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Comparative effects of single vs. double weekly plyometric training sessions on jump, sprint and COD abilities of elite youth football players

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Version: 1

Description: Figure 1

File format: application/pdf

1 Dear reviewer, thanks for your comments and for the time that you have dedicated
2 to this paper. My group and I have really appreciated your indications.
3

4
5 General comment (originality, scientific accuracy, strengths and/or weaknesses):
6 The study is very interesting and useful, providing practical and valuable
7 information for coaches and researchers. In general, it was well written, and
8 presents a good design. However, there are some important aspects that should be
9 improved before final acceptance.

10 Major corrections (main criticisms): Specific comments

11
12
13 Page 3, line 64: "It seems reasonable to investigate the effects of plyometric
14 training programs of different volume considering that, at elite level, a very limited
15 time can be
16 dedicated to specific physical development, especially throughout the season, due
17 to the
18 congested matches fixture (e.g. national and international tournaments) and
19 associated travels." Authors are correct with such statement, and it is reasonable to
20 study different volumes of plyometric training in soccer players. However, authors
21 should provide more consistent and detailed information about soccer specific
22 training content (i.e., type of training, volume, intensity), and physical fitness
23 training (apart from the plyometrics) during the interventional period. This
24 information is fundamental to help readers to better interpret/understand the results
25 of the study.
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30 Thanks for your indication. Authors added a table that reports a traditional training
31 routine during a week
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34
35 In addition, there is a great difference in terms of training volume between young
36 soccer players (U18) and adult soccer players. Authors stated that congested
37 fixtures could interfere in the plyometric training adaptations, probably due to the
38 concurrent (interference) training effects. It could be better explored to present the
39 rationale of the study. Please, see and consider the reference (s) below:
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41
42 Loturco, I., Pereira, L. A., Kobal, R., Zanetti, V., Kitamura, K., Abad, C. C. C., &
43 Nakamura, F. Y. (2015). Transference effect of vertical and horizontal plyometrics
44 on sprint performance of high-level U-20 soccer players. *Journal of sports
45 sciences*, 33(20), 2182-2191.
46

47
48 Loturco, I., Pereira, L. A., Kobal, R., Zanetti, V., Gil, S., Kitamura, K., ... &
49 Nakamura, F. Y. (2015). Half-squat or jump squat training under optimum power
50 load conditions to counteract power and speed decrements in Brazilian elite soccer
51 players during the preseason. *Journal of Sports Sciences*, 33(12), 1283-1292.
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1 **Thanks. We have improved the quality of the introduction using these papers.**
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4
5 Page 5, line 30: The players trained only 4 times per week and played once a week
6 (every Saturday). From a general perspective, this means that they had 2 rest days
7 per week. Therefore, this training volume is lower than those reported in previous
8 investigations performed with professional soccer players. Do the authors think
9 that this low training volume was responsible to the improvements observed in the
10 LPG performance? Perhaps with a more qualified group of players, training more
11 days per week (resulting in higher training volume, which is the reality of
12 professional soccer teams even in younger categories) just one plyometric training
13 session per week could not have been sufficient/adequate to elicit such adaptations.
14 Authors should present more details about the training content and discuss this
15 question accordingly.
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19 **Thanks. Done**
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21 Tests

22 Authors should provide more information about the testing procedures. Mainly for
23 jump and COD tests. Even that they are very popular in professional sport settings,
24 there are many different protocols for these tests, and specific mode detailed
25 characteristics of each tests should be provided.
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27

28 **Done.**
29

30 Statistical analysis

31 It is not clear why did the authors used a 90% confidence interval.

32 What was the significance level adopted?

33 Please, insert the effect sizes in the appropriate section of the manuscript.
34
35

36 **Thanks. Done.**

37 **Data were presented as mean \pm standard deviation (SD). Outcomes were expressed
38 as value, with 90% confidence interval (CI). Robust estimates of 90% CI and
39 heteroskedasticity were calculated using bootstrapping technique (randomly 1000
40 bootstrap samples) .24
41
42**

43 Results

44 Page 6, line 67: it is "table 1".

45 Part of the table 1 is missing, then it is not possible to fully interpret/understand the
46 results of the study.
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48 Figure caption should be placed below the figure.
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52 **Thanks for your comments. Every indication has been accepted. ES are reported in
53 table 2.**
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Minor corrections (page, paragraph, line where the author must make the corrections): Discussion

In general, the discussion is well structured and organized. The authors should extend the questions related to the “transference effects” of plyometric training to specific soccer performance, including short-accelerations, and jump & COD tasks (page 8 – line 34). This is conceivably the most important benefit of plyometric exercises for soccer players’ performance. (Please, see the reference above by Loturco et al.)

Page 8, line 21: It is difficult to understand why authors think that only the “gender” is a limitation of the study. Wider generalization of the findings cannot be extended even for soccer players with higher volumes of training and matches (e.g., senior soccer players). Authors should revise and extend this specific part of the manuscript.

