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High-load strength training reduces injury incidence and injury burden and improves physical fitness in young highly-trained soccer players

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2 Running title: Strength training to reduce injuries

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28 manuscript.

29

30 This study demonstrated the beneficial effects of a 12-week high-load strength training
31 program on injury incidence, injury burden and physical fitness, in highly-trained soccer
32 players.

33 **Abstract**

34 **Background:** There is little available information on the reduction of injury incidence
35 and injury burden after strength training programs. Therefore, this study aimed to analyze
36 the effects of a 12-week high-load strength training program on injury incidence, injury
37 burden, and fitness in young highly-trained soccer players.

38 **Hypothesis:** We hypothesize that well-targeted high-load training focused on the gluteal
39 and hamstring musculature could aid in injury prevention and increase physical fitness.

40 **Study Design:** A randomized-controlled trial design was applied, which followed the
41 CONSORT Statement.

42 **Level of Evidence:** Level 2.

43 **Methods:** Twenty players were randomly assigned to the experimental group (EG, n =
44 10 players), which performed a high-load strength training program, or to the control
45 group (CG, n = 10 players), which performed only their usual soccer training. Injury
46 incidence (injuries / 1000 h exposure) and injury burden (days of absence / 1000 h
47 exposure) were recorded during the intervention, as well as the physical fitness attributes
48 before and after the training program

49 **Results:** A significant ($p < 0.05$) lower injury incidence was observed in the EG (CG:
50 11.34 vs. EG: 1.31 injuries/1000 h of exposure) and a significant ($p < 0.001$) lower injury
51 burden in the EG (CG: 304.66 vs. EG: 19.72 days of absence/1000 h of exposure). The
52 ANCOVA model revealed significant between-group differences favoring the EG,
53 showing significantly greater improvements in jumping, change of direction ability,
54 sprinting, and imbalance strength tests ($p < 0.001$; ES = 3.02 to -7.23).

55 **Conclusions:** This study demonstrated the beneficial effects of a 12-week high-load
56 strength training program on injury incidence, injury burden and physical fitness, in
57 highly-trained soccer players.

58 **Clinical Relevance:** This study provides positive information for implementing this type
59 of strength training in the daily training sessions of young soccer players for both
60 performance enhancement and injury prevention.

61 **Keywords:** Football, strength, injury severity, hypertrophy training, health.

62 **Introduction**

63 Soccer is a highly demanding team sport which requires the execution of repetitive
64 high-intensity neuromuscular actions (e.g., jumps, accelerations, changes of direction and
65 sprints) to obtain adequate on-field performance^{14,36,57}. Developing these actions at early
66 ages can play a part in determining the chance of players proceeding to higher
67 achievement levels³². This raises the question of the most effective training strategies to
68 improve key physical determinants of soccer. However, it is also necessary to consider
69 that the relationships between training/match demands and the risk of injury²². Major
70 concerns resulting from injuries include acute or chronic alterations in health and the
71 inability to compete during the absence and rehabilitation period^{19,33}. For this reason,
72 injuries have become a relevant topic of investigation^{3,26}. Regarding non-elite soccer
73 players, some authors have noted injury rates ranging from 6.2 to 12.4 injuries per 1000
74 hours of exposure, with severe injuries (i.e., more than 28 days of absence) accounting
75 for approximately 12-18% of injuries^{4,43}. Moreover, other authors showed an injury
76 burden of 15.6 days of absence/1000 h of exposure for semiprofessional soccer players
77⁴³. Thus, it should be a priority to establish training strategies to reduce the injury
78 incidence and injury burden in soccer players.

79 The implementation of a strength training program, using intensities of 70-80%
80 of maximal effort, is a strategy employed to enhance performance and reduce the risk of
81 injury, as investigated in several studies examining its efficacy in soccer players^{7,42}.
82 Similarly, a recent study has shown that strength training with near to maximal loads (i.e.,
83 >85% 1RM) has beneficial effects on increasing physical fitness attributes and decreasing
84 the incidence and burden of injury¹⁸. Considering that most non-contact injuries in soccer
85 are due to a lack of strength in the posterior chain of the lower body (e.g., gluteus medius
86 and hip abductors), which hinders proper load production and absorption during sports

87 actions by these muscle groups ²¹, it seems relevant to implement strength training
88 programs focused on this musculature

89 High-load strength training improves coordination between motor units and the
90 muscle innervated by them ⁵², and increases muscle fascicle length ^{8,9}. This improved
91 coordination and muscle activation causes type IIa fibers (intermediate twitch fibers) to
92 act like myosin heavy chains ^{10,46}. In addition, these fibers are known to have a lower
93 stretching capacity, to fatigue more easily and to have a higher viscosity due to their
94 morphological characteristics ⁸. Therefore, due to all these improvements, there could be
95 less muscle fatigue and a consequent reduction in the number of musculotendinous
96 injuries ⁵⁶. Previous research has shown promising results in sports performance after the
97 application of strength training programs with split-based exercises, improving both
98 eccentric strength in the hamstrings, sprints and jump performance ³⁰. Other authors have
99 observed an increase in vertical jumping and sprinting abilities after a squat strength
100 training program over 8 weeks in under-19 male soccer players ¹⁶. However, it seems
101 necessary to analyze in greater depth the benefits of applying a specific high-load strength
102 training program in isolation on the injury profile of soccer players as well as injury
103 incidence and burden.

