

1 **The Increased Effectiveness of Loaded Versus Unloaded Plyometric-Jump Training in**
2 **Improving Muscle Power, Speed, Change-of-Direction, and Kicking-Distance Performance in**
3 **Prepubertal Male Soccer Players**

4 **ABSTRACT**

5 **Purpose:** This study examined the effects of loaded (LPJT) and unloaded (UPJT) plyometric jump
6 training programmes on measures of muscle power, speed, change-of-direction and kicking-
7 distance performance in prepubertal male soccer players. **Methods:** Participants ($N=29$) were
8 randomly assigned to a LPJT group ($n=13$; age= 13.0 ± 0.7 years) using weighted vests or UPJT
9 group ($n=16$; age= 13.0 ± 0.5 years) using body mass only. Before and after the intervention, tests
10 for the assessment of proxies of muscle power (i.e., countermovement-jump [CMJ], standing-
11 long-jump [SLJ]), speed (i.e., 5-m, 10-m, and 20-m sprint), change-of-direction (i.e., Illinois
12 change-of-direction test [ICoDT], modified 505 agility test), and kicking-distance test were
13 conducted. Data were analysed using magnitude-based inferences. **Results:** Within-group
14 analyses for the LPJT group showed large and very large improvements for 10-m sprint-time
15 (effect size [ES]=2.00) and modified 505 CoD (ES=2.83) tests, respectively. For the same group,
16 moderate improvements were observed in ICoDT (ES=0.61), 5- and 20-m sprint-time (ES=1.00 for
17 both tests), CMJ (ES=1.00) and MKD (ES=0.90). Small enhancements in the SLJ (ES=0.50) test were
18 apparent. Regarding the UPJT group, small improvements were observed for all tests (ES=0.33 to
19 0.57) except 5-m and 10-m sprint-time (ES=1.00 and 0.63, respectively). Between-group analyses
20 favored the LPJT group for the modified 505 CoD (ES=0.61), SLJ (ES=0.50), and MKD (ES=0.57)
21 tests, but not for 5-m sprint-time (ES=1.00). Only trivial between-group differences were shown
22 for the remaining tests (ES=0.00 to 0.09). **Conclusion:** Overall, LPJT appears to be more effective
23 than UPJT in improving measures of muscle power, speed, change-of-direction and kicking-
24 distance performance in prepubertal male soccer players.

25 **Key words:** young, football, stretch-shortening cycle, maturity, athletic performance

26
27
28
29
30
31
32
33
34

35 INTRODUCTION

36 In elite soccer players, both young and old, physical qualities such as sprinting, jumping, and
37 change of direction (CoD) speed are major determinants of performance. ¹ Indeed, previous
38 studies have demonstrated that elite soccer players are characterized by high levels of muscular
39 strength, speed and derivatives thereof (i.e., acceleration, sprinting, jumping, and CoD), when
40 compared to sub-elite soccer players.^{2,3} Accordingly, the development of muscle power, speed
41 and CoD through well-designed strength and conditioning programs is vital to optimise the
42 development of the elite soccer player.

43 Previous studies have shown that unloaded plyometric jump training (UPJT), during which the
44 performer must propel their own body mass, is an easy-to-administer, safe, effective, and
45 efficient training method to improve physical fitness during different stages of maturation and
46 long-term athlete development.² Generally, UPJT involves various forms of hopping and jumping
47 exercises in vertical and horizontal directions, on stable and unstable surfaces. The magnitude of
48 training effects following UPJT depends on the manipulation of different training modalities such
49 as the training surface, ^{1,3} intensity (e.g., drop-height), ⁴ frequency, ⁵ direction (e.g., horizontal,
50 vertical), ⁶ the number of involved limbs (i.e., unilateral, bilateral jumping), ⁷ and sequencing
51 effect (e.g., UPJT before or after the training session). ⁸

52 From a physiological perspective, plyometric jump training (PJT) exercises involve the use of the
53 stretch-shortening cycle (SSC) which is characterised by an eccentric muscle action that is
54 immediately followed by a concentric muscle action. ⁹ The immediate succession of an eccentric
55 muscle action, such as the descent phase of a jump, with a concentric action, such as the take-
56 off phase, results in stimulation of a stretch reflex, potentiating performance during the
57 propulsive phase of jumping ¹⁰. This stretch reflex can be modulated by the velocity of the stretch
58 ^{10,11} and the magnitude of the stretching load. ^{12,13} Due to this, a potential way to enhance
59 adaptations to PJT is to use extra-loads additional to body mass (LPJT). ¹⁴⁻¹⁶

60
61 In this context, Rosas et al. ¹⁶ compared the effects of a 6-week LPJT programme, using handheld
62 dumbbells, with UPJT on jump performances and maximal ball kicking-velocity in young male
63 soccer players (aged 12 years). These authors reported small performance improvements in
64 countermovement jump (CMJ), horizontal jumps, reactive strength index and maximal kicking-
65 velocity (effect size [ES]=0.27 to 0.47), with larger effects seen in LPJT than in UPJT. Additional
66 loads may have induced larger stretch reflex amplitudes during training and this could have
67 translated to larger performance gains following LPJT. ^{12,13,17} Importantly, Rosas et al. ¹⁶ did not
68 record any training-related injuries and clearly concluded that LPJT is a safe and effective training
69 approach for the studied population. However, these authors ¹⁶ did not include any measure of
70 CoD or sprinting speed performance, thus limiting the applicability of the results to an important
71 determinant of soccer performance in youth.¹⁸

