THE EFFECTS OF SINGLE VERSUS REPEATED PLYOMETRICS ON LANDING BIOMECHANICS AND JUMPING PERFORMANCE IN MEN

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ABSTRACT: The aim of this study was to examine the chronic effects of single and repeated jumps training on vertical landing force (VGRF) and jump height in untrained men. The VGRF and jump height were compared after a six-week plyometric training programme containing single and repeated jumps, together with two additional parameters: landing time (LT) and range of the knee flexion during landing (KF). Thirty-six untrained physical education students with a plyometric training background were randomly assigned to a single jump group (SJG, n =12), repeated jumps group (RJG, n =12), and control group (CON, n =12). The SJG performed only single jumps, the RJG executed repeated (consecutive) jumps, whereas the CON did not perform any exercises at all. A countermovement jump (CMJ), repeated countermovement jumps (RCMJ), and a drop jump (DJ) were tested before and after the training. Only the RJG showed a significantly reduced VGRF (p<0.05) in all tests. Both plyometric groups significantly improved (p<0.05) their jump height in all tests. The LT was significantly greater in the RJG, compared to the SJG, in all tests. The KF was also significantly (p<0.05) greater in the RJG than in the SJG for CMJ and RCMJ. The results suggest that repeated jumps are beneficial for simultaneous landing force reduction and jumping performance enhancement.

KEY WORDS: ground reaction forces, impact, injury prevention, performance improvement, jumping technique

INTRODUCTION

The effectiveness of plyometric exercises in improving jumping performance has been well documented in a large body of literature [18]. One possible mechanism explaining the efficacy of plyometrics can be associated with specific muscle action called the stretch shortening cycle (SSC). This sequence of intense eccentric (stretch) and concentric (shortening) contraction of a muscle produces large gains in jump height due to energy storage–recoil processes and stretch reflex activation [29]. Typical plyometric exercises include the counter movement jump (CMJ) and the drop jump (DJ). It should be noted that the DJ uses different movement patterns than the CMJ due to shorter contact time [24] and that there is greater contribution of the SSC mechanism for the DJ [13].

Plyometrics are associated with high ground reaction forces during landing, which may exceed 3 and 5-7 times the body mass of individuals, in the CMJ and DJ, respectively [15,28]. These forces may result in muscle soreness [12] and ligament overloading [21], and can cause musculoskeletal injuries [1,19]. Impact landing may also contribute to knee injuries, including the most common, anterior cruciate ligament (ACL) injury [9].

To reduce the vertical landing force, aquatic plyometric exercises [8], using a bungee jumping apparatus [25] or a device with an eccentric braking system to control the momentum on landing [10], are recommended. Some studies have even shown that it is possible to reduce the impact of landing force and improve jumping performance simultaneously. For example, Humphries et al. [10] reported that the braking mechanism of the Plyometric Power System (Norsearch, Lismore, Australia) significantly attenuated the impact landing force without deterioration in concentric force. Other authors have pointed out that aquatic (low impact) plyometric exercises result in similar improvement in jump height compared to traditional plyometrics in young basketball players [2].

In the context of the findings mentioned above, the research of Black [3] is notable because he observed that a single jump has a greater landing force than repeated jumps due to preparation for the subsequent jump. It may suggest that plyometric exercises, performed repeatedly, would result in a reduction of landing impact force compared to exercises performed as single jumps. The purpose of this study was to evaluate the chronic effects of single and re-
peated jumps training on vertical landing force and jump height in untrained men.

**MATERIALS AND METHODS**

Thirty-six untrained male college students volunteered to participate in this study. The subjects were physically active for 8 h·wk⁻¹ because of the nature of their studies (gymnastics, handball, swimming, and athletics track events). All of them were also experienced in plyometrics because they had been involved in 6-week plyometric studies at least twice within the previous 18 months. They were asked to abstain from any strength and conditioning programme during this study. None of the subjects were taking any medications or nutritional supplements. Participants signed an informed consent form, and approval from the university’s Ethics Committee was obtained before starting the training. Subjects were randomly assigned to a single jump group (SJG; n = 12), repeated jumps group (RJG; n = 12), and control group (CON; n = 12). During the pilot study, the 1 repetition maximum (1RM) squat was performed. Baseline characteristics for each group are presented in Table 1.

