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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 repeated 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 representsmean ± 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 (αmax) and lowest flexion value (αmin) [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

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].

one-way ANOVAs. An alpha level of $p<0.05$ was used as a criterion for significance in all statistical comparisons. Cohen's effect size (ES) was calculated by determining the difference between pre- and post-test means, divided by the pre-test SDs of the CON [26]. The thresholds for small, moderate, and large ES were set at 0.4, 0.6, and 1.0, respectively.

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

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	%	
CMJ	GRF/BW ($N \cdot N^{-1}$)	SJG	4.63 ± 0.60	4.83 ± 0.56	0.20	4.3	0.4
		RJG	4.58 ± 0.58	4.29 ± 0.48*†‡	-0.29	-6.3	0.6
		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
	KF (°)	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. 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		ES
					Absolute	%	
RCMJ	GRF/BW ($N \cdot N^{-1}$)	SJG	3.76 ± 0.60	3.88 ± 0.53	0.12	3.2	0.2
		RJG	3.83 ± 0.61	3.47 ± 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		ES
					Absolute	%	
DJ_{60}	GRF/BW ($N \cdot N^{-1}$)	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: DJ_{60} = 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 untrained 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 plyometric 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 precise 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 significant role in plyometric training, as also revealed by several other authors [16].

Landing techniques can be divided into two categories, depending on the maximum knee flexion: greater than 90 degrees is soft landing and less than 90 degrees is stiff landing [7]. From the perspective 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 without changing jump height and take-off velocity. They concluded that plyometric programmes should focus either on landing force reduction 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 achieving 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 anticipate 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 exercises 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 jumping performance simultaneously. Although single jumps also improved 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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