72 Further to the above, Kobal et al. ¹⁵ compared the effects of 6 weeks of LPJT, using handheld
73 dumbbells, and UPJT on measures of muscle power and speed in elite young male soccer players

74 (aged 16 years), reporting better improvements in vertical jumping performance in LPJT group
75 (Δ 9.4% and 8.4% for squat jump [SJ] and CMJ, respectively, in LPJT group; Δ 4.6% and 5% for the
76 SJ and CMJ in UPJT group, respectively). Recently, Coratella et al.¹⁴ studied the effects of 8 weeks
77 of LPJT or UPJT in recreationally trained male soccer players (aged 21 years). These authors found
78 that CoD and sprint performances improved to a larger extent in the LPJT group (ES=2.95, 0.52,
79 and 0.52 for T-test, 10-m and 30-m sprint tests, respectively) compared to the UPJT group (ES=
80 0.04, 0.10, and 0.06 for T-test, 10-m and 30-m sprint tests, respectively). In contrast, larger
81 increases in jump performances were found following UPJT (ES=0.89, and 0.55 for the SJ and CMJ
82 test, respectively).

83 Given inconsistent findings in the literature on the effects of LPJT when compared to UPJT¹⁵⁻¹⁷,
84 as well as considerable heterogeneity across study characteristics and outcome measures (i.e.,
85 sample size, training modalities, age categories), further research is needed. Accordingly, we
86 sought to examine the effects of LPJT and UPJT on a wider range of important performance
87 determinants (i.e., vertical and horizontal jump performance, linear sprint-time, CoD, and kicking
88 distance) in youth soccer players. The optimal PJT strategy that may elicit the largest physical
89 fitness improvements in this population is still under debate. With reference to previous research
90^{12,14,16}, we hypothesised that LPJT would induce larger improvements on measures of muscle
91 power, speed, CoD and kicking-distance performance than UPJT in prepubertal male soccer
92 players.

93

94

95 **METHODS**

96 *Participants*

97 Twenty-nine healthy young male athletes from a regional soccer academy were randomly
98 assigned either to a LPJT group (n=13) using additional weighted vests with a load of 8% of the
99 body mass during exercise¹⁵; or an UPJT group (n=16) which used no additional load during
100 training. All participants were classified as experienced players with 5.0 ± 1.3 years of systematic
101 soccer training background comprising of 3 to 5 training sessions per week. Anthropometric data
102 of both groups are presented in Table 1. Participants who missed more than 20% of the total
103 number of training sessions and/or more than two consecutive sessions, were excluded from the
104 study.³ Participants' maturation status was determined according to the offset method.¹⁹ All
105 procedures were approved by the local ethics committee for the use of human participants in
106 accordance with the latest version of the Declaration of Helsinki. Written informed parental
107 consent and participants' assent were obtained prior to the start of the study. All participants
108 and their parents/legal representatives were fully informed of the experimental protocol, and its
109 potential risks and benefits, prior to its commencement.

110

111 *Experimental design*

112 A parallel two-group repeated measures experimental design was conducted to examine the
113 effectiveness of LPJT and UPJT on measures of muscle power, speed, CoD and kicking-distance
114 performance in prepubertal male soccer players. Both training interventions were conducted
115 during the in-season period. Two weeks before baseline testing, two sessions were performed to
116 familiarise participants with the applied fitness tests. Of note, participants were used to the
117 applied PJT drills and had achieved good technical competency, through training activities, before
118 starting the study. Before and after training, tests for the assessment of proxies of muscle power
119 (i.e., countermovement-jump [CMJ], standing-long-jump [SLJ]), speed (i.e., 5-m, 10-m, and 20-m
120 sprint test), CoD (i.e., Illinois change-of-direction test [ICoDT], modified 505 agility test), and
121 kicking-distance test were conducted. All tests were scheduled at least 48 hours after players'
122 most recent training session or competition. The warm-up protocol preceding testing included 5
123 minutes of submaximal running with CoD exercises, 10 minutes of submaximal plyometrics {20
124 verticals (i.e., CMJs) and 10 horizontal jumps (i.e., bilateral ankle hops)}, dynamic stretching
125 exercises, and 5 minutes of a sprint-specific warm-up.

126

127

Table 1 near here

128

129 *Illinois change of direction test*

130 The ICoDT was conducted as previously outlined by Negra et al.³ The time needed to complete
131 the test was used as a performance outcome and it was assessed using a single beam infrared
132 photocell device (Microgate SRL, Bolzano, Italy). Each participant performed three trials with a 3-
133 min rest between each. The best trial was used for further analysis. The ICC for test-retest trials
134 was 0.94.

135

136 *The modified 505 change of direction test*

137 During a modified 505 agility test, athletes were instructed to perform a 5-m sprint from a
138 starting line, to place the preferred foot on the 5-m line, turn 180° and sprint back 5-m through
139 the start/finish line. Single beam infrared photocell gates (Microgate SRL, Bolzano, Italy) were
140 placed at the start line 0.75-m above the ground. A resting between-trial period of 3-min was
141 provided. The best performance out of three trials was used for further analysis. The ICC for test-
142 retest trials was 0.94.

143

144 *Sprint-time*

145 The performance of a 20-m linear sprint was recorded using an infrared photocell system
146 (Microgate, Bolzano, Italy). Additionally, split sprint times of 5-m and 10-m were analysed. In
147 total, four single beam photoelectric gates were used. The between-trial recovery time was 3-
148 min. The best performance out of three trials was used for further analysis. The ICCs for test-
149 retest reliability were 0.92, 0.94, and 0.97 for 5-m, 10-m, and 20-m, respectively.