104 Most previous studies ^{5,24,45} have examined the improvements in physical
105 performance, but there is limited knowledge about the benefits of high-load strength
106 training in reducing both injury incidence and injury burden. So, this study aimed to
107 analyze the effects of a 12-week high-load strength training program on injury incidence,
108 injury burden, and physical fitness attributes in highly-trained soccer players. The
109 hypothesis was there would be an improvement in physical performance in highly-trained
110 soccer players after the application of various high-load strength-oriented training
111 programs ^{5,45}. Also, considering the relevance of resistance training programs to reduce

112 injuries ⁴⁷, another hypothesis was that this type of training could aid in reducing injury
113 incidence and burden.

114

115 **Methods**

116 **Subjects**

117 Twenty young highly-trained male soccer players voluntarily participated in this
118 study. An a priori power calculation was not performed because this study enrolled a
119 sample derived from one team ⁶. This allowed the researchers to evaluate the impact of a
120 training program vs. a control limiting the confounding factors such as different coaches,
121 different training regimes, players' levels, etc. The players belonged to the same team and
122 competed in the “Division de Honor” under 18 Spanish National League. Participants
123 were randomly assigned to the control group (CG, n = 10, age: 17.7 ± 0.5 years, stature:
124 177.6 ± 7.8 cm, body mass: 68.6 ± 8.4 kg, body mass index (BMI): 21.7 ± 1.3 kg·m⁻²),
125 and to the experimental group (EG, n = 10, age: 17.5 ± 0.7 years, stature: 174.9 ± 4.3 cm,
126 body mass: 66.7 ± 4.3 kg, BMI: 21.8 ± 1.0 kg·m⁻²). Both groups were composed of four
127 defenders, four midfielders and two attackers. Participants who sustained injuries at the
128 commencement of the investigation were omitted from the study (n = 4). The EG
129 performed high-load strength training in addition to their regular soccer training routine,
130 while the CG players only performed their regular soccer training with the team. During
131 the intervention period, the players completed a recovery/compensatory session of 90
132 minutes duration and three soccer-acquisition training sessions, each lasting
133 approximately 90 minutes, resulting in a total training time of 270 minutes per week and
134 one official match at the weekend. These acquisition training sessions (i.e., microcycle)
135 aimed, in this order, to recover (i.e., starters) from match demands or to compensate (i.e.,
136 non-starters) the match stimuli, tension day (i.e., priority of small spaces, using positional

137 and small-side games), endurance day (i.e., focused in large spaces, using positional and
138 large-side games) and speed day (i.e., finding speed stimuli, using tactical drills, strategy
139 and speed training situations). The players were accustomed to resistance training;
140 however, until the implementation of this study, load orientation was not a relevant factor
141 in the prescription of resistance training. All the players met the inclusion criteria ensuring
142 a minimum of 80% of the strength training sessions (including both soccer and strength
143 sessions) throughout the 12-week period and to be free of injuries the month preceding
144 the investigation (Figure 1). Goalkeepers were not selected for the study due to their
145 special role. Participants were provided detailed information regarding the advantages,
146 procedures, and potential risks of taking part in the study. Also, they signed the informed
147 consent form prior to the start of the investigation. The study was conducted according to
148 the Declaration of Helsinki (2013), and the protocol received approval from the ethics
149 committee of Valladolid East Health Area (Code PI 22-2793 NO HCUV).

150 ***Figure 1 near here***

151 **Design**

152 To examine the effect of 12 weeks of a high-load strength training program on
153 lower limb injuries (e. g., incidence and burden) and physical fitness attributes, a
154 randomized-controlled trial design was applied, which followed the CONSORT 2010
155 Statement⁵¹. During the in-season period (i.e., from February to April) the soccer players
156 in the experimental group (EG) completed a 12-week strength training program alongside
157 their regular soccer training regimen. The participants performed some physical testing
158 sessions before (Pre) and after the training intervention (Post) on three separate days
159 within the same week. On the initial day, the 505 change of direction ability test (505-
160 CODA test) and linear sprints over distances of 10-, 20-, and 40-m were executed. After
161 a 48-hour rest period (second day), the countermovement jump (CMJ), squat jump (SJ)

