4 ± 4.1 run/stretch Drop jump (cm) = 26.5 ± 5.5 control; 27.7 ± 6.4 stretch; 25.7 ± 5.9 run; 26.5 ± 5.6 run/stretch There was no difference in contact time for drop jump EMG analysis suggests decreased activation with stretch/run compared to run alone for all tests	ROM not measured Run/stretch/jump group not reported in this review because not pertinent to this question. To test whether the effects of stretching are important even if you practice jumps after, the comparison has to be practice jumps versus stretching and practice jumps
MVC knee extension (6–10 min after, sitting position). Knee at 90° flexion ITT EMG-surface	There were no changes in any variable pre-post control Pre-post stretching: MVC decreased by 12.2% with stretching ITT inceased by 2.8% (5.7 ± 2.2 vs. 8.5 ± 6.0) EMG decreased by 20.2% for quads and 16.8% for hams Time to peak twitch decreased by 11.7% (146.0 ± 16.5 vs. 144.3 ± 16.4) Tetanic evoked force was similar	ROM not measured Not clear how the 6/12 subjects were chosen for cross-over testing Tested 5–10 min after the stretch Tested in position of hip and knee at 90°, suggesting the muscle was stretched when generating force Decreased force may be neurally caused because of decrease in EMG, and increase in ITT
Isometric MVC knee extension at 90°, 108°, 126°, 144°, and 162° knee angle (180° = full extension). There was 2 min between tests at different angles Subjects made 4 maximal efforts at each angle, but not clear if mean or maximum was used	There was a 7% decrease in force at the knee angle = 162° only. Other knee angles had no decrease in force	ROM not reported. If the stretching program was not effective (unlikely), it is possible a more effective program would have decreased strength at other angles A decrease in force only at end ROM is consistent with studies showing a decrease in 1 RM, because completion of a 1 RM task requires force throughout. For example, all participants[15] were able to initiate action but not complete it (i.e. weakness noted near extension) Statistical significance was $P < 0.01$, but figure shows virtually identical results for pre-post stetching except at 162° flexion
Isokinetic MVC at 1.05 rad-s^{-1}, 1.57 rad-s^{-1}, 2.62 rad-s^{-1}, 3.67 rad-s^{-1}, and 4.71 rad-s^{-1} Test occurred within ROM from 110° to 0° (0° = full extension) Subjects made 4 maximal efforts at each angular velocity, but not clear if mean or maximum was used	Decrease 7.2%, in isokinetic MVC at 1.05 rad-s^{-1}, and 4.5% decrease in isokinetic MVC at 1.57 rad-s^{-1}. No change at other speeds Nonsignificant change in the knee angle at which peak torque occurred at low speeds (i.e. peak torque after intervention occurred when quad more stretched)	ROM not reported, so we are not sure how effective the stretch protocol was. If it was not effective (unlikely), it is possible a more effective program would have decreased strength at other angular velocities
Changes in: (1) Active stiffness (2) ROM (3) Vertical velocity (calculated using ground reaction forces) during static and CM jumps (4) Pure Achilles jump height (5) EMG during jumps	Active stiffness decreased from 30.5 ± 1.4 to 29.7 ± 1.5 kN/m ROM increased by approximately 2.2° Vertical velocity: CM jump velocity decreased, but static jump height velocity did not change Pure Achilles jump height: CM jump height decreased by 7.9 ± 1.9%. Static jump height was identical pre-post EMG: CM jump EMG remained unchanged. Static jump EMG decreased by 9.1 ± 2.1%	IEMG decreased by 9.1% for static jump and was equal for CM jump even though effect on jump height was not present for static jump but was present for CM jump Stiffness measures and jump velocities were measured on separate days
Change in MVC EMG-fine wire H-reflex, M-wave	MVC decreased by 23.2 ± 19.7% EMG decreased by 19.9 ± 29.4% in gastroc and 16.5 ± 24.4% soleus Decreased H/M-reflex ratio by 43.8 ± 41.4 Total recovery by 15 min	ROM not measured Poststretch MVC measured under ischemia. However, this was the same for both stretched and nonstretched leg Decreased force not due to neuromuscular junction problem but could be due to excitation-contraction coupling Because there was no change in EMG of control leg, the inhibition of force must originate as a peripheral mechanism

TABLE 2. *(continued)* Detailed Summary of Clinical Studies Examining Whether Stretching Immediately Before Exercise Improves Performance

Study Acute	Population	Design	Intervention
Cramer et al[27]	14 F, college age, active but not competitors	Quasi, cross-over: pre-post with opposite leg as control	Static stretch of dominant limb only to mild discomfort. 4 reps ×3 s/rep with 20 s rest between. 4 min rest between stretch and testing Standing quad stretch, assisted prone quad stretch, assisted standing hip flexor/quad stretch, assisted supine hip flexor/quad stretch

TABLE 2. *(continued)* Detailed Summary of Clinical Studies Examining Whether Stretching Immediately Before Exercise Improves Performance

Outcome	Results			Comments
Five min warm-up prior to testing Concentric isokinetic peak torque at 60 and 240°/s of stretched vs. unstretched limb Best of 3 trials used. 2 min rest between velocities		Pre	Post	ROM not measured Five-min warm-up prior to testing Stretched limb tested 4 min after stretching, and nonstretched limb tested 16 min after stretching. Decrease in unstretched limb suggests that the effects of stretching on performance are partly due to spinal or cerebral effects, and that they last at least 16 min
	60°/s			
	Stretch	174.7 ± 7.7	170.7 ± 8.2	
	No stretch	182.4 ± 7.9	174.1 ± 7.1	
	240°/s			
	Stretch	112.4 ± 5.1	109.3 ± 4.7	
	No stretch	109.6 ± 5.0	106.9 ± 4.5	
	Peak torque decreased with stretching in both the stretched (174.1 ± 7.7 vs. Nm) and unstretched limb, with effects greater at 60°/s compared to 120°/s Joint angle at peak torque was greater for stretched limb at 60°/s but not at 240°/s, and joint angle at peak torque was greater at 60°/s compared to 240°/s for both limbs			

*1RM indicates 1 repetition maximum, or the maximum weight a subject can lift once. There are standard protocols used to determine the 1RM.

†CM jump: a counter-movement jump is when a subject begins from a standing position, lowers the body by flexing the knees and hips, and then immediately propels the body upward. In general, CM jumps are greater than static jumps.

‡MMG indicates mechanomyography. This records muscle vibrations during activity, and a lower value may suggest increased stiffness during contraction.

§Drop jump: the subject jumps down from a small height and immediately on landing goes into a crouch and jumps up. This is similar to the CM jump except one starts from jumping down instead of standing still.

||ITT indicates interpolated twitch technique. In this technique, the muscle is electrically stimulated while a MVC is performed. If the muscle is not fully recruited by the individual, the electrical stimulation increases the force generated. Calculations are made to determine the percent of activation of muscle fibers.

F indicates females; M, males.