150

151 *Countermovement jump*

152 During the CMJ, participants started from an upright erect standing position and performed a
153 fast downward movement by flexing the knees and hips before rapidly extending the legs and
154 performing a maximal vertical jump. During the test, participants were instructed to maintain
155 their arms akimbo. Jump height was recorded using an optoelectric system (Optojump,
156 Microgate, SRL, Bolzano, Italy). A rest period of 1-min was allowed between trials. The best out
157 of three trials was retained for further analysis. The ICC for test-retest reliability was 0.96.
158

159 *Standing-long-jump*

160 During the SLJ test, participants stood with their feet shoulder-width apart and in front of a
161 starting line. On the command of “ready, set, go”, participants performed a fast flexion of the
162 legs and downward movement of the arms, before jumping as far as possible in a horizontal
163 direction. Participants had to land with both feet at the same time and were not allowed to fall
164 forward or backward. The horizontal distance between the starting line and the heel of the rear
165 foot was recorded using a tape measure to the nearest 1-cm. A between-trial rest period of 1-
166 min was allowed. The best out of three trials was recorded for further analysis. The ICC for test-
167 retest reliability was 0.97.

168 *Maximal kicking distance test*

169 The maximal kicking distance test (MKD) was conducted as previously outlined by Bouguezzi et
170 al.²⁰ The maximal distance attained by the ball was measured using a metric tape. An evaluator
171 was placed near to the region where the ball landed to accurately locate the point of contact and
172 to measure the distance of the kick to the nearest 0.2-m. The wind velocity was <20 km.h⁻¹ during
173 all the testing sessions (local Meteorological Service). A between-trial rest period of 1-min was
174 provided. The best out of three trials was recorded for further analysis. The ICC for test-retest
175 trials was 0.95.

176 *Plyometric jump training*

177

178 The two experimental groups participated in an 8-week in-season PJT program consisting of two
179 training sessions per week. Overall, the UPJT and LPJT groups conducted five regular soccer
180 training sessions per week. The PJT was integrated into the regular training routine of the soccer
181 team, replacing some soccer-specific drills. The inter-day rest interval between plyometric
182 training sessions was at least 72 h. A standardised warm-up of 8 to 12-min duration was
183 completed. It included low intensity running, coordination exercises, dynamic movements,
184 sprints, and dynamic stretching for the lower limb muscles prior to each PJT session. Soccer
185 training sessions lasted between 80 and 90-min. The LPJT and UPJT drills lasted between 20 and
186 25-min. The remaining training time was dedicated to technical and tactical drills. The first
187 training session was performed at least 48 hours after the soccer match that was scheduled on
188 the weekend. The LPJT and UPJT protocols were based on that of a previously published study²¹.
189 Details of the respective protocols are illustrated in Table 2. The PJT (i.e., LPJT, UPJT) included
190 vertical (i.e., CMJs) and horizontal (i.e., bilateral forward ankle hops) jumps performed at maximal

191 effort (i.e., maximal height and forward distance with a minimal contact time for vertical and
192 horizontal jumping, respectively). Both groups performed cyclic jumps using an arm-swing.
193 According to previous studies,^{8,22} training volume was progressively increased throughout the 8-
194 week intervention period. While participants of the UPJT group performed all jump exercises
195 using no additional loads, participants in the LPJT group executed the same exercises using
196 weighted vests (8% participants' body mass)¹⁵. Both sessions consisted of a volume of 4-6 sets
197 and 6-10 repetitions. The total number of ground contacts per session was 50 during the first
198 week and gradually increased to 120 after eight weeks of training. A 90-s rest was provided
199 between each set of each exercise. The jump training protocols were supervised by a qualified
200 instructor.

201
202
203

Table 2 near here

204 STATISTICAL ANALYSES

205 Statistical analyses included calculation and interpretation of effect sizes using magnitude-based
206 inferences. The following outlined ranges were used to interpret effect size: <0.2 = trivial; 0.2–
207 0.6 = small, 0.6–1.2 = moderate, 1.2–2.0 = large, 2.0–4.0 = very large, >4.0 = extremely large.²²
208 An effect size of 0.2 was considered to be the “smallest worthwhile change”.²² The estimates
209 were considered unclear when the chance of a beneficial effect was high enough to justify the
210 use of the intervention (>25%), yet the risk of being harmful was unacceptable (>0.5%).²² An odds
211 ratio of benefit to harmful of $\square 60$ was indicative of such unclear effects.²³ This was calculated
212 using an available spreadsheet.²³ The scale used to interpret the probabilities was as follows:
213 possible = 25–75%; likely = 75–95%; very likely = 95–99.5%; most likely >99.5%.^{22,23} Uncertainty
214 in the effect sizes was represented by 90% confidence limits. Effects were considered unclear if
215 the confidence interval crossed thresholds for substantial positive and negative values.
216 Otherwise, the effect was clear and reported as the magnitude of the observed value with a
217 qualitative probability.²² Test-retest reliability was assessed using the intraclass correlation
218 coefficients (ICCs).

219 RESULTS

220 All subjects received treatment conditions as allocated. Three participants from the LPJT group
221 withdrew from attending the youth soccer training center for personal reasons and were,
222 therefore, excluded from the study. The training compliance rate was 95% for the two groups.
223 Table 3 displays test data for all components of physical fitness assessed at baseline and follow-
224 up. There were no statistically significant baseline differences between the groups in
225 chronological age, body height, body mass, APHV or soccer experience (Table 1). Additionally, no
226 between-group differences were recorded at baseline for any test of physical fitness (Table 3).

