

No effect of muscle stretching within a full, dynamic warm-up on athletic performance

Short title: Stretching during sports warm-up

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ABSTRACT

Purpose: To examine the effects of static and dynamic stretching routines performed as part of a comprehensive warm-up on flexibility and sprint running, jumping and change of direction tests in team sport athletes.

Methods: A randomized, controlled, cross-over study design with experimenter blinding was conducted. On separate days, 20 male team sport athletes completed a comprehensive warm-up routine. After a low-intensity warm-up a 5-s static stretch (5S), 30-s static stretch (30S; 3×10-s stretches), 5-repetition (per muscle group) dynamic stretch (DYN) or no stretch (NS) protocol was completed; stretches were done on 7 lower body and 2 upper body regions. This was followed by test-specific practice progressing to maximum intensity. A comprehensive test battery assessing intervention effect expectations as well as flexibility, vertical jump, sprint running and change of direction outcomes was then completed in a random order.

RESULTS: There were no effects of stretch condition on test performances. Before the study, 18/20 participants nominated DYN as the most likely to improve performance and 15/20 nominated NS as least likely. Immediately before testing, NS was rated less ‘effective’ (4.0 ± 2.2 on 10-point scale) than 5S, 30S and DYN (5.3-6.4). Nonetheless, these ratings were not related to test performances.

CONCLUSION: Participants felt they were more likely to perform well when stretching was performed as part of the warm-up, irrespective of stretch type. However, no effect of muscle stretching was observed on flexibility and physical function compared to no stretching. Based on the current evidence, the inclusion of short durations of either static or dynamic stretching is unlikely to affect sprint running, jumping or change of direction performance when performed as part of a comprehensive physical preparation routine.

Key words: athletic preparation, sprint performance, vertical jump, change of direction, muscle power, stretch-induced force loss.

1 INTRODUCTION

2 It is believed that the completion of a pre-exercise (or pre-sport) physical preparation
3 routine is required to augment performance and reduce injury risk (1-3). One component of
4 this routine that has received much scrutiny is the inclusion of static (particularly passive)
5 muscle stretching (3-8). From an injury minimization perspective, studies have typically not
6 confirmed a clear effect of pre-exercise static stretching on all-cause injury risk in sports (9,
7 10), which has resulted in some researchers suggesting a limited role for the practice (6, 7,
8 10) or for the inclusion of dynamic forms of stretching (2). However, other authors conclude
9 that static stretching might specifically provide a small-to-moderate protective effect for
10 muscle-tendon injury risk, especially in running-based sports (e.g. the various football codes
11 and court sports) (3, 4, 8, 9), which attract by far the highest participation (11) and injury (12)
12 rates. By contrast, no detailed studies have examined the effects of dynamic stretching on
13 injury risk. Therefore, current scientific evidence favors static over dynamic stretching from
14 an injury prevention perspective, even though the overall benefit may be small-to-moderate
15 and limited to a subset of sports.

16 Nonetheless, several recent reviews have also concluded that static stretching can
17 significantly and negatively impact high-intensity physical performance (4, 5, 13). Several
18 researchers and advocacy groups, including the European College of Sports Sciences (14)
19 and American College of Sports Medicine (15), do not recommend the inclusion of static
20 stretching in pre-exercise routines, or call for its replacement by dynamic forms of muscle
21 stretching (2). Indeed, in some cases the continued use of static stretching by sports
22 participants has been explicitly admonished (16). Nonetheless, the majority of studies
23 examining the effects of pre-exercise muscle stretching have not been designed to assess its
24 effects on sports performance (e.g. see Supplement G in ref. 4). Common threats to external
25 validity in previous studies include (a) total stretching durations being longer than those

26 typically performed by athletes (17, 18), (b) the stretching rarely being followed by other
27 important components of a sport-specific warm-up, including high-intensity and movement
28 pattern-specific exercises (1, 19), even though it may mitigate the negative effects of
29 stretching (20), (c) participants being only minimally familiarized with the tests (athletes, on
30 the other hand, are familiar with their sporting skills), (d) differences existing in the execution
31 (movement pattern) of static versus dynamic stretches, and (e) the imposition of non-
32 stretching rest periods in control conditions/groups, which would not be performed in sports
33 (4). Also, studies have been susceptible to serious threats to internal validity, such as the
34 expectancy effects of knowledgeable participants (21) and lack of experimenter blinding (22).
35 Notwithstanding these threats to validity, the effects of static stretching on dynamic
36 movement performance (e.g. jumping, running, sprint cycling) have been found to be small
37 on average when stretches are performed for <60 s per muscle (weighted average = -1.1%),
38 and the performance benefits of dynamic stretching performance is also surprisingly small
39 (+1.3%)(4). The call for the removal of static stretching and possible replacement with
40 dynamic stretching (16), despite the limited evidence of impact on sports performance,
41 creates a dilemma for medical practitioners, physiotherapists and physical trainers who may
42 be asked to provide their opinions on proper sports participation practices.

43 Given the above, the decision to advocate against the static stretching, particularly on
44 the grounds that it might reduce exercise performance, is questionable, especially given that
45 sports participants show a preference to stretch their muscles despite this advocacy (23) and
46 there being a potential small-to-moderate musculotendinous injury risk minimization benefit.
47 In the present study, we have attempted to overcome some of the limitations of previous
48 studies to specifically answer the question of whether the inclusion of short- or moderate-
49 duration static or dynamic muscle stretching completed as part of a comprehensive pre-
50 exercise routine (i.e. warm-up) influences performances in common, high-intensity sporting

51 tasks. Based on the available evidence, we hypothesized that the imposition of short or
52 moderate durations of static or dynamic stretching would not meaningfully impact high-
53 intensity physical performance when performed as part of a comprehensive pre-exercise
54 routine.

55 **METHODS**

56 Twenty healthy males (age = 21.1 ± 3.1 years; body mass = 73.4 ± 6.8 kg; height = $1.79 \pm$
57 0.70 m) volunteered for the study. Participants were recruited if they were: 18 - 25 years of
58 age; without recent injury or illness that would preclude exercise performance; and
59 competing in running-based sports or performing at least three running-based exercise
60 sessions per week. The study was approved by the Human Research Ethics Committee of
61 Edith Cowan University (STREAM11450/11541) and conducted in accordance with the
62 Declaration of Helsinki. All participants read and signed an informed consent document.

63 **Study design**

64 This study used a randomized, cross-over (repeated measures) design with control condition,
65 and was designed to assess the effect of dynamic vs. both shorter- (5 s) and longer- (30 s)
66 duration static muscle stretching interventions on performances in tests that mimic common
67 sporting tasks. There were three experimental (stretching) conditions and a non-stretching
68 control condition (hereafter referred to as 'pre-testing routines') performed at the same time
69 of day over four testing sessions separated by a minimum of 72 h and each followed by a
70 comprehensive test battery (see Figure 1). The order of conditions and order of tests within
71 each condition were randomized between the participants without replication by the
72 participants choosing a numbered card randomly from a pack that related to a test and stretch
73 condition order. The card was not replaced in order to ensure that some test and stretch
74 condition orders could not be allocated more often than others.