**TABLE 1. CHARACTERISTICS OF THE TRAINING AND CONTROL GROUPS AT PRE-TRAINING**

|                     | SJG        | RJG        | CON        |
|---------------------|------------|------------|------------|
| Age (years)         | 22.2 ± 1.1 | 22.7 ± 1.4 | 22.6 ± 1.8 |
| Height (cm)         | 181 ± 6    | 184 ± 7    | 182 ± 8    |
| Body mass (kg)      | 76.8 ± 5.9 | 77.4 ± 6.2 | 78.1 ± 6.9 |
| 1 RM squat (kg)     | 123 ± 11   | 127 ± 9    | 121 ± 8    |

Note: Data represents mean ± SD; None of the group differences were significant. SJG = single jump group, RJG = repeated jumps group, CON = control group, 1RM = one repetition maximum.

**Testing procedures**

Subjects were tested during three different types of plyometric exercises: CMJ, repeated CMJ (RCMJ, three consecutive jumps), and DJ from a height of 0.6 m (DJ60). The instruction given to each subject was as follows: “jump as high as you can” in CMJ, “perform three consecutive jumps as high as you can” in RCMJ, and “drop off the box, and jump as high as you can” in DJ60. The upper extremities were first swung backwards and then high upwards. The initial knee flexion angle was not specified. The highest jump or average from three jumps in RCMJ among 3 trials was used for data analysis. The interval between trials was about 1 minute and for each test was 7-8 minutes. Pre- and post-training measurements were made 3 days before and after the completion of the programme.

Peak vertical landing force (VGRF) was measured, while jump height and landing time (LT) were evaluated using data obtained from a piezoelectric force platform (Kistler 9281CA, Switzerland) working with sampling frequency of 500 Hz. Signals from the platform were amplified and recorded on a PC using a 16-bit A/D board and BioWare 3.24 software. Body mass was measured on the force plate, which was calibrated prior to each measurement. Peak vertical landing force was obtained by identifying the highest value during the landing phase. The landing time was determined as the time from the onset of vertical ground reaction force to zero velocity (equivalent to the lowest position of the centre of mass). The jump height was then calculated at the instant of take-off [6].

Three reflective markers were placed on the right side of the subjects’ body at the greater trochanter, lateral condyle of the tibia, and lateral malleolus of the fibula. The range of knee flexion (KF) during landing was calculated as the difference in the angle between the moment of contact of the foot with the ground (umax) and lowest flexion value (umin) [14]. The jumps were recorded with a digital vision camera (Basler piA640-210gc, Germany) at a sampling frequency of 100 Hz. The two-dimensional video motion analysis was carried out using the APAS software package (USA).

The reliability of CMJ, DJ60 and RCMJ measurements was evaluated two weeks before the study by testing 15 subjects. The intraclass coefficient was 0.89-93 for vertical landing force, 0.95-0.97 for jump height, 0.92-0.95 for range of knee flexion, and 0.91-0.94 for landing time.

**Training procedures**

Both experimental groups trained three times per week on non-consecutive days for six weeks. Each training session lasted 50-60 minutes. The warm-up consisted of an 8-minute jog, 5-minute dynamic stretching (swings, rotations, and bends), abdominal (2 x 10 repetitions) and back exercises (2 x 10 repetitions) to protect the back, and rope jumps 6 x 10 repetitions. The training involved only single jumps for the SJG and only repeated jumps for the RJG. Each set involved 3 repetitions, but with a 4-5 second break between each repetition for the SJG and consecutive repetitions for the RJG. The subjects rested for about 1-2 minutes between training sets. Both training groups performed the same number of contacts. The subjects did not receive feedback regarding the technical performance of jumping tasks. The training sessions were performed outdoors on a grass surface and concrete stadium steps. The details of plyometric programmes are outlined in Table 2. Each training session ended with cool-down exercises (i.e., 10-minute jog and static stretching).