227 Within-group analyses for the UPJT group showed small positive effect sizes for the ICoD,
228 modified 505 CoD, 20-m sprint-time, CMJ, SLJ, and MKD tests (Table 3). In the same group,
229 moderate performance improvements were shown for the 5-m and 10-m sprint-time tests.
230 Regarding the LPJT group, large and very large effect sizes were shown for the 10-m sprint-time

231 and modified 505 CoD tests, respectively. For the ICoD, 5- and 20-m sprint-time, CMJ, and MKD,
232 moderate positive effect sizes were recorded. The performance improvement for the SLJ test was
233 small. Outcomes of the between-group analyses favored the LPJT group for the modified 505
234 CoD, SLJ, and MKD tests with small to moderate effect sizes (Table 4). However, there were
235 greater performance improvements in the 5-m sprint for the UPJT group. For the remaining tests
236 (ICoD, 10-m, 20-m, and CMJ), trivial between-group differences were demonstrated (Table 4).

237 *--Table 3 near here--*

238 *--Table 4 near here--*

239 **DISCUSSION**

240 The aim of this study was to compare the effects of 8 weeks of LPJT or UPJT program on measures
241 of muscle power, speed, CoD and kicking-distance performance in prepubertal male soccer
242 players. The main finding of the study was that LPJT induced larger performance improvements
243 compared to UPJT on measures of muscle power, speed, CoD and kicking-distance performance
244 in prepubertal male soccer players.

245

246 *Change of direction*

247

248 Mirkov et al.²⁴ reported that CoD performance is a key determinant of high performance play in
249 the sport of soccer. Our results showed small improvements in the ICoD and 505 CoD tests after
250 UPJT whilst moderate and very large performance improvements were seen in the ICoD and 505
251 CoD tests, respectively, after LPJT. The CoD performance improvements following UPJT were
252 expected considering the extensive empirical studies supporting the effectiveness of this type of
253 training in youth populations.^{21,25,26} Recently, Coratella et al.¹⁴ studied the effects of 8 weeks of
254 loaded (1.2 x body-mass) or unloaded (body mass only) jump-squat training in recreationally
255 trained male soccer players (aged 21 years). These researchers found that the loaded jump-squat
256 group improved T-test performance (ES=2.95) whilst no changes occurred following the unloaded
257 programme (ES=-0.04). The authors attributed the greater CoD improvements to the increased
258 braking ability generated by the enhanced eccentric workload associated with loaded training.
259 Sheppard and Young,²⁷ suggest that PJT can improve eccentric strength of the thigh muscles, an
260 important determinant of performance during the deceleration phase of CoD movements.²⁸
261 Improvements in CoD performance following PJT could occur due to the interaction of several
262 training-related neuromuscular adaptations including the improvement of neural drive to agonist
263 muscles, patterns that enable athletes to rapidly switch between deceleration and acceleration
264 motions (i.e., higher efficiency of the stretch-shortening cycle), and muscle activation strategies
265 (i.e., inter- and intra-muscular coordination).^{29,30} In particular, better CoD performance following
266 LPJT, compared to UPJT, seems to be due to the potentiation of a greater stretch-reflex because
267 of additional loading during PJT.^{12,13} Additionally, as eccentric strength is an important
268 determinant of deceleration ability during CoD movements,²⁸ the higher inertia accumulated
269 during the braking phase during LPJT may have contributed to an increases in eccentric workload
270 and, therefore, larger strength improvements.¹⁴ However, further studies including
271 kinetic/kinematic and/or physiological tests have to be conducted to confirm the current
272 findings.

273

274 *Speed performance*

275

276 Sprinting activities are frequently performed prior to decisive situations in soccer matches such
277 as goal scoring.³² The findings of the present study showed small to moderate improvements in
278 sprint performance in the UPJT group and moderate to large improvements in the LPJT group.
279 These results corroborate those of Coratella et al.¹⁴ who studied the effects of 8 weeks of loaded
280 (30% of squat 1RM) and unloaded jump-squat training in recreationally trained male soccer
281 players (aged 21 years). These researchers reported improvements in sprint performance over
282 10-m and 30-m in the loaded squat-jump group only (ES=0.52 for both 10 and 30-m), attributing
283 this finding to the greater eccentric load imposed by the LPJT programme. Improvements in the
284 sprint performance of prepubertal male soccer players are well-established in the literature.^{1,4,20}
285 Indeed, the results of the present study demonstrated larger effects on sprinting speed after LPJT
286 than after UPJT. Of note, sprinting speed improvements occur primarily due to neural-orientated
287 factors and the development of the central nervous system during the prepubertal phase of
288 development.^{2,18} However, such changes are more likely to occur over the longer term. Within
289 the short timescale of the current study, enhancement of the stretch-reflex^{12,13} and a higher
290 eccentric overload during LPJT¹⁴ may have contributed to larger improvements in SSC efficiency,
291 muscle activation, and stiffness of musculotendinous tissue. In view of the importance of sprint
292 speed performance during soccer matches, LPJT seems to be preferable to UPJT in prepubertal
293 male soccer players. However, technical competency must first be attained before the
294 progression to loaded PJT formats.