75 A pre-testing routine was completed before the test battery was administered. The
76 pre-testing routine, including any muscle stretching, was monitored by a research coordinator
77 who ensured that procedures (described below) were followed correctly but who could not
78 communicate with researchers overseeing the test battery (hereafter referred to as ‘testers’).
79 After completion of the pre-testing routine, the coordinators relinquished participant
80 responsibility to the testers, who were given no information as to the pre-testing stretch
81 condition administered and were naïve to the time required to complete the pre-testing
82 routine; this prevented the possibility of guessing the pre-testing routine type since each
83 required a different time to complete. Thus, the testers were blinded to the pre-testing routine
84 condition.

85 **Familiarization of muscle stretching and performance tests**

86 At least one familiarization session was completed by each participant prior to data
87 collection to become accustomed with the stretching protocols, learn the correct testing
88 procedures, and acquaint themselves with the equipment, laboratory facility and the verbal
89 instructions issued by the coordinators and testers for the stretching exercises and tests. A
90 video demonstration of each stretch was provided to the participants in order to ensure
91 similarity in instruction of the stretches, then each participant received individual feedback to
92 correct errors. The participants were then shown how to complete each test and given
93 multiple untimed trials to become familiar. The movement patterns of the tests (described
94 below) were similar to the movement patterns used by the participants in their sports. An
95 additional familiarization session was provided to four participants who declared a lack of
96 confidence in the performance of one or more testing protocols.

97 **Pre-study Participant Outcome Expectations**

98 At the end of the familiarization session, each participant completed an outcome
99 expectation survey to determine which pre-exercise routine they believed would prove most
100 beneficial to performance. The participants were asked to “List in descending order the
101 stretch condition you believe will stimulate the best improvement in your performance
102 (dynamic, 5 s static, 30 s static and no stretch)” when compared to the other conditions. They
103 therefore nominated in order from 1 to 4 (best to worst) which routine they believed would
104 improve (or reduce) performance the most. Post hoc, these expectations were compared to the
105 outcomes of the testing to determine whether expectation was aligned with outcome.

106 **Testing Session Design**

107 Participants were required to wear the same sports shoes and athletic clothing at each
108 session, refrain from intensive exercise in the 24-h period before testing, and abstain from
109 caffeine or any form of stimulant/depressant 24 h prior to testing. As the participants were
110 team sport athletes, other physical training completed by the participants outside of the study
111 was monitored (for type, volume and intensity) by the participants providing a log book
112 record of their activities in the 48 h prior to testing as well as a rating of their muscle soreness
113 from 1 to 10 to ensure that significant (>2 units) changes in their performance of, or recovery
114 from, their programs did not occur. If the standard training programs of the participants were
115 not adhered to, the testing session was to be cancelled and completed at least 72 h later,
116 however no instances of this occurred.

117 Each session commenced with a short pre-stretching warm-up consisting of a 3-min
118 jog at 50% of perceived maximum exertion, then 5-s high knees (to ~90° hip angle) and 5-s
119 heel-to-butt (i.e. knee flexion) drills at 50% of maximum perceived exertion. Heart rate was
120 obtained immediately after the warm-up phase by manual palpation of the carotid artery for
121 post-hoc examination of the repeatability of efforts, i.e. repeatability of the physical

122 intensities used (heart rate itself could not be used as a target for intensity because of its slow
123 temporal response after exercise commencement).

124 Participants then completed one of three experimental (stretching) conditions or
125 progressed immediately to the test-specific (i.e. 'sport-specific') warm-up (described below);
126 note that a rest condition of equal duration to the experimental conditions was not included in
127 the no-stretch (control) session as this is not typical sports practice. The four conditions were
128 a 5-s of static stretching (5S), 30 s of static stretching (30S; 3 × 10-s stretches), a 5-repetition
129 (per muscle group) dynamic stretch (DYN), and a no-stretch condition (NS) (see Text,
130 Supplemental Digital Content 1, detailing the instructions [with photo] for each stretch). The
131 5S, 30S and DYN stretching protocols each consisted of nine stretches that were close
132 replicates (in body position) of each other in order to minimize the effect of stretching
133 movement pattern on test outcomes. The static stretches were held at the point of
134 'discomfort', and maximal ROM was achieved in the dynamic stretches by ensuring a
135 secondary pulling-motion with each repetition. The order of pre-exercise routines was
136 randomized without replication between participants to minimize order effects.

137 Following the stretches (or after progressing immediately from the low-intensity
138 warm-up in NS) a test-specific (i.e. 'sport-specific'), higher intensity warm-up was
139 completed. This started with a 2-min moderate-intensity jog at 60% of perceived effort, and
140 5-s high knees and 5-s heel-to-butt kick drills at 60% of perceived maximum effort. The
141 participants then performed three circuits of the six performance tests, which were organized
142 into three activity groups: 1) running vertical jump, 2) squat jump, countermovement jump
143 and drop jump, 3) T agility test, and 4) 20-m sprint run, and the participants completed them
144 in an order identical to that of the following testing session (see below). The intensity of each
145 circuit increased from 60% to 80% and then 100% of perceived maximal exertion with a 30-s

146 walk recovery between each activity set. This second part of the pre-testing routine took
147 approximately 15 min to complete.

148 In order to address the study design limitation relating to the time between completion
149 of the final stretch and the commencement of testing (4), a 7-min passive rest period was
150 imposed between the completion of the pre-testing routine and the start of testing. This was
151 done to more closely simulate game- or match-day situations where a short pre-competition
152 briefing or an individual-specific sport preparation period is completed before match or
153 competition commencement and allowed a better determination of the likely effect of the
154 different pre-exercise routines on game- or match-day performance.

155 Participants were permitted to consume plain water ad libitum throughout the testing
156 sessions, and all sessions were conducted in the biomechanics laboratory at Edith Cowan
157 University under similar environmental conditions. The test battery was completed in a
158 circuit at specified testing stations: 1) sit-and-reach flexibility test, 2) running vertical jump
159 test, 3) squat (SJ), countermovement (CMJ) and drop jump (DJ; from 40-cm height) tests, 4)
160 T agility test, 5) 20-m sprint running test. The order of tests was randomized between
161 participants without replication and then repeated at each session; however, the sit-and-reach
162 test was always completed first in order to determine the effect of the pre-testing routine on
163 flexibility (maximum range of motion) without the potential influence of other tests. The
164 performance of the sit-and-reach test was not expected to influence performances in
165 subsequent tests because of the short-duration of the stretch procedure. For the testing, 4 min
166 was allocated to each test station so that constant test timing was achieved regardless of the
167 order of tests. An audio signal prompted the commencement of each test.

