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THE EFFECT OF DROP HEIGHT AND BODY MASS ON DROP JUMP INTENSITY

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ABSTRACT: Given the nature of plyometric exercises (which overload muscles and joints), intensity control plays an important role in training. Therefore, the aim of this study was to determine the effect of drop height and mass changes on exercise intensity expressed through ground reaction forces (GRF) and the rate of eccentric force development (E-RFD). Nine elite male athletes representing 1st league athletics clubs volunteered to serve as subjects for the study. They performed unloaded and loaded drop jumps from 0.2 m, 0.4 m and 0.6 m. As for loaded jumps, loads constituted 5% and 10% of body mass (BM). It was observed that with an increase in drop height, the values of ground reaction forces at the first peak (the contact of toes with the ground; GRF_1) and at the second peak (the contact of heels with the ground; GRF_2) as well as the values of E-RFD_1 (measured from 0 to GRF_1) and E-RFD_2 (measured from 0 to GRF_2) increased significantly ($P<0.01$). An increase in BM from 5 to 10% led to a change in the values ($P<0.05$) of GRF_1, GRF_2 and E-RFD_1 but only in the case of drop jumps from 0.6 m. However, the values of these parameters in loaded drop jumps with 10% BM were lower than those with 5% BM. The study results indicate that a change in drop height is a more effective way to manipulate the intensity of drop jumps than a change in body mass.

KEY WORDS: stretch-shortening cycle, plyometric exercises, depth jumps, ground reaction forces, rate of force development

INTRODUCTION

In a number of sports, including athletics jumps [29], ski jumping [27], gymnastics as well as volleyball and basketball [7,30], performance depends, to a large extent, on the ability to resist large ground reaction forces during the landing (in the eccentric phase) [21]. For instance, in a 15-metre triple jump attempt the value of GRF in the step phase may be as high as 10 500 N, which is more than 15 times the body mass of a jumper [24]. In NBA players, during the landing after a lay-up jump shot the value may be 9 times the body mass [19]. Therefore, in these sports the application of exercises based on muscle activity in a stretch-shortening cycle (known as plyometric exercises) is well founded. These exercises increase an athlete's tolerance for heavy loads that stretch muscles. As a result, while a muscle remains stretched in the same way, its stiffness increases. Thus it helps to gain greater force production and power output in the concentric phase [10,16,29].

Plyometric exercises that mainly involve the lower extremities are mostly performed as jumps. Drop jumps, which are basic plyometric exercises, consist in jumping off a box (usually 0.3-0.6 m high), making a two-legged landing with impact absorption (eccentric phase), followed by a powerful concentric movement. Like any physical exercises, they may be defined by means of the volume expressed by work performed during jumps [31] or by the number of jumps [8] as well as by intensity, which is usually defined by such parameters as ground reaction forces (GRF) and the rate of force development (RFD) [15,18]. As far as drop jumps are concerned, these parameters are usually measured in the eccentric phase since their values are generally higher than in the concentric phase.

Some researchers maintain that due to the nature of plyometric exercises (which overload muscles and joints), the skill to control exercise intensity plays a vital role in training [15,25]. However, in order to control exercise intensity skilfully it is necessary to know how it changes depending on ground type, jump technique, the type of jumps (one- or two-legged, vertical or horizontal, single or repeated) as well as drop height and additional loads. There are only a few scientific [15] and methodological [9] studies in this area, so for the time being it is not possible to provide a systematic description of plyometric exercise intensity. In our opinion such a systematic description of intensity would facilitate planning and programming loads in plyometric training.

This study sought to assess the effectiveness of exercise intensity control in drop jumps using two methods: changing drop height [4,14,23] and increasing body mass (e.g. with a weight vest) [11,12]. The objective of this work was to determine the effect of drop height and mass changes on exercise intensity expressed through GRF and E-RFD.

MATERIALS AND METHODS

Nine elite male athletes representing 1st national league athletics clubs volunteered to serve as subjects for the study. The group consisted of five long jumpers, two triple jumpers and two high jumpers (mean age 20.4 years, SD = 2.8; body height 1.81 m, SD=0.7; body mass 78 kg, SD=5; squat – 1 repetition maximum (1 RM)=151 kg, SD=14). Every participant had been performing plyometric exercises including drop jumps regularly for at least three years. The investigation was carried out in a pre-season period (April). All subjects gave informed consent prior to participating in the study. Approval for the use of human subjects was obtained from the Research Ethics Committee.

Testing procedures. Subjects were required to perform a drop jump with an immediate vertical jump for maximum height. They performed unloaded and loaded drop jumps from 0.2 m, 0.4 m and 0.6 m. Loads (a weight vest) constituted 5 and 10% of body mass (BM). Subjects, who wore sports shoes, landed on the ball of the foot. Before the test participants were given the following instruction: "perform a drop jump and immediately after the landing jump for maximum height". After each jump subjects received both visual feedback (video analysis) and verbal feedback (instructions concerning technical performance). Each subject had three trials in given conditions (n=9), which amounted to 27 jumps in total. The best jump height of the three was used for analysis The order of applied conditions was randomised. A 30-second rest interval was maintained between each trial performed [26], while a 3-4 minute interval occurred when external loading changed.