295

296 *Jumping tests*

297 Jump performance has been shown to be a valid talent-identification marker which can
298 discriminate between potential elite and non-elite youth soccer players.³³ In this study, both PJT
299 protocols induced small performance improvements in the SLJ test. Regarding the CMJ test, while
300 UPJT showed small training-related effects, the LPJT generated a moderate effect. In prepubertal
301 male soccer players, jump performance improvements have frequently been observed following
302 UPJT programs.^{1,4,20} The novel finding of this study is that LPJT appears to generate further
303 performance increases which seem mostly restricted to vertical jumping. Rosas et al.¹⁶ studied
304 the effects of 6 weeks LPJT or UPJT on vertical and horizontal jump performance in young male
305 soccer players (aged 12 years). The study authors reported larger performance improvements in
306 vertical and horizontal jump performance tests in the LPJT group (ES=0.26 to 0.47) than in the
307 UPJT group (ES=0.26 to 0.32) and control group (ES=0.08 to 0.16). The greater vertical and
308 horizontal jump performance enhancements were attributed to higher peak ground reaction
309 forces and to greater vertical and horizontal impulses generated by LPJT.¹⁶ In another study,
310 Kobal et al.¹⁵ studied the effects of 6 weeks of LPJT, using handheld dumbbells, or UPJT on
311 measures of muscle power and speed in elite young male soccer players (aged 16 years). The
312 researchers reported higher increases in SJ (Δ 8.4%) and CMJ (Δ 9.4%) in the LPJT group compared
313 to the UPJT group (SJ: Δ 4.6% and CMJ: Δ 4.9%). Again, it was speculated that these improvements
314 were due to increased vertical ground reaction force over a shorter time period which may have
315 resulted in a higher impulse related to the addition of load during PJT, and greater jump

316 performance adaptations in the LPJT group.¹⁶ Overall, prepubertal male soccer players can
317 improve their vertical and horizontal jump performance by means of PJT executed either with or
318 without additional load stimuli. However, there seems to be an advantage in the utilisation of
319 LPJT over UPJT programmes in terms of the magnitude of the training-related effects on vertical
320 jump performance.

321

322 *Maximal kicking distance*

323

324 Effective kicking is a vital and necessary skill that is performed during soccer matches, as it is the
325 method used to score most goals.³⁴ In this study, MKD improved to a small magnitude after UPJT
326 and increased moderately following LPJT. Reinforcing our results, Rosas et al.¹⁶ demonstrated
327 greater maximal kicking velocity improvements in LPJT (effect-size=0.34) and UPJT (effect-
328 size=0.27) groups as compared to a control group (effect-size=0.15), following 6 weeks of
329 training. Improvements in some biomechanical parameters involved in kicking the ball (e.g., the
330 maximum linear velocity of the toe, ankle, knee, and hip at ball contact), due to neuromuscular
331 adaptations,²⁰ could explain MKD performance increases. The larger MKD improvements
332 following LPJT may be induced by greater levels of muscle activation,¹³ resulting in increases in
333 force production and rate of force development. However, findings should be interpreted with
334 caution because MKD can be influenced by several extraneous factors such as the trajectory and
335 rotation of the ball, as well as the technique used to kick the ball (i.e., toe, dorsum or the inside
336 part of the foot).³⁵ This might affect kicking performance irrespective of the level of muscle
337 power.

338

339 This study does have some limitations. First, we were unable to include an active control group.
340 Second, the study lacks direct physiological and/or biomechanical measures that may help
341 explain the underpinning mechanism behind the observed improvements in prepubertal soccer
342 players. This has to be considered in future research.

343

344 **PRACTICAL APPLICATIONS**

345 Larger increases in measures of muscle power, speed, CoD and kicking-distance performance
346 have been shown following LPJT as compared to UPJT in prepubertal male soccer players. These
347 study findings contribute to previous knowledge on the delivery of effective PJT programs to
348 prepubertal male soccer players. UPJT has already been well-established as beneficial for
349 improving several physical fitness components of prepubertal male soccer players. The novelty
350 in the current study is that LPJT appears to be more effective than UPJT in further enhancing the
351 main components of physical fitness (i.e., speed, muscle power, and CoD) required by soccer
352 competition, thus representing an effect progression of exercise that can be used to drive
353 continual adaptation. Based on the findings reported herein, practitioners are recommended to
354 use LPJT to improve components of physical fitness in prepubertal male soccer players, but
355 technical competency in unloaded jumps should first be established.

356

357 **CONCLUSIONS**

358 Outcomes of this study suggested that LPJT is more effective than UPJT in improving measures
359 of muscle power, speed, CoD and kicking-distance performance. Future longitudinal studies
360 should establish what physiological and biomechanical adaptations are responsible for the
361 observed functional adaptations.
362

363
364

365 **ACKNOWLEDGEMENTS**

366

367 The authors express their gratitude to the coaches and participants for their participation in this
368 study.
369

369

370 **CONFLICT OF INTERST**

371

372 The authors declare no conflict of interest.
373

373

374

375

376

377

378

379

380

381

382

383

384

385

386

387

388

389

390

391

392

393

394

395

396 **REFERENCES**

397

- 398 1. Chaabene H, Negra Y. The Effect of Plyometric Training Volume on Athletic Performance in
399 Prepubertal Male Soccer Players. *Int J Sports Physiol Perform.* 2017;12(9):1205-1211.