168 **Post-warm-up Participant Outcome Expectations**

169 To address issues around expectancy bias (21), during the 7-min rest period prior to
170 testing in each session the participants also provided a rating score ranging from 1 to 10 for
171 “how effective you believe the warm-up will be on your performance”, where 1 = no effect/
172 possibly harmful to performance, 2 = very small improvement to performance, 5 = noticeable
173 improvement in performance, and 10 = performance will improve dramatically. Obtaining
174 this information immediately after completion of each pre-testing routine was expected to
175 yield different results to the outcome expectation survey completed in the study
176 familiarization session, and thus to allow a better analysis of whether participant expectancy
177 might influence study results. Equal ratings between conditions were allowed.

178

179 **Testing Procedures**

180 *Sit-and-reach flexibility*

181 The sit-and-reach test was conducted using the Flex-Tester apparatus (Novel Products
182 Inc., USA). A double-leg protocol was used as prescribed by the Canadian Society for
183 Exercise Physiology (24). Each participant was instructed to sit bare-footed with knees in
184 maximal extension and with both feet together and flat against the device. The participant
185 then exhaled and stretched forward with palms overlapping and fingertips aligned, holding
186 the furthest end point for 2 s. The score was recorded to the nearest 0.1 cm and repeated after
187 a 30-s rest, with the greatest touch distance used for analysis.

188 *3-m running vertical jump*

189 A jump-and-reach system (Vertec, Swift Performance Equipment, Australia) was
190 used for the running vertical jump to directly measure jump height based on the difference
191 between reach height and the jump height obtained. Reach height was obtained before each
192 test with the participant standing in a static position underneath the Vertec device and

193 reaching as high as possible with the arm touching their ear but with shoulders remaining
194 parallel to the floor. The fingers displaced vanes (each 1 cm apart) within touching distance,
195 and the maximum reach height was obtained. For jump testing, each participant's take-off
196 foot was pre-determined during the familiarization session, and a self-selected starting
197 position was assumed 3 m from the device, which was kept consistent across all testing
198 sessions. At their own volition, the participant executed a running, single-leg jump to displace
199 the vanes with the opposite hand. The maximum jump-and-reach height was recorded as the
200 number below the score reflected on the Vertec device, and the true jump height was then
201 calculated as the difference between the maximum jump-and-reach height and the standing
202 reach height. Each participant was given a maximum of five attempts; however the test was
203 stopped when the participant failed to further improve jump scores on two successive
204 attempts. A 30-s passive rest was imposed between each jump, and the best (i.e. final) true
205 jump height score was used for analysis.

206 ***Squat (SJ), countermovement (CMJ) and drop (DJ) jump***

207 A piezoelectric force platform (987B, Kistler Instrumente, Switzerland) was used to
208 measure vertical jump height using the flight time method ($\text{height} = \frac{1}{2} g (t/2)^2$, where $g =$
209 $9.81 \text{ m}\cdot\text{s}^{-2}$ and $t =$ time in air). The analog signal from the force platform was converted to a
210 digital signal using Bioware software (Kistler Instrumente, Switzerland) sampling at 1000
211 Hz. Flight time was identified as the period between take-off and contact after flight and this
212 was obtained in each jump via analysis of the force-time curve. A 15-s passive recovery was
213 imposed between each jump, which allowed the tester to record vertical jump height and to
214 reset the systems for recording of the next trial. Two attempts were allowed for each jump
215 type, however a third trial was completed if jump heights varied $>5\%$. The best score was
216 used for analysis.

217 SJ trials were performed from a squatted position with heels in contact with the
218 platform and with a self-selected knee angle ($\sim 75^\circ$). Each participant's hands were kept on
219 their hips throughout the jump and a countermovement was not allowed. The participant was
220 instructed to hold the squat position for at least 2 s before jumping. Visual observation of
221 both jumping technique and the force-time trace was made to ensure that there was no
222 countermovement in the jump. Trials were repeated if a countermovement could be visually
223 observed by the tester. CMJ trials were performed from a vertical standing position with
224 hands on hips and knees about shoulder-width apart. The participants then executed a two-
225 footed vertical jump immediately following an eccentric countermovement to a self-selected
226 depth (although the thighs could not be lower than parallel to the floor (19)). In the DJ, the
227 participant stepped horizontally off a 40-cm box onto the force platform and then
228 immediately jumped vertically. The instruction was given to "jump with minimal ground
229 contact time upon landing" and then to jump as high as possible. The starting position on the
230 top of the box was identical to the CMJ start position.

231 *T agility test*

232 For the T agility (change of direction) test, participants started at their own volition
233 from a standing start 0.4 m behind a start line, sprinted forwards to touch the base of a cone
234 located 10 m in front of them, shuffled 5 m to the left to touch a cone, shuffled 10 m to the
235 right to touch a cone, shuffled 5 m left to touch the center cone once again, and then ran
236 backwards past the start line. A dual-beam photocell timing gate (Swift Performance,
237 Australia) positioned at the start line was triggered when the participant broke the light beam
238 after the start and was stopped when the participant completed the course. Each athlete faced
239 forwards at all times and could not cross their feet while shuffling. The participants were
240 instructed to use a standing sprint start and were not allowed to build momentum by rocking

241 back and forth at the start line. They performed the test twice with a 30-s passive rest between
242 and the fastest time was used for analysis.

243 *20-m sprint run*

244 The 20-m sprint test was performed on an indoor synthetic 60-m sprint track. The
245 participants used the same starting position as for the T agility test, and ran with maximum
246 speed to a cone placed 1.5 m past a 20-m mark. This cone was included to prevent the
247 participants from decelerating before crossing the 20-m mark. The tester counted down and
248 then instructed the participants to sprint at their own volition, and timing gates placed at 0
249 and 20 m measured running time. Two attempts were given with a 30-s walk-back recovery
250 between attempts, and the fastest time was used for analysis.

251 **Statistical Analysis**

252 Using IBM SPSS statistical software (version 22; IBM, New York), repeated
253 measures multivariate analyses of variance (MANOVAs) were performed to compare test
254 performances between conditions (5S, 30S, DYN, and NS), whilst a repeated measures
255 ANOVA was used to compare the performances between conditions specifically for sit-and-
256 reach scores. The alpha level was set at 0.05, and significant main or interaction effects were
257 examined in further detail using ANOVA and univariate tests, as appropriate. Additionally,
258 magnitude-based inference tests were performed and the precision of estimation was
259 calculated. Qualitative descriptors of standardized effects used the criteria: trivial < 0.2, small
260 0.2-0.6, moderate 0.6-1.2, large >1.2. Effects where the 95% confidence limits substantially
261 overlapped the thresholds for small positive and negative effects (i.e. exceeding 0.2 of the SD
262 on both sides of zero) were defined as unclear. Clear small or larger effect sizes (i.e., those
263 with > 75% likelihood of being > 0.20), as calculated using the spread sheet developed by
264 Hopkins (25), were defined as definitive. Precision of estimates was indicated with 95%

265 confidence limits, which defined the range representing the uncertainty in the true value of
266 the (unknown) population mean (26). To better assess the similarity (or lack) of performances
267 between trials, both Pearson's (r) and intra-class (ICC) correlations were calculated; no
268 corrections were required for outliers or non-uniformity of scatter. ICC values less < 0.5, 0.5
269 - 0.75, 0.75 - 0.9, and > 0.90 were considered indicative of poor, moderate, good, and
270 excellent reliability, respectively. 90% confidence intervals were also computed for ICC
271 values, but this is not possible for r values calculated from multiple repeated measurements.
272 Finally, the Bland-Altman method for calculating correlation coefficients for repeated
273 measurements (within subjects) was used to determine if higher participant expectation
274 scores were correlated with better performances (27).