162 and repeated sprint ability (RSA) test were carried out in this order. Lastly, on the third
163 day, following another 48-hour rest, isometric strength exercises were performed
164 following this order: hamstring dominant (ISOHAMSd) and non-dominant
165 (ISOHAMSnd), quadriceps dominant (ISOQUAd) and non-dominant (ISOHAMSnd),
166 abductor dominant (ISOABDd) and non-dominant (ISOABDnd), and adductor dominant
167 (ISOADDd) and non-dominant (ISOADDnd) limbs. For jumps, the 505-CODA test and
168 speed assessments, a specific warm-up comprised running and joint mobility exercises
169 lasting 10 minutes. In contrast, isometric strength tests involved a dedicated 15-minute
170 warm-up, incorporating the five exercises developed for the test. This warm-up was
171 executed at an intensity ranging from 40–60% of 1RM (repetition maximum), involving
172 two sets of each exercise (comprising 10 to 15 repetitions) with a rest interval of 30–60
173 seconds between sets. The performance laboratory was used to measure jump testing and
174 isometric strength. The laboratory was maintained at a temperature of 18°C with a relative
175 humidity of 60-70%. The assessment of the 505-CODA test, sprints, and RSA took place
176 on an artificial grass field where the team usually trained. During these tests, players wore
177 their own soccer boots. All testing occurred in the afternoon, specifically between 5-7
178 pm. To ensure consistency, players were instructed to have their last meal three hours
179 before the start of the tests and to abstain from consuming caffeinated beverages or
180 engaging in intense physical exercise. Throughout the protocols, a strength and
181 conditioning specialist supervised the tests and provided verbal encouragement⁴⁸. The
182 intervention was focused on high-load strength training. The strength sessions occurred
183 on two non-consecutive days weekly (Tuesdays and Thursdays at 18:00 h), lasting
184 approximately 45-50 minutes. These sessions were scheduled after the conclusion of the
185 regular soccer training sessions^{34,37}.

186

187 **Procedures**

188 **High-load strength training**

189 A total of 24 sessions were completed for the high-load strength training by the
190 EG, ensuring a minimum of two rest days between each session before proceeding to the
191 post-tests. Prior to each strength session, a tailored warm-up routine was undertaken,
192 involving the execution of the five exercises used in the intervention period. The selected
193 exercises included: hip thrust with a barbell; Bulgarian split squat on a Multipower
194 machine; clamshell with elastic band (TheraBand); split with external hip rotation; and
195 Bulgarian split squat on Bosu. All exercises used free weights (barbell and dumbbells),
196 except the exercise performed with an elastic band. The exercises were incorporated into
197 circuit training sessions with intensities and repetitions shown in Table 1.

198 A submaximal and modified protocol was employed to determine the 1RM in
199 free-weight exercises⁴¹. Initially, players selected a weight for 8–10 repetitions, allowing
200 3 minutes for recovery. Subsequently, they increased the load to perform one set of 5–6
201 repetitions, with a 5 min rest period. Finally, the load was increased once more for one
202 set of 3–4 repetitions. An estimated calculation of 1RM was then derived using the
203 formula proposed by O'Connor et al.⁴¹ ($1RM = \text{Weight lifted in kilograms} \times [1 + 0.025$
204 $\times n \text{ repetitions}]$), and corresponding training percentages were computed for each player.
205 To calculate the intensity in the Clamshell exercise (performed with an elastic band), the
206 "TheraBand Manual" was used as a reference and the intensity was increased by
207 modifying the resistance of the bands from blue to black^{2,38}.

208 ***Table 1 near here***

209 **Measures**

210 *Injuries.* Throughout the 12-week intervention, records were maintained for the
211 number, mechanism, type, body region, muscle structure, time, and duration of injuries,

212 as well as lower extremity load. The Union of European Football Associations (UEFA)
213 model criteria ²⁵ guided the data collection. Lower extremity injuries were diagnosed and
214 documented by the medical staff. Treatment and recovery follow-up were overseen by
215 the medical team. An injury was defined as "an injury occurring during a scheduled
216 training session or match that caused absence from the next training session or match" ²⁵.
217 Subsequently, incidence rate ²⁸, injury incidence (injuries / 1000 h exposure) and injury
218 burden (days of absence / 1000 h exposure) were calculated, with the latter defined as
219 "the number of days lost per 1000 h of exposure" ³. Exposure was determined based on
220 the time (in hours) spent in training and matches, and the incidence rate referred to the
221 number of injuries sustained during both practice settings per 1000 h of exposure ⁵⁰. A
222 player was deemed fully recovered post-injury when cleared by the medical staff for full
223 participation in team training and matches ⁴⁷.

224 *Vertical jump performance.* The soccer players executed a bilateral CMJ, CMJ
225 with the dominant (CMJd) and non-dominant (CMJnd) leg, and a bilateral SJ ¹¹.
226 Dominant leg determination criteria were based on each player's soccer ability (i.e.,
227 kicking leg) ²⁹. The CMJ involved a flexion-extension of the hips and knees at the highest
228 velocity, reaching a maximum knee flexion angle of 90°, and keeping hands on the hips.
229 The SJ was performed with hands on the hips, a straight trunk, and executing a maximum
230 vertical jump from the 90° knee flexion position, without any rebound or
231 countermovement. For all jumps, two attempts were made, and the best one was selected
232 for further analysis, with a 1 min rest between attempts. Jump height (cm) was measured
233 using a contact platform (Optojump Next, MicrogateTM, Bolzano, Italy), calculated as h
234 $= gt^2/8$ (where h = height in cm, g = acceleration due to gravity $9.81 \text{ m}\cdot\text{s}^{-2}$, and t = flight
235 time in seconds of the jump) ²³. The intraclass correlation coefficient (ICC) values for

236 CMJ, CMJd, CMJnd, and SJ were 0.986, 0.975, 0.935, and 0.906, respectively. The
237 coefficients of variation (CV) were in the range of 2.82-5.57% for all jumping measures.