- 400 2. Granacher U, Lesinski M, Busch D, Muhelbauer T, Prieske O, Puta C, Golhofer A, Behm DG.
401 Effects of Resistance Training in Youth Athletes on Muscular Fitness and Athletic Performance: A
402 Conceptual Model for Long-Term Athlete Development. *Frontiers Physiol.* 2016;7:164.
- 403 3. Negra Y, Chaabene H, Sammoud S, Bouguezzi R, Abbes MA, Hachana Y, Granacher U. Effects of
404 Plyometric Training on Physical Fitness in Prepuberal Soccer Athletes. *Int J Sports Med.*
405 2017;38(5):370-377.
- 406 4. Ramirez-Campillo R, Alvarez C, Garcia-Pinillos F, Sanchez-Sanchez J, Yanci J, Castillo D, Loturco I,
407 Chaabene H, Moran J, Izquierdo M. Optimal Reactive Strength Index: Is It an Accurate Variable
408 to Optimize Plyometric Training Effects on Measures of Physical Fitness in Young Soccer Players?
409 *J Strength Cond Res.* 2018;32(4):885-893.
- 410 5. Ramirez-Campillo R, García-Pinillos F, García-Ramos A, Yanci J, Gentil P, Chaabene H, Granacher
411 U. Effects of Different Plyometric Training Frequencies on Components of Physical Fitness in
412 Amateur Female Soccer Players. *Frontiers Physiol.* 2018;9(934).
- 413 6. Ramirez-Campillo R, Gallardo F, Henriquez-Olguin C, Maylan CM, Martinez C, Alvarez C,
414 Caniugueo A, Cadore EL, Izquierdo M. Effect of Vertical, Horizontal, and Combined Plyometric
415 Training on Explosive, Balance, and Endurance Performance of Young Soccer Players. *J Strength*
416 *Cond Res.* 2015;29(7):1784-1795.
- 417 7. Ramirez-Campillo R, Burgos CH, Henriquez-Olguin C, Andrade DC, Martinez C, Alvarez C, Castro-
418 Supelveda M, Marques MC, Izquierdo M. Effect of unilateral, bilateral, and combined plyometric
419 training on explosive and endurance performance of young soccer players. *J Strength Cond Res.*
420 2015;29(5):1317-1328.
- 421 8. Pereira LA, Abad CCC, Kobal R, Kitamura K, Orsi RC, Ramirez-Campillo R, Loturco I. Differences in
422 Speed and Power Capacities Between Female National College Team and National Olympic
423 Team Handball Athletes. *J Hum Kinet.* 2018;63:85-94.
- 424 9. Nicol C, Avela J, Komi PV. The stretch-shortening cycle : a model to study naturally occurring
425 neuromuscular fatigue. *Sports Med.* 2006;36(11):977-999.
- 426 10. Taube W, Leukel C, Gollhofer A. How neurons make us jump: the neural control of stretch-
427 shortening cycle movements. *Exerc Sport Sci Rev.* 2012;40(2):106-115.
- 428 11. Komi PV. Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. *J*
429 *Biomechanics.* 2000;33(10):1197-1206.
- 430 12. Avela J, Santos PM, Komi PV. Effects of differently induced stretch loads on neuromuscular
431 control in drop jump exercise. *Eur J Appl Physiol Occup Physiol.* 1996;72(5-6):553-562.
- 432 13. Gollhofer A, Kyrolainen H. Neuromuscular control of the human leg extensor muscles in jump
433 exercises under various stretch-load conditions. *Int J Sports Med.* 1991;12(1):34-40.
- 434 14. Coratella G, Beato M, Milanese C, Longo S, Limonta E, Rampichini S, Cé E, Bisconti AV, Schena F,
435 Esposito F. Specific Adaptations in Performance and Muscle Architecture After Weighted Jump-
436 Squat vs. Body Mass Squat Jump Training in Recreational Soccer Players. *J Strength Cond Res.*
437 2018;32(4):921-929.
- 438 15. Kobal R, Pereira LA, Zanetti V, Ramirez-Campillo R, Loturco I. Effects of Unloaded vs. Loaded
439 Plyometrics on Speed and Power Performance of Elite Young Soccer Players. *Frontiers Physiol.*
440 2017;8:742.
- 441 16. Rosas F, Ramirez-Campillo R, Diaz D, Abad-Colil F, Martinez-Salazar C, Caniugueo A, Canas-Jamel
442 R, Loturco I, Nakamura FY, McKenzie C, Gonzales-Rivera J, Sanchez-Sanchez J, Izquierdo M. Jump
443 Training in Youth Soccer Players: Effects of Haltere Type Handheld Loading. *Int J Sports Med.*
444 2016;37(13):1060-1065.
- 445 17. Komi PV, Gollhofer A. Stretch reflexes can have an important role in force enhancement during
446 SSC exercise. *J Appl Biomechanics.* 1997;13(4):451-460.