275 **RESULTS**

276 **Participant Bias**

277 When assessed during the familiarization session (i.e. before the commencement of
278 the data collection period), 18 of the 20 participants nominated DYN as the most likely
279 beneficial pre-testing routine (i.e. they ranked it 1st out of the four conditions) whilst two
280 participants nominated 30S as the most likely beneficial. Additionally, 15 of the 20
281 participants nominated NS to be least likely beneficial (i.e. ranked it 4th out of the four
282 conditions) whilst five participants nominated 30S. The commonest ranking order among the
283 participants was DYN > 5S > 30S > NS. Thus, there was a clear *a priori* bias within the
284 participant group.

285 When asked upon completion of each pre-testing routine to rate (on a scale of 1 – 10)
286 how effective they believed the routine would be for their performance, NS was rated
287 consistently worst (4.0 ± 2.2), and 5S (5.7 ± 1.9) and DYN (6.4 ± 1.6) were rated statistically
288 higher ($p < 0.05$) than NS; a tendency towards a greater rating for 30S (5.3 ± 2.3) did not reach

289 statistical significance. No statistical differences were observed between the three stretching
290 conditions and, using magnitude-based inference, it was found that all three stretch conditions
291 were rated definitively (>75%) higher by participants than the no-stretch condition, with
292 97%, 87% and 100% likelihoods of 5S, 30S and DYN, respectively, being perceived of
293 greater benefit than NS. Nonetheless, correlation coefficients computed for repeated
294 measurements (within subjects) were small, ranging -0.16 – 0.21 and with explained variance
295 (R^2) ranging 0.1 – 4.5%, indicating a lack of relationship between ratings of perceived benefit
296 and performance outcomes.

297 **Jumping, running, change of direction and flexibility**

298 No statistical differences were detected between conditions for the 3-m running
299 vertical jump, SJ, CMJ, or DJ tests ($p = 0.471$ for condition \times time interaction; see Figure 2),
300 indicating a lack of effect of pre-testing routine on performance, and no statistical difference
301 was detected between sessions 1 – 4, indicating a lack of order effect (i.e. effect of session
302 number irrespective of condition). All three stretch conditions were definitively (>75%
303 likelihood) found to elicit trivial effects on running vertical jump (95%, 92% and 86%
304 likelihood of trivial effect for 5S, 30S and DYN, respectively) and CMJ (97%, 89% and 95%
305 likelihood of trivial effect) performances when compared to NS. The effects on SJ (44%,
306 65% and 74% likelihood of trivial effect) and DJ scores (72%, 38% and 50% likelihood of
307 trivial effect) were less clear in SJ (56%, 32%, and 22% likelihood of higher jump in 5S, 30S
308 and DYN, respectively) and DJ (7%, 62% and 50% likelihood of lower jump).

309 No statistical differences were detected between conditions for the 20-m sprint run (p
310 = 0.354 for condition \times time interaction) or T agility test ($p = 0.996$; see Figure 3), indicating
311 a lack of effect of pre-testing routine on performances. Furthermore, no differences were
312 detected between sessions 1 – 4, indicating a lack of order effect. All three stretch conditions

313 were found to definitively (>75%) elicit trivial effects on 20-m sprint run time (88%, 86%
314 and 91% likelihoods of trivial effect for 5S, 30S and DYN, respectively) and T agility time
315 (84%, 93% and 75% likelihood of trivial effect) when compared to NS.

316 No statistical differences were detected for sit-and-reach scores ($p = 0.076$ for
317 condition \times time interaction) between 5S (27.1 ± 8.9 cm), 30S (27.8 ± 8.8 cm), DYN ($28.4 \pm$
318 8.36 cm) and NS (28.9 ± 9.2 cm). A definitively trivial effect of condition was observed for
319 DYN (98% likelihood of trivial effect) when compared to NS, but 45% and 31% likelihoods
320 of trivial effects for 5S and 30S, with 55% and 68% likelihoods of lower sit-and-reach scores,
321 were observed in these conditions when compared to NS.

322 **Reliability Analysis**

323 Both Pearson's (r) and intra-class (ICC [$\pm 90\%$ CI]) correlation analyses completed on
324 the test data revealed a high between-session repeatability of performances for SJ ($r = 0.87$;
325 $ICC = 0.84[0.73-0.92]$), CMJ ($r = 0.90$; $ICC = 0.92[0.83-0.95]$), DJ ($r = 0.88$; $ICC =$
326 $0.87[0.78-0.93]$), 3-step jump ($r = 0.92$; $ICC = 0.92[0.85-0.96]$) and 20-m sprint running ($r =$
327 0.93 ; $ICC = 0.92[0.87-0.96]$) tests despite the different stretching interventions being
328 imposed. Reliability estimates were slightly lower, but still moderate, for the T agility test (r
329 $= 0.70$; $ICC = 0.71[0.54-0.84]$).

330 **Pre-testing routine intensities**

331 Heart rates measured immediately upon completion of the low-intensity jogging bouts
332 during the pre-testing routine were not different between conditions. The heart rates after the
333 3-min jog at 50% of perceived maximum exertion (before the stretching) and after the 2-min
334 jog at 60% of perceived exertion (after the stretching) were 125 ± 4 bpm and 139 ± 19 bpm,
335 respectively.