The warm-up prior to test trials consisted of 5-minute work on a cycle ergometer at a pedal rate of 80 • min^{-1} at a constant power output of 150 W [22]. Then subjects performed three dynamic stretching exercises: hip rotations (x 10), leg swings in a sagittal plane (x 10), single leg standing calf raises as well as abdominal and back exercises (1 x 10 and 1 x 8 respectively) consisting in raising legs while hanging down the wall bars. After a 3-minute passive rest period subjects performed the first test trial.

Instrumentation. A 0.4 x 0.6 m Kistler piezoelectric force platform (Kistler 9281CA, Switzerland) set to sample at 500 Hz was used for data collection. Signals from the platform were amplified and recorded on a computer using a 16-bit A/D board and Bio Ware 3.24 software. The platform was installed flush with the floor to ensure a safe landing surface.

All parameters were measured in the eccentric phase. It was assumed that the first (GRF$_1$) and the second (GRF$_2$) peak of vertical force, taken from the time-force curve, were equivalent to the toe and heel contact with the ground respectively [28] (Fig. 1). E-RFD$_1$ was defined as GRF$_1$ divided by the time from onset of ground reaction forces to GRF$_1$. Similarly, E-RFD$_2$ was defined as GRF$_2$ divided by the time from onset of ground reaction forces to GRF$_2$ [15].

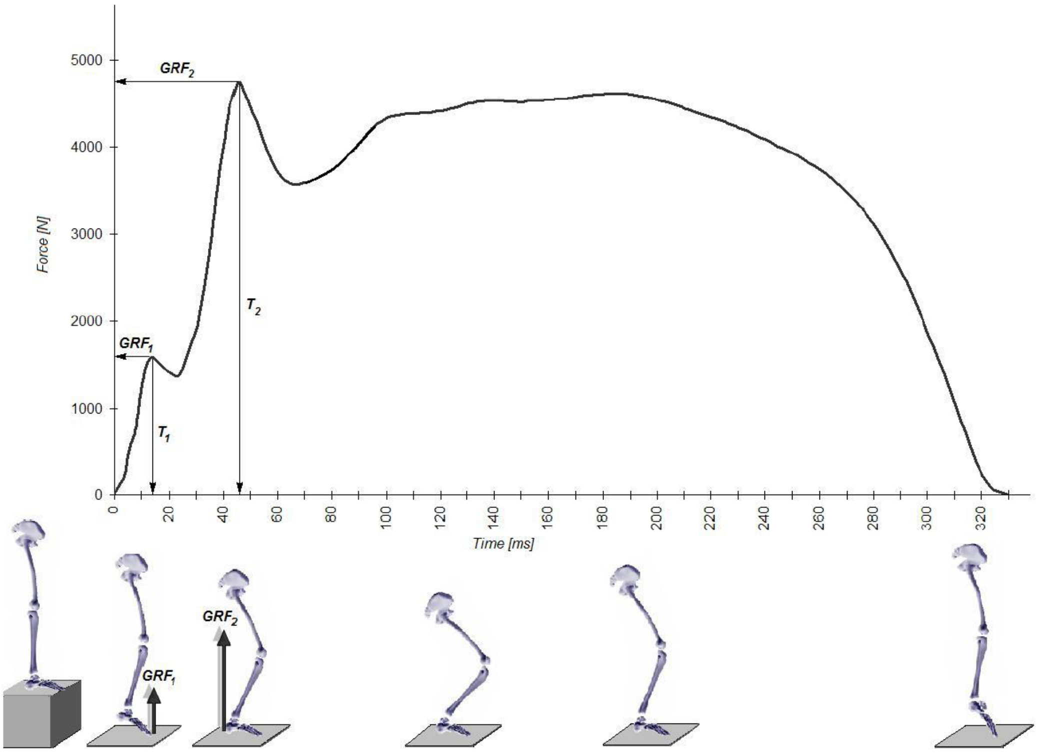

FIG. 1. EXEMPLARY GROUND REACTION FORCE-TIME CURVE FOR A 0.4 M DROP JUMP WITH A WEIGHT VEST (5% BODY MASS). GRF$_1$ INDICATES THE FIRST VERTICAL PEAK OF FORCES; GRF$_2$ – THE SECOND VERTICAL PEAK OF FORCES; T$_1$ – TIME TO THE FIRST PEAK OF FORCES; T$_2$ – TIME TO THE SECOND PEAK OF FORCES.

Two weeks prior to the main tests a pilot study (n=9) was carried out during which jump reliability was estimated by means of the test-retest method in the same conditions as the main test. Reliability estimates expressed by the intra class correlation coefficient for ground reaction forces (GRF_1 and GRF_2) and the rate of eccentric force development ($E\text{-}RFD_1$ and $E\text{-}RFD_2$) were ICC= 0.91 – 0.96.