Conclusions

In my opinion, the authors should not use the findings of this study to recommend training strategies for senior soccer players. I can guarantee that senior soccer players who compete “at the top-level” are not able to improve their speed-power capacities performing only one plyometric training session per week. Certainly, this population depends on greater training frequencies to improve their neuromuscular performance.

Thanks for your comments. Every indication has been accepted.

Introduction

In football, the requirement for frequent changes in the type of movements (e.g., walking, running, sprinting, jumping, tackling), speed (e.g., accelerations, decelerations), direction, and technical tasks features the activity profile as intermittent in nature¹⁻³. Briefly, high-intensity running and sprint-type activities are considered to be crucial determinants for successful performance⁴. Previous analyses showed that outfield football players cover distances of between 10 and 13 km during the matches³. Of these, 8% to 12% were represented by high-intensity running or sprinting, with inter-player differences occurring due to the

1 specific playing role ³. Based on the multifaceted nature of physical requirements in football,
2
3 several methods have been developed to improve players' fitness parameters such as
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5 endurance, strength, power and speed ^{5,6}.
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8 During a football match, muscle power and strength are critical physical factors for
9
10 successful participation ^{2,7}. Plyometric activities are widely implemented as training
11
12 methodology for enhancing functional sports performance ⁸. Plyometric training generally
13
14 involves bounding exercises (e.g. multiple jumps), as well as high-impact exercises (e.g. drop
15
16 jumps) ⁹⁻¹¹. Previous studies found that a combination of vertical and horizontal plyometric
17
18 exercises offer practical advantages compared with methods that involve a single directional
19
20 component (e.g. only vertical or horizontal jumps) ^{6,12}. These conditioning activities, eliciting
21
22 improvements of the mechanical muscle properties (i.e. strength, power and rate of force
23
24 development) that cover a great functional role for most of the demanded movements of a
25
26 football match, which may have a critical impact of the match physical performances such as
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28 sprinting, change of directions (COD), side cutting, throwing and fights situations ^{4,10,13-15}.
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32 The literature suggests that the plyometric training effects may depend on several key
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34 variables, including: the volume, the frequency, and the duration of the protocol, as well as the
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36 period of the season and the subjects' fitness characteristics ¹⁶⁻¹⁸. Training variables
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38 management has a critical impact on players' fitness adaptations that occur in elite youth
39
40 football players ¹⁹. However, despite the popularity and wide appeal of plyometric training,
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42 few published studies have employed a randomised trial design involving elite young players.
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44 Although several studies have analysed the plyometric training-induced effects with a
45
46 frequency of 2-3 times a week (effect size (ES) from 0.26 to 2.8), few of them provided
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48 evidences supporting an equal efficiency of similar training programs implementing lower
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50 training frequency such as one training session a week ¹⁰. It seems reasonable to investigate
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52 the effects of plyometric training programs of different volume considering that, at elite youth
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1 level, a very limited time can be dedicated to specific physical development due to the
2
3 congested matches fixture (e.g. national and international tournaments) and associated travels
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5 20.
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7 To date, evidences about the effect of a single plyometric session a week are limited,
8
9 and few are the randomised trial involving elite young players ^{21,22}. Moreover, no data are
10
11 available regarding comparisons between the magnitude of the effects of a single plyometric
12
13 session a week compared with a higher training volume (twice a week). Therefore, the aim of
14
15 this study was to compare the effects of two 8-week plyometric training programs including
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17 either a single or two sessions a week, on the on jump, sprint and COD abilities of young elite
18
19 football players during the pre-season period.
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22 23 24 **Methods**

25 *Participants*

26
27 Twenty-three youth football players (elite academy, Switzerland) were considered
28
29 during the enrolment process. Only outfield players were included (two goalkeepers were
30
31 excluded). Therefore, twenty-one participants were included in the current study (mean \pm SD;
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33 age 17 ± 0.8 years, weight 70.1 ± 6.4 kg, height 177.4 ± 6.2 cm). All participants were informed
34
35 about the potential risks and benefits of the study and signed an informed consent (parental
36
37 consent has been given). The Ethics Committee of the Department of Science and Technology,
38
39 University of Suffolk (UK) approved this study. All procedures were conducted according to
40
41 the Declaration of Helsinki for human studies.
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48 *Design*