336 **DISCUSSION**

337 The main finding of the present study was that the inclusion of a period of either static
338 (passive) or dynamic stretching within a comprehensive pre-exercise physical preparation
339 routine (i.e. a ‘warm-up’) did not detectibly influence flexibility or maximal vertical jump,
340 sprint running acceleration or change of direction (T agility) test performances compared to a
341 no-stretching control condition. In fact, inter-session test reliability coefficients were good to
342 excellent for 3-m running, squat, countermovement and drop jump (ICC = 0.87 – 0.92) and
343 20-m sprint running (ICC = 0.93) tests, and moderate (ICC = 0.71) for the T agility test,
344 despite the stretching component of the warm-up differing between sessions. Based on these
345 results, athletic individuals who are well familiarized with the physical performance tasks and
346 who complete a properly-structured warm-up period (e.g. ref. 1) may not experience
347 alterations in performance when short- or moderate-duration muscle stretching interventions
348 are included within the warm-up period. The participants showed a clear bias in their beliefs
349 with regard to the effects of stretching in the warm-up routine, with 90% (18/20) of
350 participants expecting performances to be better after inclusion of a dynamic stretching
351 period when asked to “list in descending order the stretch condition you believe will stimulate
352 the best improvement in your performance”. This might result from participants having
353 knowledge of sports science research, either as a university-level student or as an interested
354 reader. It may also have influenced perceptions of preparedness for high-intensity physical
355 activity after the warm-up period, with participants scoring 6.4 ± 1.6 on a 1 – 10 scale after a
356 warm-up incorporating dynamic stretching when asked to rate “how effective you believe the
357 warm-up will be on your performance” (1 = no effect/possibly harmful, 5 = noticeable
358 improvement in performance, 10 = performance will improve dramatically). Nonetheless, no
359 statistical difference was observed between ratings after any stretching condition, and warm-
360 up routines incorporating 5-s static, 30-s static or dynamic stretching were 97%, 87% and

361 100% were likely to be perceived of greater benefit than when no stretching was allowed.
362 Furthermore, correlation coefficients (computed for repeated measurements within subjects;
363 (27)) were small ($R^2 = 0.1 - 4.5\%$), indicating a lack of relationship. These data differ
364 slightly from those presented recently by Janes et al. (21), where improvements in knee
365 extensor, although not knee flexor, strength were observed after static stretching in
366 participants who were told that the stretching should improve performance (i.e. there was an
367 expectancy effect). We conclude that the participants felt as though the warm-up period
368 prepared them better for high-intensity exercise performance when stretching was performed,
369 irrespective of the type of stretching, than when no stretching was allowed. Whilst such
370 beliefs did not meaningfully influence test performances in the present study, participants
371 might theoretically perform better in a competitive sport environment when their perceptions
372 of preparedness are higher, and this might be examined in future studies.

373 The current results, that static (passive) muscle stretching did not compromise, and
374 dynamic stretching did not enhance, high-intensity exercise performance (Figures 2 and 3),
375 appear to contradict the consensus findings of previous research. However, several previous
376 studies have shown a lack of effect of muscle stretching on high-intensity exercise
377 performance when comprehensive warm-ups were performed. Taylor et al. (20) found no
378 differences in vertical jump and 20-m sprint performances after a progressive, skill-based
379 warm-up in high-level netball athletes despite performance decrements being observed
380 immediately after a preceding static stretch period (VJ = -4.2% and 20-m sprint = -1.4%). In
381 professional (English Premier League) soccer players, Little and Williams (28) observed no
382 differences in 20-m sprint time or CMJ height after static or dynamic stretching, although a
383 statistically faster zig-zag agility (change of direction) performance after dynamic stretching,
384 when the stretching was performed as part of a full warm-up session (notably, 20-m sprint
385 performance was improved in both static and dynamic stretch conditions). Also, Samson et

386 al. (19) found no differences in rapid kicking, CMJ or 20-m sprint test performances between
387 static and dynamic stretch conditions when performed alongside general and specific warm-
388 up activities in recreational and competitive athletes. Such outcomes are not always observed
389 when a warm-up opportunity is provided, however. Static stretching has resulted in
390 decrements in high-intensity exercise performances when the sport-specific warm-ups were
391 brief (e.g. 2 × 50-m sprints (29)) or of moderate duration and/or intensity (e.g. 10-m high
392 knees, side-stepping, carioca and skipping and 20-m zig-zag run; (30, 31)). When considered
393 together, the available evidence indicates that muscle stretching does not influence high-
394 intensity exercise test performances when they are followed by a warm-up period of
395 sufficient duration and incorporating exercises performed at high (or maximal) intensities.
396 Such warm-up periods have been endorsed for the improvement of sports performance and
397 reduction in musculoskeletal injury risk, even when static stretching is incorporated (3, 32).

398 It is of practical importance that static or dynamic stretching early in the warm-up did
399 not improve flexibility more than warm-up alone, as measured by a maximal sit-and-reach
400 test. Time constraints did not allow for the specific testing of ranges of motion at different
401 joints, however a single, multi-joint test was expected to reveal changes given that nine
402 different stretches were performed. The lack of change in sit-and-reach distance indicated
403 that any effect of a stretch condition within the warm-up on maximal range of motion was
404 negligible, which is in agreement with previous evidence (33). Thus, the dynamic warm-up
405 activities may have elicited improvements in maximal range of motion that were not
406 improved upon by the performance of further stretching, as has been observed previously (34,
407 35). Alternatively, changes may have occurred in muscles other than those in the lower back
408 and hamstrings and did not meaningfully impact sit-and-reach performance. While it cannot
409 be excluded that the addition of muscle stretching to a warm-up routine might improve
410 maximal range of motion at specific joints, especially if longer or more intense stretch

411 periods are practiced (36), the present results indicate that stretching provided negligible
412 flexibility benefit in addition to the low- and high-intensity dynamic activities (i.e. high
413 knees, butt kicks and test practice) of the warm-up. It would be of interest to determine
414 whether the stretching protocols evoked changes in muscle-tendon stiffness (extensibility) as
415 opposed to maximum length (range of motion), as these have been shown to be differentially
416 influenced by warm-up and stretching (36). Nonetheless, any possible effects in the current
417 study were clearly insufficient to affect physical performance.

418 Steps were taken in the current study to improve both the external and internal
419 validity of the results. With respect to external validity, we accepted only participants who
420 competed in running-based sports or performed at least three running-based exercise sessions
421 per week, and then allowed time for extensive familiarization of the tests. We also used
422 stretching durations that are common in athlete populations (17, 18), ensured that the static
423 and dynamic stretch movement patterns were identical, did not allow a passive rest condition
424 in the non-stretch condition, and imposed a 7-min no-activity period after the completion of
425 the full warm-up period. These steps were taken to replicate as closely as possible what might
426 occur in the sporting environment. With respect to internal validity, we ensured that the
427 researchers who conducted the tests were blinded to the warm-up conditions completed by
428 the participants (although these were closely supervised by another researcher) and all
429 instructions were scripted so that they were identical on each test occasion; the stretch
430 maneuvers were also shown by video with written instructions so that variations in
431 instruction were minimized. It was not possible to recruit participants who lacked prior
432 knowledge of the potential effects of stretching. However, by assessing participant beliefs
433 before the study as well as after the completion of each warm-up condition we were able to
434 examine relationships between participant expectation and study outcomes. Together, these
435 steps will have reduced both experimenter and participant bias, allowing us to more

436 confidently accept the study outcomes. It should be acknowledged, however, that the study
437 was not designed to examine the effects of prolonged periods of static (passive) stretching
438 performed *immediately* prior to a physical task, as might be reflective of practice in some
439 rehabilitation and resistance training settings.