**Data analysis**

The data are presented as group mean values ± SD and they were initially tested for normality and homogeneity of variance assumptions. Because the assumptions were not violated, one-way analysis of variance (ANOVA) was conducted to examine whether there were significant differences among the 3 groups in pre-test values for each dependent variable. The significance of differences between dependent variables was assessed with 3 x 2 (group x time) repeated-measures ANOVA. When significant effects were observed, Tukey post-hoc tests were applied. The difference in the magnitude of changes between the pre- and post-tests was analyzed by separate
Single vs. repeated plyometrics

**RESULTS**

The CMJ test results are presented in Table 3. Only the RJG showed a significant (p<0.01) reduction of VGRF and this change was significantly (p<0.05) greater than that found in the SJG and CON. Both the SJG and RJG significantly (p<0.01) improved jump height in CMJ and these improvements were significantly (p<0.05) greater when compared to the CON. The SJG showed significant (p<0.01) decreases in KF and LT, whereas in the RJG there were significant (p<0.01) increases in these parameters. The changes in KF and LT were significantly (p<0.05) greater in the SJG and RJG than in the CON.

The RCMJ test results are shown in Table 4. The RJG showed a decrease (p<0.01) in VGRF, whereas the SJG and CON did not show a change in this parameter. The change in VGRF was significantly (p<0.05) greater in the RJG compared with the SJG and CON. Both training groups significantly (p<0.01) improved jump height in RCMJ and these enhancements were significantly (p<0.05) greater than that observed in the CON. The SJG showed significant (p<0.01) decreases in KF and LT, while these parameters increased in the RJG (p<0.01). The changes were significantly (p<0.05) different between the SJG and RJG.

The DJ60 test results are reported in Table 5. The RJG showed a significant (p<0.01) reduction of VGRF, while in the SJG VGRF

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**TABLE 2. PLYOMETRIC EXERCISE PROGRAMME**

| Week | Exercise programme for SJG* and RJG** (set x repetition) |
|------|----------------------------------------------------------|
| 1    | Side-to-side ankle hop over a slat 4 x 3                  |
|      | Pogo jumps 4 x 3                                         |
|      | Hurdle jumps (40 cm) 8 x 3                               |
|      | Double leg step jumps 6 x 3                              |
| 2    | Side-to-side ankle hop over a hurdle (30 cm) 4 x 3       |
|      | Standing triple jump 6 x 3                               |
|      | Hurdle jumps (60 cm) 8 x 3                               |
|      | Double leg step jumps 8 x 3                              |
| 3    | Single foot side-to-side ankle hop over a slat 4 x 3     |
|      | Standing triple jump uphill 6 x 3                        |
|      | Hurdle jumps (76 cm) 8 x 3                               |
|      | Single leg step jumps 6 x 3                              |
| 4    | Single foot side-to-side ankle hop over a hurdle (30 cm) |
|      | 4 x 3                                                     |
|      | Jump onto a box and jump off backward (30 cm) 6 x 3      |
|      | Hurdle jumps (84 cm) 8 x 3                               |
|      | Single leg step jumps 8 x 3                              |
| 5    | Tuck jump with heel kick 4 x 3                           |
|      | Jump onto a box and jump off backward (40 cm) 6 x 3      |
|      | Multiple box-to-box (20 cm) squat jumps 6 x 3             |
|      | Hurdle jumps (91 cm) 8 x 3                               |
| 6    | Single leg push-off 4 x 3                                |
|      | Jump onto a box and jump off backward (50 cm) 6 x 3      |
|      | Multiple box-to-box (40 cm) squat jumps 6 x 3             |
|      | Hurdle jumps (100 cm) 6 x 3                              |

Note: SJG = single jump group (with 4-5 second break between each repetition in a set); RJG = repeated jumps group (consecutive jumps in a set). Exercise descriptions are presented in books [4,19].