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50 This study used a randomised pre-post parallel group trial design. The randomisation
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52 was performed according to a computer-generated sequence. The participants were then
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1 assigned to either a low-volume plyometric training group (LPG = 10 participants) or a high-
2
3 volume plyometric training group (HPG = 11 participants). Nineteen participants completed
4
5 the study, while two participants (one for each group) dropped out due to contact injuries not
6
7 associated with the protocol execution. Every player was considered for the final statistical
8
9 analysis (intentional to treat analysis). CONSORT participant flow is reported in figure 1²³.
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11 Considering the players' level, the period of the season, the proximity to international
12
13 tournaments, and the necessity of elite players to maximise their performance, the investigators
14
15 took the decision to randomised the sample in two training groups without any control group.
16
17 The duration of this study was 8 weeks. Training protocols, as well as the baseline tests and
18
19 post-training assessments, were performed before the beginning of the official season (from
20
21 August 2017). Players were familiarised with the testing procedures because it was part of the
22
23 fitness test routine of the club. During this study, the team performed 4 training session a week
24
25 as team practices as well as an official match every Saturday (Friday and Sunday were days
26
27 off).
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33 *Tests*

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35 The participants replicated the same tests 3 times, with an adequate recovery among the
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37 trials and the best scores in every test were used for the data analysis. A long jump test was
38
39 utilised to evaluate the ability in horizontal non-rebounding jumping task. A single-leg triple
40
41 hop distance test (triple hop test) was performed with both the legs to evaluate the performance
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43 in rebounding jump ability²⁴. Players performed 3 consecutive maximal hops forward with the
44
45 same limb. Arm swing was allowed. The intraclass correlation coefficient (ICC) of this test
46
47 was 0.95. Sprint 10, 30 and 40 m were performed to evaluate players' improvements in sprint
48
49 ability. For this purpose, infrared timing gates (Microgate, Bolzano, Italy) were placed at the
50
51 start and each of the mentioned distances. 505 COD test was utilised to evaluate improvements
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1 in the COD ability ²⁵. On the “Go” command, the subjects were instructed to sprint for 15 m
2
3 (through the timing gates at 10 m), turn on their preferred foot, and sprint back through the
4
5 timing gates. The validity and specifically of this test was proved previously in football ²⁵.
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8 9 10 *Training*

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12 LPG performed once time per week (on Monday) a protocol of 4 x 5 drop jumps from
13
14 60 cm height followed by a subsequent jump over two obstacles (15 cm height), 4 x 6 horizontal
15
16 jumps, as well as 4 x 6 jumps over obstacles of 15 cm height. The HJG performed the same
17
18 protocol but twice a week (Monday and Wednesday). Both groups after the plyometric protocol
19
20 performed a COD and sprint training (3 sets of 3 short shuttle runs with 4 COD each, for an
21
22 amount of 36 COD).
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27 Please, table 1 here.
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30 31 *Statistical analysis*

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33 In the current study, an intention-to-treat analysis was performed, which involved all
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35 the participants as originally randomized and used the baseline values for the follow up (thus,
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37 drop out were included in the final analysis, see figure 1) ²⁶. Data were presented as mean ±
38
39 standard deviation (SD). Outcomes were expressed as value, with 90% confidence interval
40
41 (CI). Robust estimates of 90% CI and heteroskedasticity were calculated using bootstrapping
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43 technique (randomly 1000 bootstrap samples) ²⁷. Analysis of variance (ANOVA) was used to
44
45 evaluate within-group differences. Analysis of covariance (ANCOVA), using baseline values
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47 as covariate, was employed to detect possible between-groups differences ²⁸. When significant
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49 F-values were found, post hoc analysis was performed (Bonferroni). The significance level was
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51 set at $p \leq 0.05$. ES based on the Cohen d principle was interpreted as trivial <0.2, small 0.2-
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1 0.6, moderate 0.6-1.2, large 1.2-2.0, very large >2.0²⁸. Statistical analyses were performed by
2
3 SPSS software version 20 for Windows 7, Chicago, USA.
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6 7 8 **Results**

9
10 Exercise-induced meaningful changes in performance for both LPG and HPG occurred
11 after the training. Within-group changes for LPG and HPG are reported in Tables 1. However,
12 between-group analysis did not report any statistical difference: long jump ($F = 1.118$, $p =$
13 0.304), triple hop test right ($F = 1.576$, $p = 0.225$), triple hop test left ($F = 0.388$, $p = 0.541$), 10
14 m sprint ($F = 0.666$, $p = 0.425$), 30 m sprint ($F = 0.627$, $p = 0.439$), 40 m sprint ($F = 3.50$, $p =$
15 0.078) and 505 agility ($F = 0.706$, $p = 0.412$).
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25 **Please, table 2 here.**
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29 **Discussion**

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31 As hypothesised, after 8 weeks of training, meaningful within-group differences were
32 found, with positive effects for both groups (LPG and HPG) in most of the assessed tests
33 (except for the LPG in the 505-COD test). This study shows that both short-term (8 weeks)
34 plyometric protocols offered some meaningful improvements in jump, speed and agility
35 capabilities. However, after the between group analysis, no meaningful differences were found
36 when comparing the effectiveness of the two training protocols.
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44 **Plyometric training is a widespread form of physical conditioning that involves jumping**
45 **exercises wherein the stretch-shortening cycle muscle action represents the potentiating**
46 **underlying neurophysiological mechanism¹.** Studies generally report that plyometric training
47 regimen is effective for improving neuromuscular impulse-dependent components^{10,29,30}, with
48 positive transfer effects on specific tasks such as acceleration, jumping, sprinting, and COD
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1 ability^{12,29,30}. In a recent review, Asadi and colleagues reported positive effects (ES from 0.26
2 to 2.8) of plyometric training in sports, thus supporting the results found in this study²².
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4
5 Moreover, Loturco et al., found that plyometrics can transfer specific neuromuscular gains to
6 acceleration and speed abilities of football players, such findings confirm our results⁶. The
7 data reported in the current study support the positive effect found in previous research studies
8 using plyometric training.
9