238 *Change of direction ability (CODA).* To assess CODA, the players carried out the
239 505-CODA test. The test involved an acceleration run from the starting line to the first
240 marker at 10 m, followed by a 5-m sprint to the second marker (positioned 15 m from the
241 starting line). Subsequently, a 180° change of direction was executed, followed by a 5 m
242 sprint back past the first marker (placed 10 m from the starting line) ⁵³. Timing was
243 recorded using a photocell (Polifemo, Microgate™, Bolzano, Italy) positioned over the
244 start/finish line. Each player performed two attempts to turn with each leg (dominant:
245 505-CODAd; non-dominant: 505-CODAnd), and the best result was selected. A 2-minute
246 rest interval was observed between attempts. The ICC values for CODA tests were 0.858-
247 0.878, and the CVs were 2.46-2.61%.

248 *Linear test sprints.* The soccer players performed a 40 m linear sprint, with splits
249 at 10 (SPR10), 20 (SPR20), and 40 m (SPR40) distances ⁴⁰. The sprint commenced 0.5
250 m before the starting point. Three attempts were made, and the fastest time was selected.
251 A 4 min rest period was implemented between sprints, and players received verbal
252 encouragement to achieve optimal performance. Four photoelectric cells (Polifemo,
253 Microgate™, Bolzano, Italy) measured the sprint times. The ICC values for SPR10,
254 SPR20 and SPR40 were 0.930, 0.954 and 0.968, respectively. The CVs were in the range
255 of 0.64-1.60% for all sprint tests.

256 *Repeated Sprint Ability (RSA 5 x 30 m).* Each player completed five sprints of 30
257 m at maximum speed with 25 s of recovery between each sprint ⁵⁵. The starting point for
258 the sprints was 0.5 m before the start. Sprint times were measured using two photoelectric
259 cells (Polifemo, Microgate™, Bolzano, Italy) positioned at 0 m and 30 m distances, and
260 the total time for the five sprints (RSA_{total}) was calculated.

261 *Isometric Strength.* The soccer players engaged in isometric strength contractions
262 lasting 5 s for the quadriceps, hamstrings, hip abductors, and hip adductors. A previously
263 validated dynamometer (Carp Spirit Water Queen Digital Scale 50, BIODEX System Pro
264 4TM, System 4 advance v.4.2, New York, USA) ⁴⁹, was used measure isometric strength.
265 For ISOHAMSd and ISOHAMSnd, players sat on the stretcher with the knee fixed at 90°
266 flexion, performing knee flexion against the dynamometric tape ¹⁸. ISOQUAd and
267 ISOQUAnd involved players seated on the stretcher with the knee completely fixed at
268 90° flexion, performing knee extension against the dynamometric tape. ISOABDd,
269 ISOABDnd, ISOADDd, and ISOADDnd required players to be supine with the knee fully
270 extended and the hip neutral, performing hip abduction and adduction against the
271 dynamometric tape while keeping the knee fully extended. Two attempts were made with
272 each leg, and the best result was chosen for analysis. A 1-minute rest occurred between
273 attempts, with verbal encouragement given to maximize force. The ICC values were in
274 the range of 0.994-0.997, and the CVs were 0.87-1.74% for all isometric strength tests.

275 Statistical Analysis

276 Data are reported as mean \pm standard deviations (SD). Normality of data
277 distribution and homogeneity of variances were assessed using the Shapiro-Wilk test and
278 Levene test, respectively. Metrics related to lower extremity injuries, including incidence
279 and burden, are presented as the number per 1000 hours of exposure and the number of
280 absence days per 1000 hours of exposure, each accompanied by 95% confidence intervals
281 (CI). Rate ratios (RR) with 95% CI and Z-tests ³¹ were computed to assess between-group
282 differences (i.e., EG and CG) in lower extremity injury incidence and burden. Parametric
283 tests were used for all the variables analyzed and independent t-tests were employed to
284 assess initial differences at the pre-intervention stage. An analysis of covariance
285 (ANCOVA) was conducted to identify potential training effects, with baseline values

286 treated as covariates ⁶. Within-group pre-to-post differences were evaluated using paired-
287 samples t-tests. Cohen's d effect size (ES) ¹⁵ was calculated to assess practical
288 significance, with results interpreted as small ($0.00 \leq d \leq 0.49$), moderate ($0.50 \leq d \leq$
289 0.79), and large ($d \geq 0.80$). Data analysis was conducted using the Statistical Package for
290 the Social Sciences (SPSS™ Inc, version 27.0 for IOS, Chicago, IL, USA). The
291 significance level for all analyses was set at $p < 0.05$.