- 447 18. Moran J, Sandercock G, Rumpf MC, Parry DA. Variation in responses to sprint training in male
448 youth athletes: A meta-analysis. *Int J Sports Med.* 2017; 38(1):1-11.
- 449 19. Malina RM, Koziel SM. Validation of maturity offset in a longitudinal sample of Polish boys. *J*
450 *Sports Sci.* 2014;32(5):424-437.
- 451 20. Bouguezzi R, Chaabene H, Negra Y, Ramirez-Campillo R, Jllia Z, Mkaouer B, Hachana Y. Effects
452 of Different Plyometric Training Frequency on Measures of Athletic Performance in Prepuberal
453 Male Soccer Players. *J Strength Cond Res.* 2018.
- 454 21. Bedoya AA, Miltenberger MR, Lopez RM. Plyometric Training Effects on Athletic Performance in
455 Youth Soccer Athletes: A Systematic Review. *J Strength Cond Res.* 2015;29(8):2351-2360.
- 456 22. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports
457 medicine and exercise science. *Med Sci Sports Exerc.* 2009;41(1):3-13.
- 458 ~~23. Spencer M, Fitzsimons M, Dawson B, Bishop D, Goodman C. Reliability of a repeated-sprint test~~
459 ~~for field hockey. *J Sci Med Sport.* 2006;9(1-2):181-184.~~
- 460 ~~24. Meylan CM, Cronin JB, Oliver JL, Hopkins WG, Contreras B. The effect of maturation on~~
461 ~~adaptations to strength training and detraining in 11-15-year-olds. *Scand J Med Sci Sports.*~~
462 ~~2014;24(3):e156-164.~~
- 463 23. Hopkins WG. A Spreadsheet for Deriving a Confidence Interval, Mechanistic Inference and
464 Clinical Inference from a P Value. *Sports Science.* 2017;21.
- 465 24. Mirkov DM, Kukulj M, Ugarkovic D, Koprivica VJ, Jaric S. Development of anthropometric and
466 physical performance profiles of young elite male soccer players: A longitudinal study. *J Strength*
467 *Cond Res.* 2010 ; 24: 2677–2682.
- 468 25. Ramirez-Campillo R, Alvarez C, Garcia-Hermoso A, Ramirez-Velez R, Gentil P, Asadi A, Chaabene
469 H, Moran J, Meylan C, Garcia-de-Alcaraz A, Sanchez-Sanchez J, Nakamura FY, Granacher U,
470 Kraemer W, Izquierdo I. Methodological Characteristics and Future Directions for Plyometric
471 Jump Training Research: A Scoping Review. *Sports Med.* 2018;48(5):1059-1081.
- 472 26. Asadi A, Arazi H, Ramirez-Campillo R, Moran J, Izquierdo M. Influence of Maturation Stage on
473 Agility Performance Gains After Plyometric Training: A Systematic Review and Meta-analysis. *J*
474 *Strength Cond Res.* 2017;31(9):2609-2617.
- 475 27. Sheppard JM, Young WB. Agility literature review: classifications, training and testing. *J Sports*
476 *Sci.* 2006;24(9):919-932.
- 477 28. Chaabene H, Prieske O, Negra Y, Granacher U. Change of Direction Speed: Toward a Strength
478 Training Approach with Accentuated Eccentric Muscle Actions. *Sports Med.* 2018.
- 479 29. Markovic G, Mikulic P. Neuro-musculoskeletal and performance adaptations to lower-extremity
480 plyometric training. *Sports Med.* 2010;40(10):859-895.
- 481 30. Hakkinen K, Alen M, Komi PV. Changes in isometric force- and relaxation-time,
482 electromyographic and muscle fibre characteristics of human skeletal muscle during strength
483 training and detraining. *Acta physiol Scand.* 1985;125(4):573-585.
- 484 31. Bradley PS, Sheldon W, Wooster B., Olsen P, Boanas P, Krusturup P. High-intensity running in
485 english FA premier league soccer matches. *J Sports Sci.* 2009 ;27, 159–168.
- 486 32. Faude O, Koch T, Meyer T. Straight sprinting is the most frequent action in goal situations in
487 professional football. *J Sports Sci.* 2012; 30(7):625-31.
- 488 33. Meylan C, Malatesa D. Effects of in-season plyometric training within soccer practice on
489 Explosive actions of young players. *J Strength Cond Res.* 2009; 23(9):2605-13.
- 490 34. Kellis E, Katis A. Biomechanical characteristics and determinants of instep soccer kick. *J Sports Sci*
491 *Med.* 2007; 6(21) :154-65.
- 492
- 493 35. Ramirez-Campillo R, García-Pinillos F, García-Ramos A, Yanci J, Gentil P, Chaabene H, Granacher
494 U. Effects of different plyometric training frequencies on components of physical fitness in

495 amateur female soccer players. *Front Physiol.* 2018. In press

496

497

498

499

500

501

502

503

504

505

506

507

508

509

510

511

512

513

514

515

516

517

518

519

520

521

Table 1: Anthropometric characteristics of the included subjects

	UPJT (n=16)		LPJT (n=13)	
	Pre-test	Post-test	Pre-test	Post-test
Age (years)	13.0±0.5	13.2±0.5	13.0±0.7	13.2±0.7
Body height (cm)	159.6±11.6	160.3±11.7	162.6±8.3	162.8±8.4
Body mass (kg)	42.4±8.8	41.6±10.8	45.7±8.0	46.5±7.4
Maturity offset (years)	-1.3±1.1	-1.2±1.2	-1.1±0.5	-1.0±0.5
Predicted APHV (years)	14.3±0.8	14.4±0.9	14.1±0.6	14.1±0.6

Data are presented as means and standard deviations (SD); UPJT: Unloaded plyometric jump training group; LPJT: Loaded plyometric jump training group; APHV: Age at peak-height-velocity.