10 The outcomes found in the current study are particularly interesting since pertaining to
11 elite academy athletes. Elite players are accustomed to performing specific sport related
12 actions, thus, improvements in their fitness capabilities are much harder to achieve when
13 compared with other populations (e.g. amateurs)³¹. This could explain the meaningful but
14 generally small effect found in this study (table 2). The players enrolled in this study have a
15 training frequency of 4 times per week and played once a week (every Saturday). This training
16 volume is lower than that reported in previous investigations performed with professional
17 football players, therefore the positive effects found in this study could be likely smaller
18 whether a senior professional sample (accustomed to higher training volume) would have been
19 involved¹⁰. Therefore, once plyometric training session per week could not have been
20 sufficient to elicit such adaptations in a different sample (e.g. senior professional players).
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37 As reported above, both LPG and HPG showed improvements in the post-training tests.
38 Nevertheless, we have not found any significant between-group difference following the
39 protocols. However, HPG had a beneficial effect on 505 COD test ($p = 0.039$), while LPG did
40 not report meaningful results ($p = 0.197$). Therefore, this study highlight that a higher
41 plyometric training volume could not be advantageous than a lower one with elite academy
42 players in pre-season (also if it is plausible from a theoretical point of view)³⁰. These results
43 could be explained considering the low plyometric volume adopted (around 90 jumps a
44 session), as well as the level of the players enrolled^{10,13}. The decision to develop such a
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1 plyometric volume per training session was chosen to satisfy the professional duties (based on
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3 the competitive calendar) of the players/team, and should not be considered a limitation (it is
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5 an ecological protocol).
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8 This study presents some limitations, firstly, the small sample enrolled. A greater
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10 sample could have offered a better understanding about the effect obtained by LPG and HPG.
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12 Future studies could replicate this protocol to confirm our findings. Another limitation that
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14 should be considered is that the adopted research design, including a homogeneous group of
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16 youth football players and the lack of an additional parallel control group, may limit the
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18 opportunity to make broader generalizations to other populations represented by different age
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20 groups or athletes of different levels or gender. Therefore, wider generalisation cannot be
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22 inferred and the results could not be extended to other specific populations (e.g. professional
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24 male and elite female players).
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27 28 29 **Conclusions**

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31 This study supports previous findings suggesting that one plyometric training session a
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33 week may provide a sufficient training-dose leading to meaningful improvements in jump and
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35 speed parameters in elite young football players^{12,29}. Both LPG and HPG are effective training
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37 modalities inducing benefits in jump tests, as well as in 10, 30 and 40 m sprint tests for elite
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39 young football players. Fitness coaches and sports scientists could integrate their training plans
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41 with the protocols described in this study. Due to the lack of statistical difference between LJG
42
43 and HJG, authors recommend using a low plyometric training volume equivalent to 80-100
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45 jumps a week during the pre-season for improving jump, sprinting and COD abilities in elite
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47 young football players. Future studies are needed to confirm the results of this study.
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1 **Comparative effects of single vs. double weekly plyometric training sessions on jump,**
2 **sprint and COD abilities of elite youth football players**

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8 Mattia Bianchi¹, Giuseppe Coratella², Antonio Dello Iacono^{3,4}, Marco Beato⁵

- 9
10 1. Department of Sports Science, Team Ticino AC, Tenero, Switzerland.
11 2. Department of Biomedical Sciences for Health, University of Milan, Italy.
12 3. The Academic College at Wingate, Wingate Institute, Netanya, Israel.
13 4. Sport Science Department, Maccabi Tel Aviv FC, Tel Aviv, Israel.
14 5. School of Science, Technology and Engineering, University of Suffolk, Ipswich, UK.
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22 **Abstract**