292 **Results**

293 Table 2 shows the characteristics of injuries in total, for the CG and EG. Eight
294 injuries were suffered during the intervention period of the study, with seven belonging
295 to the CG and one to the EG. A total of seven muscle-tendon injuries were reported in
296 CG, of which six were muscle injuries (two hamstring muscle injuries, two hip adductor
297 injuries, one hip flexor injury, and one quadriceps injury), and one was a ligamentous
298 injury to the medial collateral ligament. As such, injured players suffered 188 absence
299 days. The maximum absence days was 58, and the minimum was 18 absence days. In
300 contrast, the EG experienced only one musculoskeletal injury, leading to 15 absence days.
301 In the EG, only one player, suffered an injury throughout the 12-week intervention period.
302 Examining the distribution of injuries over time, five injuries occurred in weeks 1–6 (four
303 in the CG and one in the EG), while three injuries were reported in weeks 7–12 (all in the
304 CG, with none in the EG).

305 ***Table 2 near here***

306 Regarding the injury profile, significant ($p < 0.05$) higher injury incidence (CG:
307 11.34 vs. EG: 1.31 injuries/1000 h of exposure, RR = 8.63; 95% CI = 1.06-70.12) and
308 significant ($p < 0.001$) higher injury burden (CG: 304.66 vs. EG: 19.72 days of
309 absence/1000 h of exposure, RR = 15.45; 95% CI = 9.13-26,14) were observed in the CG
310 compared to the EG.

311 Table 3 presents the alterations in physical fitness attributes following the 12-
312 week intervention period. There were no initial differences between groups in any
313 variable. The ANCOVA model revealed significant between-group differences ($p <$
314 $0.001-0.02$) favoring the EG in most physical fitness attributes and imbalance variables.
315 The EG demonstrated improvements from pre- to post-training in most physical fitness
316 attributes ($p < 0.001-0.024$; $ES = 1.57$ to -7.23 , large).

317 ***Table 3 near here***

318 Discussion

319 This study analyzed the effects of a 12-week high-load strength training program
320 on injury incidence, injury burden and physical fitness attributes in highly-trained soccer
321 players. Given the limited scientific evidence on high-load strength training and injury
322 prevention, this study examined both the performance improvements resulting from this
323 type of training and its potential impact on reducing injury incidence and burden
324 throughout the season. It found that players in the CG experienced higher injury incidence
325 (~10 injuries/1000 h of exposure) and burden (~285 days of absence/1000 h of exposure)
326 compared to those in the EG. Additionally, the EG showed greater improvements (~2-
327 15%) in all the assessed physical fitness attributes. Therefore, the proposed high-load
328 strength training program can be suggested as an effective way to reduce injuries (i.e.,
329 incidence and burden) as well as to improve the physical fitness level of the participants.

330 Prior studies have revealed that the application of strength training programs could
331 lead to the reduction of the number of injuries^{47,54} and the improvement of physical
332 fitness⁵⁰. However, few investigations have analyzed the effect of strength training
333 programs with high-load orientation on risk of injury and physical fitness levels⁵. In our
334 study, the EG players suffered a significantly lower injury incidence compared to those
335 in the CG (i.e., EG: 1.31 vs. CG: 11.34 injuries/1000 h of exposure). Additionally, the

336 EG players had a significantly lower injury burden in comparison to their counterparts in
337 the CG (i.e., EG: 19.72 vs. CG: 304.66 days of absence/1000 h of exposure). Although
338 not directly measured, we speculate that these results might be attributed to the benefits
339 of strength training programs with a high-load orientation, which enhances coordination
340 between motor units and the muscle they innervate ⁸, as well as increases in muscle
341 fascicle length, mainly due to eccentric work ^{35,58}. Regarding the period of injuries, the
342 majority occurred during weeks 1-6. The EG suffered only one injury during weeks 1-6
343 (compared to four injuries in the CG) and none during weeks 7-12 (compared to three
344 injuries in the CG). So, it seems that the program was also effective during weeks 1-6.
345 This aspect is particularly relevant as it highlights that the intervention program had
346 positive effects in reducing injuries, even during the initial weeks.

347 It is worth noting that the five strength exercises performed in this study primarily
348 targeted the activation of the gluteus medius, gluteus maximus, and hamstrings ^{1,17}.
349 Recent studies have highlighted the significance of lumbo-pelvic muscle function in
350 preventing and treating hamstring injuries, demonstrating the correlation between gluteus
351 medius activation and strength during running and the occurrence of hamstring injuries
352 ²¹. It is crucial to emphasize the role of the gluteus medius and maximus in specific soccer
353 tasks such as jumps and changes of direction. Some authors have revealed the
354 electromyographic activation of over 80% in these two muscles during various types of
355 jumps, including the crossover jump, hurdle jump, and split jump ²⁷. Additionally,
356 research has shown that besides enhancing jumping performance, there is also a notable
357 improvement in reducing the knee valgus angle by up to 60% ²⁰. These improvements
358 could potentially aid in preventing major knee injuries such as patellofemoral pain
359 syndrome or anterior cruciate ligament injuries ²⁰. Moreover, it is believed that a
360 significant proportion of hamstring injuries occur during the eccentric phase of the

361 movement³⁰. Exercises like splits have been shown to enhance both eccentric strength in
362 the hamstrings and power in sprints and jumps³⁰.