440 One potential limitation of the current study design is that the tests were conducted in
441 a circuit, with 4 min being allowed for the completion of each test block (i.e. 3-m running
442 jump; SJ, CMJ, DJ; 20-m sprint run; T agility test). Therefore, the final test on any test day
443 may have commenced up to 12 min after the commencement of the test battery, and it will
444 have been performed after several other maximal-intensity tests. It can then be questioned
445 whether tests performed closer to the end of the warm-up period might have been more
446 strongly influenced by the interventions. However, our analysis did not reveal any evidence
447 of an order effect of the tests so performances achieved when a test was first in the circuit
448 (immediately after the 7-min imposed rest) were not different to those when the same test
449 was completed at another time point. Based on this evidence, it appears that the (lack of)
450 effect of the stretching is consistent when a full warm-up is completed and a short post-
451 warm-up rest is imposed regardless of the time elapsed or the number of other tests
452 performed in the intervening period.

453 **CONCLUSIONS**

454 The results of the present randomized, controlled, cross-over trial indicate that neither short-
455 or moderate-duration static (passive) nor dynamic muscle stretching influence flexibility or
456 high-intensity running, jumping or change of direction (agility) performances in young,
457 athletic individuals who perform a complete, progressive pre-exercise warm-up routine.
458 However, the incorporation of static (passive) or dynamic stretching into a warm-up routine
459 allowed for individuals to feel more confident of high performance in the ensuing sports-

460 related tests; i.e. there was a psychological effect. Based on the present results and previous
461 findings of small-to-moderate reductions in muscle injury risk in running based sports, we
462 conclude that short- or moderate-duration static stretching should be allowed, or even
463 promoted, as part of the warm-up routine prior to sports participation. According to our
464 results, dynamic stretching practices may also be incorporated into the warm-up routine,
465 although it should be reminded that no data currently exist documenting the influence of
466 dynamic stretching on injury risk.

467

468

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472

473 The results of the present study do not constitute endorsement by the American College of
474 Sports Medicine. The authors declare that the results of the study are presented clearly,
475 honestly, and without fabrication, falsification, or inappropriate data manipulation.

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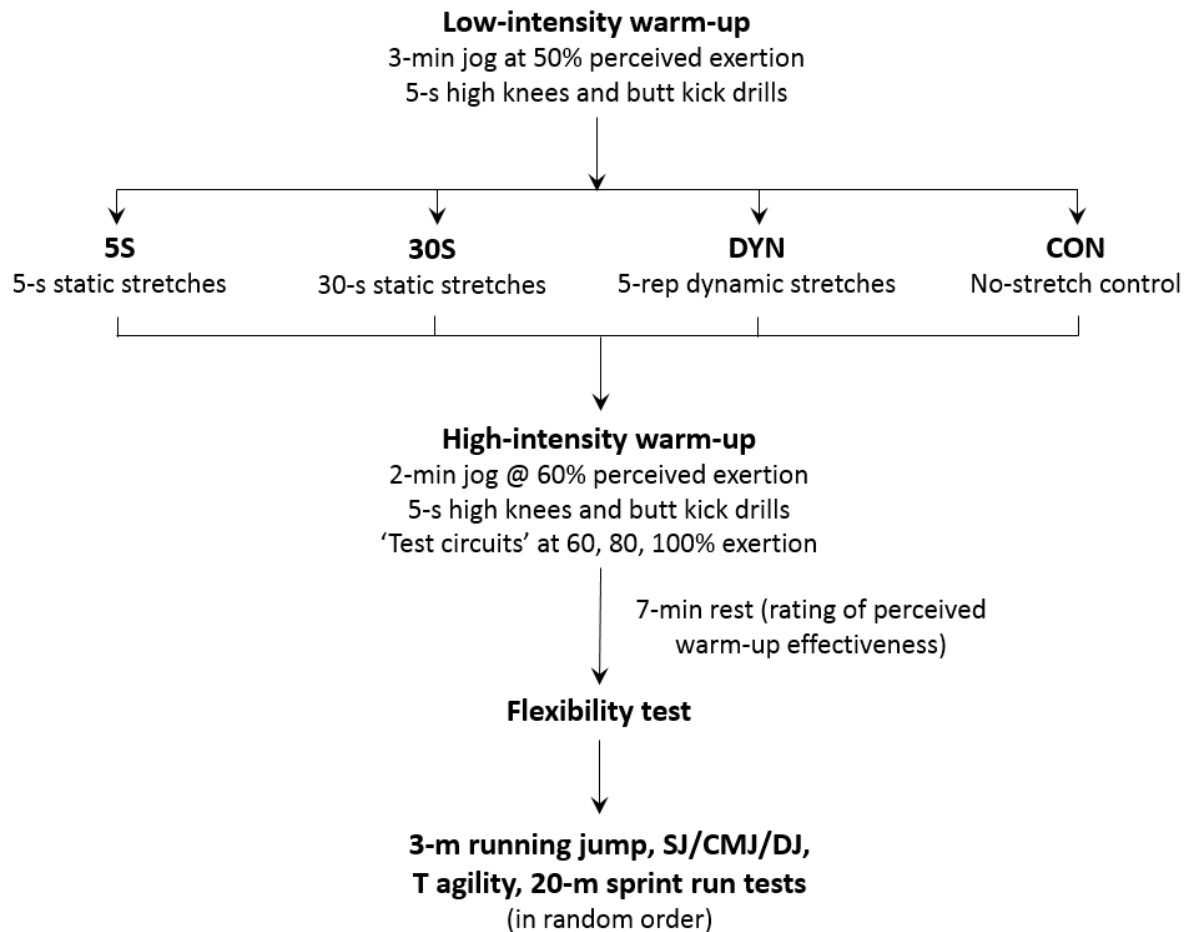
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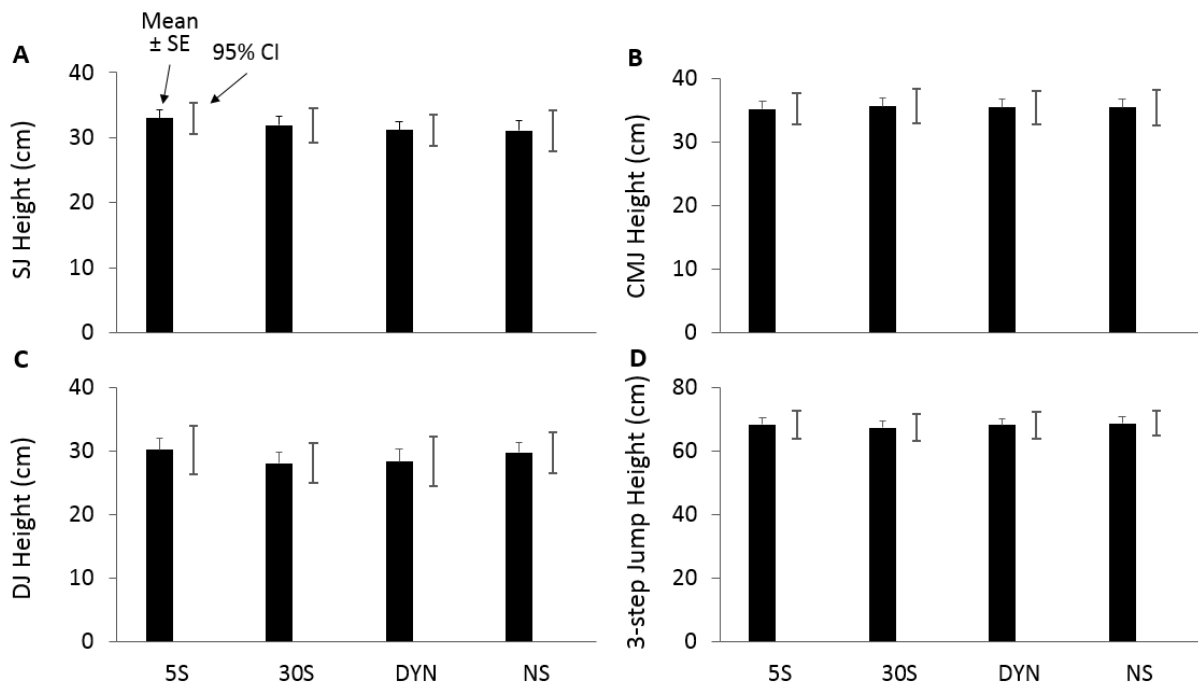
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567