Table 2: Characteristics of the plyometric jump training programs

Week	Plyometric exercises*	Volume (sets×reps)	Ground contacts per session
1	Bilateral forward ankle hops (hurdle height: 20 cm)	4 × 6-7	50
	CMJ	4 × 6-7	
2	Bilateral forward ankle hops (hurdle height: 20 cm)	4 × 7-8	60
	CMJ	4 × 7-8	
3	Bilateral forward ankle hops (hurdle height: 20 cm)	4 × 8-9	70
	CMJ	4 × 9	
4	Bilateral forward ankle hops (hurdle height: 20 cm)	4 × 10	80
	CMJ	4 × 10	
5	Bilateral forward ankle hops (hurdle height: 20 cm)	4 × 10	90
	CMJ	6 × 8-9	
6	Bilateral forward ankle hops (hurdle height: 20 cm)	6 × 8-9	100
	CMJ	6 × 8-9	
7	Bilateral forward ankle hops (hurdle height: 20 cm)	6 × 8	110
	CMJ	6 × 10	
8	Bilateral forward ankle hops (hurdle height: 20 cm)	6 × 10	120
	CMJ	6 × 10	

*Reps: repetitions; CMJ: countermovement jump; * The loaded plyometric jump training group conducted plyometric exercises with weighted vest, while athletes of the unloaded plyometric jump training group performed the same exercises with their body mass load only.*

Table 3: Within-group effect sizes, confidence limits, likelihood effects and odds ratios for performance data

Variable	Baseline	Post-test	Effect size	Confidence limits	Chances (%) Beneficial/trivial/harmful	Effect description	Odd ratio of benefits to harm
Unloaded plyometric jump training group (n=16)							
ICoD test (s)	18.6±1.1	18.2±1.1	0.36	-0.2 to 0.9	77.8/21.5/0.8	Likely beneficial	454
Modified 505 CoD test (s)	2.9±0.2	2.8±0.2	0.50	-0.1 to 1.1	84.4/14.3/1.3	Likely beneficial	409
5-m sprint (s)	1.2±0.1	1.1±0.1	1.00	0.4 to 1.6	90.9/6.5/2.5	Likely beneficial	373
10-m sprint (s)	2.1±0.1	2.0±0.2	0.63	0.0 to 1.2	87.5/10.8/1.8	Likely beneficial	391
20-m sprint (s)	3.7±0.3	3.6±0.3	0.33	-0.3 to 0.9	75.2/24.2/0.6	Likely beneficial	473
CMJ (cm)	23.7±4.8	26.6±5.4	0.57	0.0 to 1.2	86.2/12.2/1.5	Likely beneficial	398
SLJ (m)	1.6±0.2	1.7±0.2	0.50	-0.1 to 1.1	84.4/14.3/1.3	Likely beneficial	409
MKD (m)	23.4±5.2	26.2±6.0	0.50	-0.1 to 1.1	84.4/14.3/1.3	Likely beneficial	409
Loaded plyometric jump training group (n=13)							
ICoD test (s)	18.6±0.6	18.2±0.7	0.61	0.0 to 1.3	87.4/10.8/1.8	Likely beneficial	379
Modified 505 CoD test (s)	2.9±0.0	2.7±0.1	2.83	1.9 to 3.7	93.8/2.2/4.0	Likely beneficial	362
5-m sprint (s)	1.3±0.1	1.2±0.1	1.00	0.3 to 1.7	91.0/6.3/2.7	Likely beneficial	368
10-m sprint (s)	2.2±0.1	2.0±0.1	2.00	1.2 to 2.8	93.3/3.1/3.7	Likely beneficial	363
20-m sprint (s)	3.8±0.2	3.6±0.2	1.00	0.3 to 1.7	91.0/6.3/2.7	Likely beneficial	368
CMJ (cm)	22.3±4.4	27.1±5.1	1.00	0.3 to 1.7	91.0/6.3/2.7	Likely beneficial	368
SLJ (m)	1.7±0.2	1.8±0.2	0.50	-0.2 to 1.2	84.7/13.9/1.4	Likely beneficial	388
MKD (m)	25.0±4.6	29.5±5.4	0.90	0.2 to 1.6	90.4/7.1/2.5	Likely beneficial	369

COD: change of direction; ICoDT: Illinois change of direction test; CMJ: countermovement jump; SLJ: standing long jump; RSI: reactive strength index; MKD: maximal kicking distance.

Table 4: Between-group effect sizes, confidence limits, likelihood effects and odds ratios for performance data

Variable	Mean difference	Effect size	Confidence limits	Chances (%) Unloaded is beneficial / Similar / Loaded is beneficial	Effect description	Odd ratio of benefits to harm
ICoD test (s)	0.00	0.00	-0.6 to 0.6	0.0/100.0/0.0	Most likely similar	0
Modified 5-0-5 CoD test (s)	-0.09¥	0.61	0.0 to 1.2	1.9/11.5/86.9	Likely beneficial	409
5-m sprint (s)	-0.02£	1.00	0.4 to 1.6	90.8/6.7/2.5	Likely beneficial	378
10-m sprint (s)	0.00	0.00	-0.6 to 0.6	0.0/100.0/0.0	Most likely similar	0
20-m sprint (s)	0.00	0.00	-0.6 to 0.6	0.0/100.0/0.0	Most likely similar	0
CMJ (cm)	0.53¥	0.09	-0.7 to 0.5	0.0/96.5/3.5	Very likely similar	6442
SLJ (m)	0.08¥	0.50	0.1 to 1.1	1.2/14.6/84.2	Likely beneficial	434
MKD (m)	3.32¥	0.57	0.1 to 1.2	1.5/12.4/86.2	likely beneficial	416

¥ Mean difference in favor of the loaded plyometric jump group; £ Mean difference in favor of the unloaded plyometric jump group

COD: change of direction; ICoDT: Illinois change of direction test; CMJ: countermovement jump; SLJ: standing long jump; RSI: reactive strength index; MKD: maximal kicking distance.