363 By enhancing the physical fitness of soccer players, improvements can be seen in
364 actions such as sprints, jumps and changes of direction, thereby boosting overall
365 performance. The players in the EG demonstrated improvements in all the physical fitness
366 tests conducted. These findings are consistent with previous studies following the
367 application of various high-load strength-training programs^{5,24}. Additionally, our
368 findings are consistent with those of Barjaste and Mirzaei⁵, who demonstrated that high-
369 load strength training (i.e., loads between 70-85% of 1RM) led to improved maximal
370 strength (1RM) and vertical jump, in semi-professional soccer players. Furthermore,
371 Griffiths et al.²⁴ observed significant improvements in strength, sprint speed, and jump
372 height in young soccer players following high-load training. This could be attributed to
373 the development of tendons with greater stiffness and thickness, leading to increased
374 power and maximum strength⁴⁴. Moreover, strength training targets the physical aspects
375 that determine the speed of CODA, such as muscle strength and power^{13,60}. It is worth
376 noting that different CODA actions are either force or velocity oriented, depending on
377 approach speed and the angle of change. Modest CODA angles (<90°) are more speed-
378 oriented, whereas angles higher than 90° are more strength-oriented¹². Thus, high-load
379 strength-training may be more beneficial for improving strength-oriented CODA (> 90°),
380 as observed in this study. Moreover, significant differences ($p < 0.001$) in the percentage
381 change in fitness tests between the EG and CG were observed in this study, with the EG
382 players experiencing fewer and less severe injuries and greater improvements in physical
383 fitness tests. Therefore, future studies focusing on high-load strength training and its
384 effects on physical abilities and injury reduction would be valuable to corroborate and
385 complement these findings.

386 This study has some limitations that warrant consideration. The main limitation is
387 the difference in overall training load between the EG and CG, since the EG included
388 additional strength training without reducing the regular soccer training. This may
389 suggest that the fact of having a greater stimulus than the CG is enough to have some
390 specific physical adaptations. Secondly, the generalizability of the results may be limited
391 to young, highly-trained players; however, most soccer players are not professionals,
392 therefore, we believe that this study has great ecological validity. Third, the study was
393 conducted with a single team, and therefore, the unique characteristics of that team may
394 have influenced the outcomes; however, this is at the same time an advantage because the
395 technical and tactical elements of the training were controlled (and so no other
396 confounding factors were added to the study). Finally, this study has not provided
397 information on whether the EG were protected against injury long-term because only
398 injuries sustained during the intervention period were registered. To address these
399 limitations, future studies could consider the following: (1) implementing this training
400 program across a larger number of teams of different competitive levels to assess its
401 effectiveness; (2) extending the study period to quantify injury incidence and injury load
402 over the entire season, providing a more comprehensive understanding of the long-term
403 effects of the training program; (3) exploring the effects of high-load training at different
404 periods during the season to determine optimal timing for implementation; (4) equating
405 training load (e.g., soccer exposure) between the CG and EG, thus eliminating training
406 time as a confounding factor (the groups should have similar training and competition
407 load); and (5) recording injuries over a longer period to examine the long-term effect of
408 preventive programs.

409 **Conclusion**

410 The implementation of a 12-week high-load strength training program in addition to
411 the usual training within regular soccer training showed reductions in injury incidence
412 and injury burden in the young soccer players participating in this study. Additionally,
413 this type of training demonstrated improvements in all physical fitness attributes, such as
414 jumping ability, CODA, sprinting, RSA and isometric strength. Overall, it may be
415 positive to implement this type of strength training in the daily training sessions of young
416 highly-trained soccer players for both performance enhancement and injury prevention.

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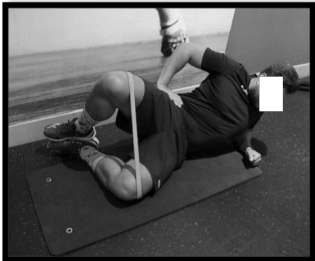


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Table 1. Types of exercises, volume, intensity, and recovery time for the 12-week intervention strength training period.

Exercise	Temporal sequence	Series	Repetitions	Rest between sets
<p>Hip thrust</p> 	<p>W1-2: 70% 1RM W3-4: 75% 1RM W5-7: 80% 1RM W8-12: 85% 1RM</p>	3	<p>W1-2: 10 Rep. W3-4: 10 Rep. W5-7: 8 Rep. W8-12: 6 Rep.</p>	2 min
<p>Bulgarian split squat Multipower</p> 	<p>W1-2: 70% 1RM W3-4: 75% 1RM W5-7: 80% 1RM W8-12: 85%1RM</p>	3	<p>W1-2: 10 Rep. W3-4: 10 Rep. W5-7: 8 Rep. W8-12: 6 Rep.</p>	2 min
<p>Clamshell</p> 	<p>Blue elastic band Blue elastic band Black elastic band Black elastic band</p>	3	<p>W1-2: 10 Rep. W3-4: 10 Rep. W5-7: 8 Rep. W8-12: 8 Rep.</p>	2 min
<p>Split external hip rotation</p> 	<p>W1-2: 70% 1RM W3-4: 75% 1RM W5-7: 80% 1RM W8-12: 85% 1RM</p>	3	<p>W1-2: 10 Rep W3-4: 10 Rep W5-7: 8 Rep W8-12: 6 Rep</p>	2 min
<p>Bulgarian Split Squat Bosu</p> 	<p>W1-2: 70% 1RM W3-4: 75% 1RM W5-7: 80% 1RM W8-12: 85% 1RM</p>	3	<p>W1-2: 10 Rep W3-4: 10 Rep W5-7: 8 Rep W8-12: 6 Rep</p>	2 min