568 **Figure 1.** Study design. After completing a low-intensity warm-up including 3-min jog and
 569 running drills, a randomly-assigned stretching (no no-stretch control) condition was
 570 completed. This was followed by a high-intensity warm-up comprising further jogging and
 571 running drills and then three circuits at increasing intensity (to maximum) comprised of the
 572 performance tests. After a 7-min rest, during which time the participants rated their
 573 confidence that the warm-up would improve their performance (see text for details), a sit-
 574 and-reach flexibility test was completed before the high-intensity performance tests were
 575 completed in a random order (order repeated at each session). 5-rep: 5-repetition.

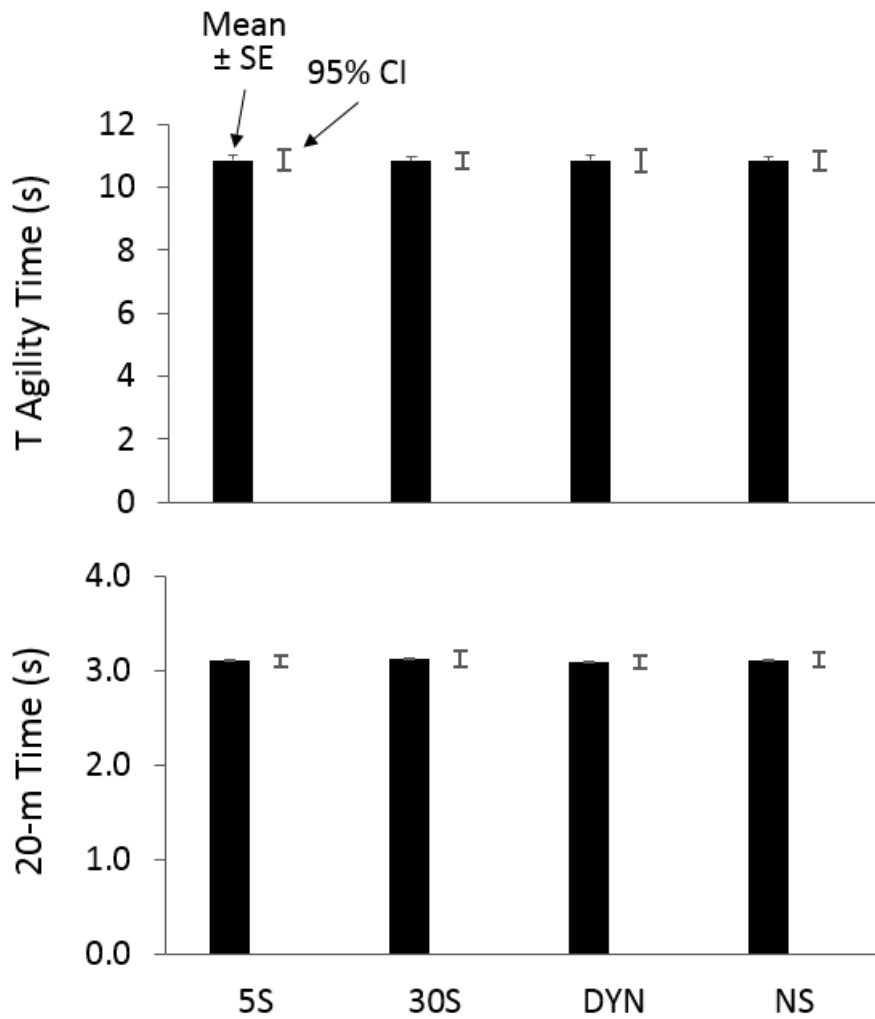
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578 **Figure 2.** Squat (SJ; A), countermovement (CMJ; B), drop (DJ; C) and 3-step
 579 Jump; D) heights recorded in 5S (5-s static stretch), 30S (30-s static stretch), DYN (dynamic
 580 stretch) and NS (no-stretch, control) conditions. There were no differences in jump test
 581 performances between the conditions. Shown are the mean \pm SE (black column with error
 582 bar) and 95% confidence intervals of the mean (separate gray bar) jump performances.

583



584

585 **Figure 3.** 20-m sprint run (bottom panel) and T agility (top panel) times recorded in 5S (5-s
 586 static stretch), 30S (30-s static stretch), DYN (dynamic stretch) and NS (no-stretch, control)
 587 conditions. There were no differences in test performances between the conditions. Shown
 588 are the mean \pm SE (black column with error bar) and 95% confidence intervals of the mean
 589 (separate gray bar) jump performances.

590

591

Supplemental Digital Content 1. Stretch instructions and photo

592
593

A. Calves

594
595 *Static*

- 596 1. Assume push-up position, keeping knees and elbows straight.
- 597 2. Allow one knee to drop by rolling onto ball of foot.
- 598 3. Gently lower heel of planted foot down as low to the ground as possible until stretch
599 is felt at the calf.
- 600 4. Hold the stretch at point of discomfort (POD) for 5 or 10 seconds (depending on
601 instructions for the day) before switching legs.