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27 **BACKGROUND:** Plyometrics are widely implemented as training methodology for
28 enhancing functional sports performance. Although several studies have analysed the
29 plyometrics effects due to training plans with a frequency of 2-3 times a week, few of them
30 provided evidence supporting an equal efficiency of similar training programs implementing
31 lower training frequency such as one training session a week.
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37 **METHODS:** Twenty-one players (elite academy, Switzerland) were included in the current
38 study (mean \pm SD; age 17 ± 0.8 years, weight 70.1 ± 6.4 kg, height 177.4 ± 6.2 cm). This
39 study used a randomised pre-post parallel group trial design. The participants were assigned
40 to either a low-volume plyometric training group (LPG = 10 participants) or a high-volume
41 plyometric training group (HPG = 11 participants). A long jump test, a single-leg triple hop
42 test, sprint (10, 30 and 40 m) and 505 change of directions (COD) test were performed.
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50 **RESULTS:** Exercise-induced meaningful changes in performance for both LPG and HPG
51 occurred after the training. LPG and HPG reported improvements in long jump (ES=1.0 and
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1 26 0.77), triple hop right (ES=0.32 and 0.28), triple hop left (ES=0.46 and 0.32), 10 m sprint
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3 27 (ES=0.62 and 1.0). CONCLUSIONS: both LPG and HPG are effective training modalities
4
5 28 inducing benefits in jump and sprint tests for elite young football players. Fitness coaches and
6
7 29 sports scientists could integrate their training plans with the protocols described in this study.
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12 31 Keywords: soccer, agility, exercise training
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The Journal of Sports Medicine and
Physical Fitness

Introduction

In football, the requirement for frequent changes in the type of movements (e.g., walking, running, sprinting, jumping, tackling), speed (e.g., accelerations, decelerations), direction, and technical tasks features the activity profile as intermittent in nature¹⁻³. Briefly, high-intensity running and sprint-type activities are considered to be crucial determinants for successful performance⁴. Previous analyses showed that outfield football players cover distances of between 10 and 13 km during the matches³. Of these, 8% to 12% were represented by high-intensity running or sprinting, with inter-player differences occurring due to the specific playing role³. Based on the multifaceted nature of physical requirements in football, several methods have been developed to improve players' fitness parameters such as endurance, strength, power and speed^{5,6}.

During a football match, muscle power and strength are critical physical factors for successful participation^{2,7}. Plyometric activities are widely implemented as training methodology for enhancing functional sports performance⁸. Plyometric training generally involves bounding exercises (e.g. multiple jumps), as well as high-impact exercises (e.g. drop jumps)⁹⁻¹¹. Previous studies found that a combination of vertical and horizontal plyometric exercises offer practical advantages compared with methods that involve a single directional component (e.g. only vertical or horizontal jumps)^{6,12}. These conditioning activities, eliciting improvements of the mechanical muscle properties (i.e. strength, power and rate of force development) that cover a great functional role for most of the demanded movements of a football match, which may have a critical impact of the match physical performances such as sprinting, change of directions (COD), side cutting, throwing and fights situations^{4,10,13-15}.

The literature suggests that the plyometric training effects may depend on several key variables, including: the volume, the frequency, and the duration of the protocol, as well as the period of the season and the subjects' fitness characteristics¹⁶⁻¹⁸. Training variables

1 58 management has a critical impact on players' fitness adaptations that occur in elite youth
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3 59 football players¹⁹. However, despite the popularity and wide appeal of plyometric training,
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5 60 few published studies have employed a randomised trial design involving elite young players.
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13 64 training frequency such as one training session a week¹⁰. It seems reasonable to investigate
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17 66 level, a very limited time can be dedicated to specific physical development due to the
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19 67 congested matches fixture (e.g. national and international tournaments) and associated travels
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25 69 To date, evidences about the effect of a single plyometric session a week are limited,
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27 70 and few are the randomised trial involving elite young players^{21,22}. Moreover, no data are
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29 71 available regarding comparisons between the magnitude of the effects of a single plyometric
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37 75 football players during the pre-season period.
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42 77 **Methods**

43 44 78 *Participants*

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46 79 Twenty-three youth football players (elite academy, Switzerland) were considered
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48 80 during the enrolment process. Only outfield players were included (two goalkeepers were
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11 88 *Design*

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35 99 control group. The duration of this study was 8 weeks. Training protocols, as well as the
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37 100 baseline tests and post-training assessments, were performed before the beginning of the
38
39 101 official season (from August 2017). Players were familiarised with the testing procedures
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41
42 102 because it was part of the fitness test routine of the club. During this study, the team
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44 103 performed 4 training session a week as team practices as well as an official match every
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46 104 Saturday (Friday and Sunday were days off).
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49 106 *Tests*

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1 107 The participants replicated the same tests 3 times, with an adequate recovery among
2
3 108 the trials and the best scores in every test were used for the data analysis. A long jump test
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5 109 was utilised to evaluate the ability in horizontal non-rebounding jumping task. A single-leg
6
7 110 triple hop distance test (triple hop test) was performed with both the legs to evaluate the
8
9
10 111 performance in rebounding jump ability ²⁴. Players performed 3 consecutive maximal hops
11
12 112 forward with the same limb. Arm swing was allowed. The intraclass correlation coefficient
13
14 113 (ICC) of this test was 0.95. Sprint 10, 30 and 40 m were performed to evaluate players'
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16 114 improvements in sprint ability. For this purpose, infrared timing gates (Microgate, Bolzano,
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18 115 Italy) were placed at the start and each of the mentioned distances. 505 COD test was utilised
19
20 116 to evaluate improvements in the COD ability ²⁵. On the "Go" command, the subjects were
21
22 117 instructed to sprint for 15 m (through the timing gates at 10 m), turn on their preferred foot,
23
24 118 and sprint back through the timing gates. The validity and specificity of this test was proved
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27 119 previously in football ²⁵.