Note. W: week; Rep.: repetitions; 1RM: 1 repetition maximum; min: minutes.

624 **Table 2.** The number of injuries, type, mechanism, region, structure, time of injury and absence time values of the control (CG) and experimental group (EG) players.

	Total	CG	EG
Injuries (n)	8 (100%)	7(87.5%)	1(12.5%)
Type of injury			
Muscular	6 (75%)	6 (75%)	0
Ligament	2 (25%)	1 (12.5%)	1 (12.5%)
Mechanism of injury			
Direct	1	0	1 (12.5%)
Indirect	4 (50%)	4 (50%)	0
Overuse	3 (37.5%)	3 (37.5%)	0
Body region			
Pubis	3 (37.5%)	3 (37.5%)	
Thigh	3 (37.5%)	3 (37.5%)	0
Knee	1 (12.5%)	1 (12.5%)	0
Ankle	1 (12.5%)	0	1 (16.7%)
Musculoskeletal structure			
Hamstrings	2 (25%)	2 (50%)	0
Quadriceps	1 (12.5)	1 (12.5%)	
Knee ligament	1 (12.5%)	1 (12.5%)	0
Adductors	3 (37.5%)	3 (37.5%)	0
Ankle ligament	1 (12.5%)	0	1 (12.5%)
Time and epoch			
Training session	3 (37.5%)	3 (37.5%)	0
Competition session	5 (62.5%)	4 (50%)	1 (12.5%)
W1-6	5 (62.5%)	4 (50%)	1 (12.5%)
W-7-12	3 (37.5%)	3 (37.5%)	0
Time of absence (days)			
Total	203 (100%)	188 (92.6%)	15 (7.4%)

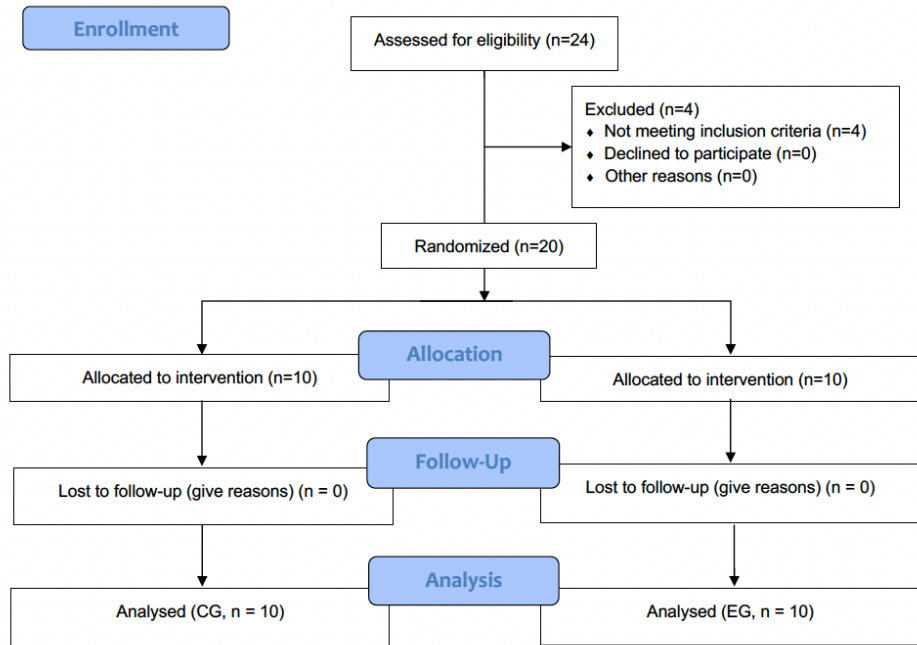
Note. %: the percentage values correspond to the percentage with respect to the total number of injuries.

Table 3. Changes in physical fitness attributes after the 12-week period intervention of control group (CG) and experimental group (EG).