602
603 *Dynamic*

- 604 1. Assume push-up position, keeping knees and
605 elbows straight.
- 606 2. Allow one knee to drop by rolling onto ball of
607 foot.
- 608 3. Gently lower heel of planted foot down as low to the ground as possible until stretch
609 is felt at the calf.
- 610 4. Hold at POD only briefly (0.5 s) before lifting the heel up again.
- 611 5. Repeat for 5 repetitions per leg in a down-pause-up motion.

612
613 *Performance points*

- 614 1. Point grounded foot straight ahead
- 615 2. Keep the back straight.
- 616 3. Lower the heel as close to the ground as possible to POD.

617
618
619
620

B. Quadriceps

621
622 *Static*

- 623 1. Grasp ankle and gently pull your heel up and back until you feel the
624 stretch in the front of your thigh.
- 625 2. Tighten your stomach muscles to prevent your stomach from sagging
626 outward, and keep your knees close together.
- 627 3. Hold at POD for 5 or 10 seconds.
- 628 4. Switch legs and repeat.

629

630 *Dynamic*

- 631 1. Grasp ankle and gently pull your heel up and back until you feel the
632 stretch in the front of your thigh.
- 633 2. Tighten your stomach muscles to prevent your stomach from sagging
634 outward, and keep your knees close together.
- 635 3. Add a secondary pulling/tugging motion (pull foot upwards along
636 your back) before releasing the ankle and switching legs.
- 637 4. Repeat for 10 repetitions per leg in an up-tug-down motion.

638
639



640 C. Hamstrings

641 *Static*

- 642 1. Lie on back and lift knee up, keeping knees straight as far as possible and maintaining
- 643 dorsiflexion.
- 644 2. Grasp behind thigh near knee with both hands
- 645 and pull knee close to chest.
- 646 3. Hold stretch for 5 or 10 seconds at POD.
- 647 4. Release and repeat with opposite leg.



649 *Dynamic*

- 650 1. Lie on back and lift knee up, keeping knees
- 651 straight as far as possible and foot maintaining
- 652 dorsiflexion.
- 653 2. Grasp behind thigh near knee with both hands and pull knee close to chest.
- 654 3. Add a secondary pulling/tugging motion before releasing leg.
- 655 4. Repeat with opposite leg, 5 repetitions per leg.

657 *Performance points*

- 658 1. Maintain foot dorsiflexion
- 659 2. Keep knee extended

660
661
662
663

664 D. Hip Flexors

665 *Static*

- 666 1. Stand with hands on hips and with one leg approximately a leg
- 667 length in front of the other, with the forward leg slightly bent at the
- 668 knees and rear leg maximally extended.
- 669 2. Slowly lunge forward by bending forward leg.
- 670 3. With chest high, straighten hip of rear leg by pushing hips forward.
- 671 4. Hold stretch at POD for 5 or 10 seconds and repeat with opposite
- 672 side.



674 *Dynamic*

- 675 1. Stand with hands on hips and with one leg approximately a leg
- 676 length in front of the other, with the forward leg slightly bent at the
- 677 knees and rear leg maximally extended.
- 678 2. Slowly lunge forward by bending forward leg.
- 679 3. With chest high, straighten hip of rear leg by pushing hips forward.
- 680 4. Hold stretch at POD for about a second before returning to starting position.
- 681 5. Repeat for 5 repetitions in a 'forward-pause-back' motion before switching to
- 682 opposite leg.

683

684 *Performance points*

- 685 1. Keep torso upright, close to vertical.

686

687

688 E. Hip Adductors

689 *Static*

- 690 1. Stand with feet facing forward and slightly more than shoulder
- 691 width apart
- 692 2. Lean to one side by dropping one knee, causing the muscles of the
- 693 other leg to go into tension
- 694 3. Hold the stretch for 5 or 10 seconds at POD
- 695 4. Switch legs and repeat.



696
697 *Dynamic*

- 698 1. Stand with feet facing forward and slightly more than shoulder
- 699 width apart
- 700 2. Lean to one side by dropping one knee, causing the muscles of the
- 701 other leg to go into tension
- 702 3. Pause and hold at stretch position at POD for about a second before leaning to the
- 703 other side
- 704 4. Repeat for 5 repetitions per side in a ‘lean-pause-back’ motion.

705
706 *Performance points*

- 707 1. Maintain vertical upper body

708
709
710
711

712 F. Ankles

713 *Static*

- 714 1. Stand with hands on hips and feet shoulder-width apart.
- 715 2. Supporting bodyweight on one leg, roll ankle of other leg
- 716 laterally until stretch is felt to POD.
- 717 3. Hold for 5 or 10 seconds.
- 718 4. Return and repeat with opposite ankle.



719
720 *Dynamic*

- 721 1. Stand with hands on hips and feet shoulder-width apart.
- 722 2. Supporting bodyweight on one leg, roll ankle of other leg
- 723 laterally until stretch is felt to POD.
- 724 3. Hold stretch position for about a second before returning to
- 725 starting position.
- 726 4. Repeat for 5 repetitions in a ‘roll-pause-back’ motion before
- 727 switching legs.

728
729
730
731

732 G. Gluteals

733 *Static*

- 734 1. Standing on one leg, grasp below the knee of the other leg
- 735 and pull it as close to your chest as possible.
- 736 2. Hold the stretch at POD for 5 or 10 seconds.
- 737 3. Release and repeat with other leg.

738

739 *Dynamic*

- 740 1. Standing on one leg, grasp below the knee of the other leg
- 741 and pull it as close to your chest as possible.
- 742 2. Add a secondary tugging motion before releasing and
- 743 switching legs.
- 744 3. Repeat for 5 repetitions per leg.

745

746

747

748

749 H. Upper chest and shoulder

750 *Static*

- 751 1. Interlock fingers of both hands behind your back, palms together,
- 752 and lift both arms up and back as high as possible while
- 753 maintaining full elbow extension.
- 754 2. Hold the stretch at POD for 5 or 10 seconds.

755

756 *Dynamic*

- 757 1. Interlock fingers of both hands behind your back, palms together,
- 758 and lift both arms up and back as high as possible while
- 759 maintaining full elbow extension.
- 760 2. Pause at stretch position for ~0.5 s before releasing.
- 761 3. Repeat for 5 repetitions in a stretch-pause-release motion.

762

763 *Performance points*

- 764 1. Minimize shoulder shrug

765

766



767 I. Upper back

768

769 *Static*

770 1. Interlock fingers of both hands in front of torso, palms together, and
771 lift both arms forward and up until it is directly above your head.

772 2. Hold the stretch at POD for 5 or 10 seconds, feeling the stretch
773 through the back muscles.

774

775 *Dynamic*

776 1. Interlock fingers of both hands in front of torso, palms together, and
777 lift both arms forward and up until it is directly above your head.

778 2. Pause at stretch position for ~0.5 s before releasing, feeling the stretch
779 through the back muscles.

780 3. Repeat for 5 repetitions in a 'stretch-pause-release' motion.

781

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785

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