31 121 *Training*

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33 122 LPG performed once time per week (on Monday) a protocol of 4 x 5 drop jumps from
34
35 123 60 cm height followed by a subsequent jump over two obstacles (15 cm height), 4 x 6
36
37 124 horizontal jumps, as well as 4 x 6 jumps over obstacles of 15 cm height. The HJG performed
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39
40 125 the same protocol but twice a week (Monday and Wednesday). Both groups after the
41
42 126 plyometric protocol performed a COD and sprint training (3 sets of 3 short shuttle runs with 4
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44 127 COD each, for an amount of 36 COD).

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48 129 Please, table 1 here.

50 130 51 52 131 *Statistical analysis*

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1 132 In the current study, an intention-to-treat analysis was performed, which involved all
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3 133 the participants as originally randomized and used the baseline values for the follow up (thus,
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5 134 drop out were included in the final analysis, see figure 1)²⁶. Data were presented as mean \pm
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7 135 standard deviation (SD). Outcomes were expressed as value, with 90% confidence interval
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9 136 (CI). Robust estimates of 90% CI and heteroskedasticity were calculated using bootstrapping
10
11 137 technique (randomly 1000 bootstrap samples)²⁷. Analysis of variance (ANOVA) was used to
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13 138 evaluate within-group differences. Analysis of covariance (ANCOVA), using baseline values
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15 139 as covariate, was employed to detect possible between-groups differences²⁸. When
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17 140 significant F-values were found, post hoc analysis was performed (Bonferroni). The
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19 141 significance level was set at $p \leq 0.05$. ES based on the Cohen d principle was interpreted as
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21 142 trivial <0.2 , small 0.2-0.6, moderate 0.6-1.2, large 1.2-2.0, very large >2.0 ²⁸. Statistical
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23 143 analyses were performed by SPSS software version 20 for Windows 7, Chicago, USA.
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29 145 **Results**

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31 146 Exercise-induced meaningful changes in performance for both LPG and HPG
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33 147 occurred after the training. Within-group changes for LPG and HPG are reported in Tables 2.
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35 148 However, between-group analysis did not report any statistical difference: long jump ($F =$
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37 149 1.118, $p = 0.304$), triple hop test right ($F = 1.576$, $p = 0.225$), triple hop test left ($F = 0.388$, p
38
39 150 $= 0.541$), 10 m sprint ($F = 0.666$, $p = 0.425$), 30 m sprint ($F = 0.627$, $p = 0.439$), 40 m sprint
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41 151 ($F = 3.50$, $p = 0.078$) and 505 agility ($F = 0.706$, $p = 0.412$).
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46 153 Please, table 2 here.
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50 155 **Discussion**

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1 156 As hypothesised, after 8 weeks of training, meaningful within-group differences were
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3 157 found, with positive effects for both groups (LPG and HPG) in most of the assessed tests
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5 158 (except for the LPG in the 505-COD test). This study shows that both short-term (8 weeks)
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7 159 plyometric protocols offered some meaningful improvements in jump, speed and agility
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9 160 capabilities. However, after the between group analysis, no meaningful differences were
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11 161 found when comparing the effectiveness of the two training protocols.
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14 162 Plyometric training is a widespread form of physical conditioning that involves
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16 163 jumping exercises wherein the stretch-shortening cycle muscle action represents the
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18 164 potentiating underlying neurophysiological mechanism¹. Studies generally report that
19
20 165 plyometric training regimen is effective for improving neuromuscular impulse-dependent
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22 166 components^{10,29,30}, with positive transfer effects on specific tasks such as acceleration,
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24 167 jumping, sprinting, and COD ability^{12,29,30}. In a recent review, Asadi and colleagues reported
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26 168 positive effects (ES from 0.26 to 2.8) of plyometric training in sports, thus supporting the
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28 169 results found in this study²². Moreover, Lotureo et al., found that plyometrics can transfer
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30 170 specific neuromuscular gains to acceleration and speed abilities of football players, such
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32 171 findings confirm our results⁶. The data reported in the current study support the positive
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34 172 effect found in previous research studies using plyometric training.
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37 173 The outcomes found in the current study are particularly interesting since pertaining to
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39 174 elite academy athletes. Elite players are accustomed to performing specific sport related
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41 175 actions, thus, improvements in their fitness capabilities are much harder to achieve when
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43 176 compared with other populations (e.g. amateurs)³¹. This could explain the meaningful but
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45 177 generally small effect found in this study (table 2). The players enrolled in this study have a
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47 178 training frequency of 4 times per week and played once a week (every Saturday). This
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49 179 training volume is lower than that reported in previous investigations performed with
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51 180 professional football players, therefore the positive effects found in this study could be likely
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1 181 smaller whether a senior professional sample (accustomed to higher training volume) would
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3 182 have been involved ¹⁰. Therefore, once plyometric training session per week could not have
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5 183 been sufficient to elicit such adaptations in a different sample (e.g. senior professional
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7 184 players).