**TABLE 3. EFFECTS OF PLYOMETRIC TRAINING ON VERTICAL LANDING FORCE, JUMP HEIGHT, RANGE OF KNEE FLEXION, AND LANDING TIME IN COUNTERMOVEMENT JUMP (CMJ). DATA ARE PRESENTED AS THE MEAN (± SD) AND EFFECT SIZE (ES)**

| Test    | Parameter                        | Group   | Pre     | Post    | Change  | ES       |
|---------|----------------------------------|---------|---------|---------|---------|----------|
|         |                                  |         |         |         |         | Absolute | %       |
| SJ      | CMJ                              | SJG     | 4.63 ± 0.60 | 4.83 ± 0.56 | 0.20   | 4.3      | 0.4      |
|         |                                  | GRF/BW (N·N −1) | RJG     | 4.58 ± 0.58 | 4.29 ± 0.48†‡ | -0.29 | -6.3     | 0.6      |
|         |                                  |         | 4.67 ± 0.52 | 4.71 ± 0.45 | 0.04   | 0.9      | 0.1      |
|         |                                  | CON     | 4.67 ± 0.52 | 4.71 ± 0.45 | 0.04   | 0.9      | 0.1      |
|         | h (cm)                           | SJG     | 38.9 ± 6.2 | 45.0 ± 5.9†‡ | 6.1    | 15.7     | 0.8      |
|         |                                  | RJG     | 39.8 ± 6.4 | 43.7 ± 6.5†‡ | 4.8    | 12.3     | 0.5      |
|         |                                  | CON     | 39.5 ± 7.2 | 38.5 ± 6.3  | -0.5   | -1.3     | 0.1      |
|         |                                  | SJG     | 73.3 ± 3.4 | 70.9 ± 3.9†‡ | -2.4   | -3.3     | 0.6      |
|         |                                  | RJG     | 74.8 ± 3.1 | 77.5 ± 2.9†‡ | 2.7    | 3.6      | 0.6      |
|         |                                  | CON     | 73.7 ± 4.2 | 74.1 ± 4.4  | 0.4    | 0.5      | 0.2      |
|         | LT (s)                           | SJG     | 0.148 ± 0.024 | 0.136 ± 0.021†‡ | -0.012 | -8.1     | 0.6      |
|         |                                  | RJG     | 0.139 ± 0.020 | 0.158 ± 0.018†‡ | 0.019  | 13.6     | 0.9      |
|         |                                  | CON     | 0.146 ± 0.021 | 0.150 ± 0.022 | 0.004  | 2.7      | 0.2      |

Note: CMJ = countermovement jump; VGRF = vertical landing force; h = jump height; KF = range of knee flexion during landing; LT = landing time. SJG = single jump group; RJG = repeated jumps group; CON = control group. * Significant difference from pre-training values (p < 0.01). † Significantly different change than in SJG (p < 0.05). ‡ Significantly different change than in CON (p < 0.05).
increased \((p < 0.01)\). These changes in the VGRF were significantly \((p < 0.05)\) different when compared to the CON. In addition, there was a significant \((p < 0.05)\) difference in VGRF between the SJG and RJG. Both experimental groups significantly \((p < 0.01)\) improved their jump height and these increases were significantly \((p < 0.05)\) greater than in the CON. In addition, there was a significant \((p < 0.05)\) difference in VGRF between the SJG and RJG. Both experimental groups significantly \((p < 0.01)\) improved their jump height and these increases were significantly \((p < 0.05)\) greater than in the CON. Only the RJG showed a significant \((p < 0.01)\) increase of KF. The analysis also indicated that in the SJG LT decreased \((p < 0.01)\), whereas in the RJG this parameter increased \((p < 0.01)\). There were significant \((p < 0.05)\) differences between changes in LT for the SJG and RJG and between the experimental groups and the CON.

**DISCUSSION**

The main results of this study indicated that repeated jump training methods may be more effective for reducing vertical landing force in common plyometric exercises during 6-week training than single jump training. At the same time, the results showed that there was an improvement in jump height regardless of training mode. The overall ES for jump height was moderate for all testing exercises in the SJG, while a large ES was found for RCMJ and DJ60 and a small ES for CMJ in the RJG.

Based on previous studies [3], it was expected that repeated jumps would decrease vertical landing force due to a soft landing.