Variables	CG					EG					Between-group differences	
	Pre	Post	%Diff	P	ES	Pre	Post	%Diff	p	ES	p	F
CMJ (cm)	37.00 ± 3.34	36.98 ± 3.39	-0.05	0.850	0.06	38.84 ± 2.28	41.33 ± 2.14	6.02	<0.001***	-7.23	<0.001***	248.19
CMJd (cm)	20.17 ± 3.02	20.15 ± 3.02	-0.10	0.832	0.07	22.78 ± 1.31	24.12 ± 1.03	5.56	<0.001***	-3.69	<0.001***	75.84
CMJnd (cm)	21.81 ± 2.24	21.62 ± 2.19	-0.88	0.252	0.39	22.30 ± 2.15	23.44 ± 1.90	4.86	<0.001***	-3.64	<0.001***	63.73
SJ (cm)	29.09 ± 3.57	28.92 ± 3.49	-0.59	0.113	0.56	31.64 ± 3.62	33.47 ± 3.45	5.47	<0.001***	-4.34	<0.001***	159.66
505-CODAd (s)	2.29 ± 0.08	2.28 ± 0.07	-0.44	0.259	0.38	2.19 ± 0.07	2.14 ± 0.06	-2.34	<0.001***	2.06	<0.001***	35.05
505-CODAnd (s)	2.32 ± 0.07	2.31 ± 0.06	-0.43	0.331	0.33	2.25 ± 0.08	2.17 ± 0.04	-3.69	<0.001***	2.02	<0.001***	37.85
SPR10 (s)	1.72 ± 0.06	1.72 ± 0.06	0.00	0.153	0.49	1.69 ± 0.05	1.62 ± 0.06	-4.32	<0.001***	2.37	<0.001***	28.07
SPR20 (s)	2.95 ± 0.11	2.95 ± 0.11	0.00	0.591	0.18	2.88 ± 0.09	2.81 ± 0.08	-2.49	<0.001***	2.16	0.002**	40.18
SPR40 (s)	5.29 ± 0.17	5.29 ± 0.17	0.00	0.405	-0.28	5.16 ± 0.13	5.06 ± 0.14	-1.98	<0.001***	3.02	<0.001***	51.69
RSAtotal (s)	21.46 ± 0.87	21.48 ± 0.85	0.09	0.219	-0.42	21.09 ± 0.47	20.58 ± 0.33	-2.48	<0.001***	1.57	<0.001***	31.68
ISOQUAd (kg)	40.82 ± 4.28	40.88 ± 4.11	0.15	0.677	-0.14	39.34 ± 3.27	42.52 ± 3.30	7.48	<0.001***	-5.46	<0.001***	169.08
ISOQUAnd (kg)	38.32 ± 4.10	38.64 ± 4.26	0.83	0.011*	-1.01	38.03 ± 4.84	42.17 ± 3.54	9.82	<0.001***	-1.86	<0.001***	35.89
ISOHAMSd (kg)	22.09 ± 2.16	22.19 ± 2.21	0.45	0.397	-0.28	22.20 ± 2.29	25.78 ± 2.48	13.89	<0.001***	-6.40	<0.001***	267.26
ISOHAMSnd (kg)	21.86 ± 2.22	21.90 ± 2.30	0.18	0.778	-0.09	21.78 ± 2.54	25.72 ± 2.26	15.32	<0.001***	-5.61	<0.001***	230.54
ISOABDd (kg)	30.59 ± 4.49	30.78 ± 4.39	0.62	0.041*	-0.76	28.15 ± 4.22	30.85 ± 3.76	8.75	<0.001***	-3.24	<0.001***	83.33
ISOABDnd (kg)	29.22 ± 3.92	29.48 ± 4.03	0.88	0.009**	-1.04	27.57 ± 4.38	30.60 ± 3.98	9.90	<0.001***	-2.11	<0.001***	32.31
ISOADDd (kg)	24.76 ± 2.94	24.76 ± 2.96	0.00	1.000	0.00	26.13 ± 2.99	29.41 ± 2.67	11.15	<0.001***	-7.04	<0.001***	359.12
ISOADDnd (kg)	23.94 ± 2.73	24.21 ± 2.90	1.12	0.060	-0.68	25.43 ± 1.56	29.43 ± 1.77	13.59	<0.001***	-3.22	<0.001***	69.02

Note. CMJ: counter movement jump; CMJd: dominant leg counter movement jump; CMJnd: non-dominant leg counter movement jump; SJ: squat jump; 505-CODAd: dominant leg change of direction ability; 505-CODAnd: non-dominant leg change of direction ability; SPR10: linear sprint in 10m; SPR20: linear sprint in 20m; SPR40: linear sprint in 40m; RSAtotal: repeated sprint ability total; ISOQUAd: dominant leg isometric strength in quadriceps muscles; ISOQUAnd: non-dominant leg isometric strength in quadriceps muscles; ISOHAMSd: isometric strength in hamstrings muscles in dominant leg; ISOHAMSnd: isometric strength in hamstrings muscles in non-dominant leg; ISOABDd: isometric strength in abductors muscles in dominant leg; ISOABDnd: isometric strength in abductors muscles in non-dominant leg; ISOADDd: isometric strength in adductors muscles in dominant leg; ISOADDnd: isometric strength in adductors muscles in non-dominant leg; %Diff: difference in percentage between groups; p = level of significance; ES: effect size. *p < 0.05, **p < 0.01 *** p < 0.001

627 **Figure legends**



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629 **Figure 1.** CONSORT diagram of participants' recruitment, allocation follow-up and analysis. CG: control group; EG: experimental Group.