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10 185 As reported above, both LPG and HPG showed improvements in the post-training
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12 186 tests. Nevertheless, we have not found any significant between-group difference following the
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14 187 protocols. However, HPG had a beneficial effect on 505 COD test ($p = 0.039$), while LPG did
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16 188 not report meaningful results ($p = 0.197$). Therefore, this study highlight that a higher
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18 189 plyometric training volume could not be advantageous than a lower one with elite academy
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20 190 players in pre-season (also if it is plausible from a theoretical point of view) ³⁰. These results
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22 191 could be explained considering the low plyometric volume adopted (around 90 jumps a
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24 192 session), as well as the level of the players enrolled ^{10,13}. The decision to develop such a
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26 193 plyometric volume per training session was chosen to satisfy the professional duties (based on
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28 194 the competitive calendar) of the players/team, and should not be considered a limitation (it is
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30 195 an ecological protocol).

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33 196 This study presents some limitations, firstly, the small sample enrolled. A greater
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35 197 sample could have offered a better understanding about the effect obtained by LPG and HPG.
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37 198 Future studies could replicate this protocol to confirm our findings. Another limitation that
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39 199 should be considered is that the adopted research design, including a homogeneous group of
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41 200 youth football players and the lack of an additional parallel control group, may limit the
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43 201 opportunity to make broader generalizations to other populations represented by different age
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45 202 groups or athletes of different levels or gender. Therefore, wider generalisation cannot be
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47 203 inferred and the results could not be extended to other specific populations (e.g. professional
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49 204 male and elite female players).

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206 **Conclusions**

207 This study supports previous findings suggesting that one plyometric training session a
208 week may provide a sufficient training-dose leading to meaningful improvements in jump and
209 speed parameters in elite young football players^{12,29}. Both LPG and HPG are effective
210 training modalities inducing benefits in jump tests, as well as in 10, 30 and 40 m sprint tests
211 for elite young football players. Fitness coaches and sports scientists could integrate their
212 training plans with the protocols described in this study. Due to the lack of statistical
213 difference between LJG and HJG, authors recommend using a low plyometric training
214 volume equivalent to 80-100 jumps a week during the pre-season for improving jump,
215 sprinting and COD abilities in elite young football players. Future studies are needed to
216 confirm the results of this study.

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Table 1. A standard weekly programme for an elite youth football team.

Day	Training Programme
Monday	Warm-up, 20 min; Pliometrics (LPG and HPG) 20 min; Technical/tactical, 25 min; Play, 15 min
Tuesday	Morning: Strength training and injury prevention (gym), 40 min. Afternoon: Warm-up, 15 min; Technical/tactical, 25 min; Play, 25 min; Moderate-intensity aerobic training or SSG, 20 min
Wednesday	Warm-up, 15 min; Pliometrics (HPG) 20 min Technical/tactical, 30 min; Play, 20 min
Thursday	Warm-up, 15 min; Speed training (long and short), 15 min Technical/tactical, 25 min; Play, 15 min
Friday	Day off
Saturday	Match
Sunday	Day off

CODs = Change of directions; SSG = Small sided games

Table 2. Summary of baseline and post-training data before and after 8 weeks of plyometric training, LPG (n = 10) and HPG (n = 11). Data are presented in mean \pm SDs.

Variable	Baseline Mean \pm SD	Follow-up Mean \pm SD	Delta difference (90% CI)	P level	ES (interpretation)
LPG					
Long jump (cm)	2.33 \pm 0.15	2.48 \pm 0.21	0.15 (0.07; 0.27)	0.030	1.0 (moderate)
Triple hop right (m)	7.02 \pm 0.72	7.25 \pm 0.56	0.23 (0.12; 0.34)	0.022	0.32 (small)
Triple hop left (m)	6.90 \pm 0.60	7.18 \pm 0.66	0.28 (0.07; 0.48)	0.031	0.46 (small)
Sprint 10 m (s)	1.84 \pm 0.08	1.79 \pm 0.08	-0.04 (-0.02; -0.07)	0.003	0.62 (moderate)
Sprint 30 m (s)	4.25 \pm 0.15	4.19 \pm 0.15	-0.05 (-0.02; -0.09)	0.014	0.4 (small)
Sprint 40 m (s)	5.48 \pm 0.24	5.27 \pm 0.27	-0.21 (-0.05; -0.04)	0.029	0.87 (moderate)
505 COD test (s)	4.78 \pm 0.12	4.69 \pm 0.17	-0.08 (0.03; -0.19)	0.197	0.75 (moderate)
HPG					
Long jump (cm)	2.18 \pm 0.14	2.30 \pm 0.17	0.12 (0.04; 0.20)	0.040	0.77 (moderate)
Triple hop right (m)	6.81 \pm 0.52	6.96 \pm 0.59	0.15 (0.05; 0.30)	0.021	0.28 (small)