**TABLE 4. EFFECTS OF PLYOMETRIC TRAINING ON VERTICAL LANDING FORCE, JUMP HEIGHT, RANGE OF KNEE FLEXION, AND LANDING TIME IN REPEATED COUNTERMOVEMENT JUMP (RCMJ). DATA ARE PRESENTED AS THE MEAN (± SD) AND EFFECT SIZE (ES)**

| Test   | Parameter | Group | Pre    | Post   | Change Absolute | Change % | ES  |
|--------|-----------|-------|--------|--------|-----------------|----------|-----|
| RCMJ   | GRF/BW (N\(\text{N}^{-1}\)) | SJG   | 3.76 ± 0.60 | 3.88 ± 0.53 | 0.12 | 3.2 | 0.2 |
|        |           | RJG   | 3.83 ± 0.61 | 4.47 ± 0.55†‡ | -0.36 | -9.4 | 0.6 |
|        |           | CON   | 3.73 ± 0.58 | 3.79 ± 0.57 | 0.6 | 1.6 | 0.1 |
| h (cm) | SJG       | 36.1 ± 6.4 | 41.4 ± 5.1† | 5.3 | 14.7 | 0.9 |
|        | RJG       | 37.3 ± 5.3 | 43.6 ± 5.5† | 6.3 | 16.8 | 1.1 |
|        | CON       | 35.1 ± 5.8 | 35.8 ± 5.9 | 0.7 | 2.0 | 0.1 |
| KF (°) | SJG       | 85.5 ± 3.6 | 83.9 ± 4.1* | -1.6 | -1.9 | 0.5 |
|        | RJG       | 84.1 ± 3.1 | 87.5 ± 3.4*†‡ | 3.4 | 4.0 | 1.0 |
|        | CON       | 85.9 ± 3.3 | 85.1 ± 3.5 | -0.8 | -0.9 | 0.2 |
| LT (s) | SJG       | 0.216 ± 0.028 | 0.198 ± 0.021†‡ | -0.018 | -8.3 | 0.7 |
|        | RJG       | 0.205 ± 0.022 | 0.225 ± 0.021†‡ | 0.020 | 9.8 | 0.7 |
|        | CON       | 0.215 ± 0.027 | 0.218 ± 0.027 | 0.003 | 1.4 | 0.1 |

Note: RCMJ = repeated countermovement jump; VGRF = vertical landing force; h = jump height; KF = range of knee flexion during landing; LT = landing time. SJG = single jump group; RJG = repeated jumps group; CON = control group. * Significant difference from pre-training values \((p < 0.01)\). † Significantly different change than in SJG \((p < 0.05)\). ‡ Significantly different change than in CON \((p < 0.05)\).

**TABLE 5. EFFECTS OF PLYOMETRIC TRAINING ON VERTICAL LANDING FORCE, JUMP HEIGHT, RANGE OF KNEE FLEXION, AND LANDING TIME IN DROP JUMP (DJ) FROM HEIGHT OF 60 CM. DATA ARE PRESENTED AS THE MEAN (± SD) AND EFFECT SIZE (ES)**

| Test | Parameter | Group | Pre    | Post    | Change Absolute | Change % | ES |
|------|-----------|-------|--------|---------|-----------------|----------|----|
| DJ60 | GRF/BW (N\(\text{N}^{-1}\)) | SJG   | 5.87 ± 0.61 | 6.26 ± 0.56†‡ | 0.39 | 6.6 | 0.6 |
|      |           | RJG   | 5.91 ± 0.77 | 5.59 ± 0.72†‡ | -0.32 | -5.4 | 0.5 |
|      |           | CON   | 5.94 ± 0.63 | 5.98 ± 0.73 | 0.04 | 0.7 | 0.1 |
| h (cm) | SJG       | 35.5 ± 6.4 | 39.6 ± 5.9†‡ | 4.1 | 11.6 | 0.7 |
|       | RJG       | 35.8 ± 6.9 | 40.8 ± 5.6†‡ | 5.0 | 14.1 | 1.0 |
|       | CON       | 35.1 ± 5.2 | 35.5 ± 0.06 | 0.4 | 1.0 | 0.1 |
| KF (°) | SJG       | 82.3 ± 5.4 | 81.5 ± 4.8 | -0.8 | -1.0 | 0.1 |
|       | RJG       | 81.2 ± 5.7 | 83.6 ± 4.3* | 2.4 | 3.0 | 0.4 |
|       | CON       | 82.7 ± 6.1 | 83.4 ± 6.3 | 0.7 | 0.8 | 0.1 |
| LT (s) | SJG       | 0.178 ± 0.014 | 0.161 ± 0.021†‡ | -0.017 | -9.5 | 1.1 |
|        | RJG       | 0.169 ± 0.020 | 0.187 ± 0.015†‡ | 0.018 | 10.6 | 1.1 |
|        | CON       | 0.172 ± 0.016 | 0.178 ± 0.013 | 0.006 | 3.5 | 0.4 |