1	Triple hop left	6.75 ± 0.70	6.96 ± 0.68	0.2	0.015	0.32
2						
3	(m)			(0.08; 0.33)		(small)
4						
5	Sprint 10 m (s)	1.85 ± 0.07	1.77 ± 0.08	-0.07	0.004	1.0
6						
7				(-0.02; -0.12)		(moderate)
8						
9	Sprint 30 m (s)	4.36 ± 0.16	4.26 ± 0.15	-0.09	0.007	0.64
10						
11				(-0.04; -0.14)		(moderate)
12						
13	Sprint 40 m (s)	5.52 ± 0.18	5.46 ± 0.17	-0.06	0.004	0.39
14						
15				(-0.03; -0.09)		(moderate)
16						
17	505 COD test	4.83 ± 0.16	4.73 ± 0.16	-0.10	0.039	0.64
18						
19	(s)			(-0.14; -0.01)		(moderate)
20						
21						

353

354 SD = Standard deviations; CI = Confidence intervals; ES = Effect size, m = meters; s =

355 seconds, COD = Changes of direction, LPG = low volume plyometric group, HPG = high

356 volume plyometric group

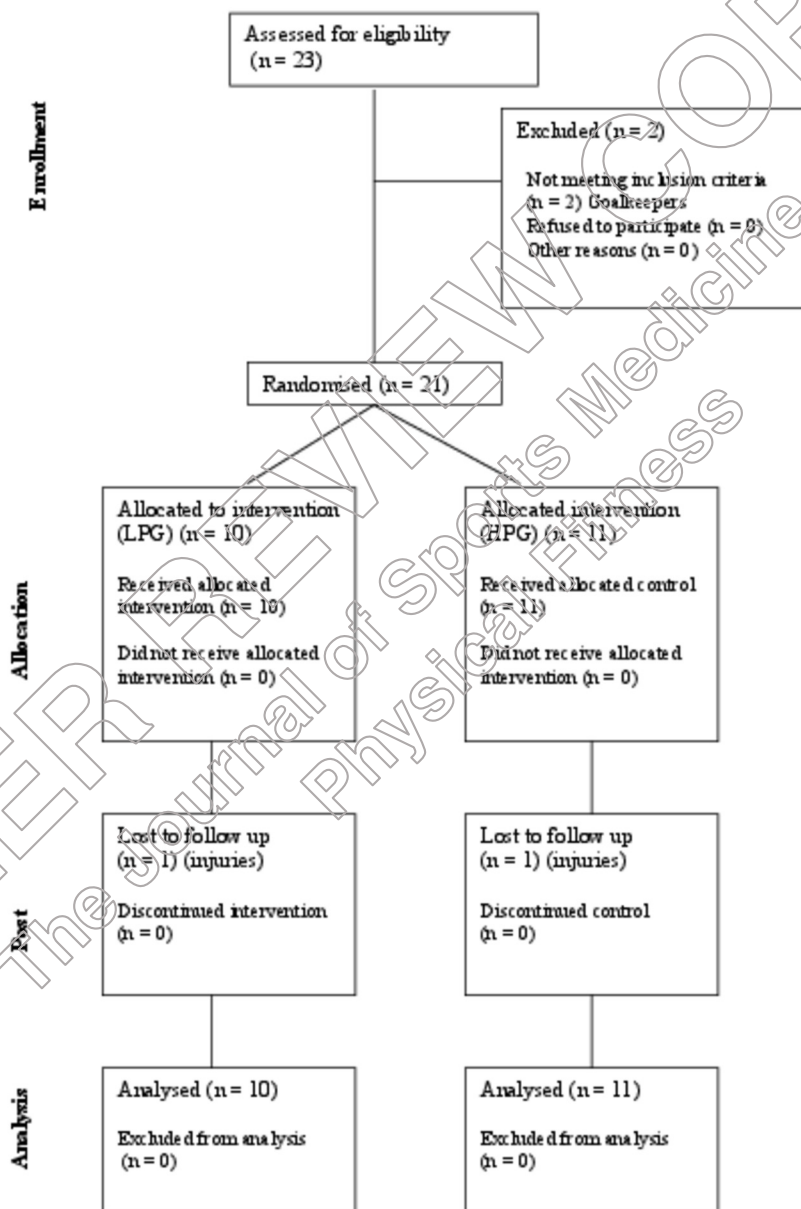
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Figure 1. CONSORT diagram showing the flow of participants through each stage of a randomized trial.



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