Note: DJ60 = drop jump from height of 0.6 m; VGRF = vertical landing force; h = jump height; KF = range of knee flexion during landing; LT = landing time. SJG = single jump group; RJG = repeated jumps group; CON = control group. * Significant difference from pre-training values \((p < 0.01)\). † Significantly different change than in SJG \((p < 0.05)\). ‡ Significantly different change than in CON \((p < 0.05)\).
technique [6] which involves greater knee flexion and a longer contact
time. However, it was unexpected to find an increase in vertical
landing force after training in the SJG in the DJ60 test. This increased
VGRF is because plyometric training has been usually shown to be
effective for decreasing the landing impact force of trained and un-
trained subjects [11, 27]. When examining possible mechanisms for
a difference in vertical landing force between the SJG and RJG, it is
logical to suggest that changes in technique of performing plyome-
tric exercises occurred. The SJG decreased and the RJG increased
the range of knee flexion and landing time, which may indicate that
the landing pattern was changed for a stiffer technique in the SJG
and a softer technique in the RJG. In addition, we speculate that
individuals in the SJG did not prepare the muscles for soft landings
because, after achieving the target of the task (maximum height),
they did not focus their attention on control of impact absorption
during landing. Therefore, it is necessary to highlight here that pre-
cise instructions about proper landing techniques should be required
in single jumps.

In turn, the changes in landing technique in the RJG may have
been caused by predictive control mechanisms [23] which allow
impact force to be absorbed during landing and preparing for the
next takeoff. The fact that a VGRF reduction was found only in the
RJG strongly suggests that selection of type of exercise plays a sig-
nificant role in plyometric training, as also revealed by several other
authors [16].

Landing techniques can be divided into two categories, depend-
ning on the maximum knee flexion: greater than 90 degrees is soft
landing and less than 90 degrees is stiff landing [7]. From the per-
spective of injury prevention, it is advisable to minimize impact
landing force by using soft landing. However, for a better athletic
performance, there is a need to find a compromise between a stiff
and a soft landing technique, which can provide a longer contact
time and which then may decrease the efficacy of the SSC by a loss
of stored elastic energy [29]. The results of the current study showed
that similar plyometric exercises significantly increase jump height,
which is consistent with previous studies where different movement
strategies allowed for an improvement in jumping performance [17].

However, Vescovi et al. [27] observed that a female plyometric group,
whose training focused on soft landing, reduced landing force with-
out changing jump height and take-off velocity. They concluded that
plyometric programmes should focus either on landing force reduc-
tion or on maximizing jumping performance. This conclusion does
not correspond with our results in the RJG. The discrepancy in results
may be due to different instructional strategies between studies since
our participants were encouraged to achieve the maximum height
for 6 weeks, while participants in Vescovi’s study [27] at first learnt
landing and jumping mechanics for 4 weeks, then focused on achiev-
ing maximum jump height only for 2 weeks. The differences in results
may also be attributed to gender and the training level of subjects.
Clowers [5] reported that elite female athletes did not change their
movement patterns to attenuate the impact forces, whereas elite
male athletes were able to adjust movement patterns to different
overload conditions. He also suggested that elite athletes could ant-
icipate the landing by increasing the tension in the lower extremity
muscles and dissipated impact energy more effectively than novice
athletes. Nevertheless, we are convinced that not only gender or the
training level of the subjects significantly determine the jumping
technique and training effects, but also the type of plyometric exer-
cises is essential for improving the training results.

CONCLUSIONS

The current study has demonstrated that repeated jumps during
plyometric training may attenuate landing force and improve jump-
ing performance simultaneously. Although single jumps also im-
proved jumping performance, they did not reduce landing force
and changed the landing pattern for a stiffer technique in common
plyometric exercises. This fact implies the need for monitoring
exercise technique during plyometric training.

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