Before undertaking the statistical analysis, normal distribution and homogeneity of the data variance were checked. Two-way ANOVA (general linear model with repeated measures; factors: height x mass) was used to determine whether significant differences existed between conditions of drop jumps. If the result was significant ($p<0.05$), Scheffe's test was applied. Statistica v. 5.1 PL software was used for calculations.

RESULTS

The values of all measured parameters are presented in Table I. The interaction between drop height and body mass for each parameter was significant: $F_{4,32} = 18.5$, $p<0.001$ for GRF_1; $F_{4,32}= 68.8$, $p<0.01$ for GRF_2; $F_{4,32}= 30.7$, $p<0.001$ for $E\text{-}RFD_1$ and $F_{4,32} = 72.9$, $p<0.001$ for $E\text{-}RFD_2$. It was observed that with an increase in drop height, GRF_1, GRF_2, $E\text{-}RFD_1$ and $E\text{-}RFD_2$ values increased significantly ($p<0.01$), with the exception of 0.4 m and 0.6 m drop jumps with a weight vest (10% BM), where GRF_2 values were not significantly different ($p>0.05$). An increase in BM from 5 to 10% led to a significant reduction in GRF_1, GRF_2 and $E\text{-}RFD_1$ values but only in drop jumps from 0.6 m. However, the values of these parameters in loaded drop jumps with 10% BM were lower than those with 5% BM. Furthermore, in unloaded drop jumps from 0.6 m $E\text{-}RFD_1$ values were higher than in loaded jumps (10% BM), while in the case of a 0.2 m drop jump the values were lower ($p<0.05$).

DISCUSSION

In this study it was assumed that the intensity of plyometric exercises determined their effectiveness and safety of performance to a significant extent. Another assumption was that in training where drop jumps were applied intensity might be defined by such parameters as ground reaction forces and the rate of force development. It was observed that a change in drop height was a more effective method of manipulating the intensity in drop jumps than a change in body mass.

An increase in drop height from 0.2 m to 0.4 m and 0.6 m led to an increase in ground reaction forces both at the first peak (the contact of toes with the ground; GRF_1) and the second peak (the contact of heels with the ground; GRF_2). The issues of the effect of drop height on GRF in drop jumps have been raised by a number of authors. Most of them noted that GRF values increased together with increase in drop height irrespective of gender, age and training experience [6,20,28,31]. The research conducted by Caster [6] showed that GRF_{max} increased in drop jumps from 0.15, 0.3, 0.45 and 0.6 m; in the investigation by McKay et al. [20] the heights 0.1, 0.3 and 0.5 m were applied, while Seegmiller and McCaw [28] found that an increase in GRF_2 occurred when 0.3 m jumps were followed by 0.6 and then 0.9 m jumps. Therefore, it may be assumed that drop height is a parameter that determines GRF to a large extent, and which can help to control drop jump intensity.

However, increasing drop height is only reasonable until a certain height is reached, beyond which it becomes ineffective or even hazardous. According to Bobbert et al. [2], the occurrence of a sharp GRF_2 peak indicates that subjects hit the ground hard with their heels, which means that they are incapable of withstanding overloads. Prolonged duration of the eccentric phase, which results in a decrease in GRF, may be another sign of excessive overloading [17].

TABLE I. VERTICAL GROUND REACTION FORCES AT THE FIRST AND SECOND PEAK (GRF_1, GRF_2), RATE OF ECCENTRIC FORCE DEVELOPMENT TO THE FIRST AND SECOND PEAK ($E\text{-}RFD_1$ AND $E\text{-}RFD_2$) IN DROP JUMPS FROM DIFFERENT DROP HEIGHTS AND WITH DIFFERENT LOADS (MEAN ± SD; N=9).

Parameter	Drop height	0% body mass	5% body mass	10% body mass
GRF1 (N)	0.2 m	765± 191	832 ± 142	892 ± 132
	0.4 m	1322 ± 202§	1401 ± 137§	1377 ± 233§
	0.6 m	2203 ± 308$^{\S,\#}$	2410 ± 475$^{\S,\#}$	1846 ± 165$^{\S,\#,b}$
GRF2 (N)	0.2 m	3421 ± 624	3365 ± 832	3624 ± 614
	0.4 m	4416 ± 753§	4429 ± 892§	4631 ± 551§
	0.6 m	4993 ± 991$^{\S,\#}$	5484 ± 603$^{\S,\#}$	4677 ± 657^{§,b}
E-RFD1 ($N \cdot ms^{-1}$)	0.2 m	39 ± 12	43 ± 12	56 ± 9^{a}
	0.4 m	94 ± 17§	91 ± 15§	90 ± 18§
	0.6 m	146 ± 21$^{\S,\#}$	152 ± 24$^{\S,\#}$	116 ± 18$^{\S,\#,a,b}$
E-RFD2 ($N \cdot ms^{-1}$)	0.2 m	49 ± 11	46 ± 12	58 ± 16
	0.4 m	74 ± 13§	72 ± 16§	76 ± 14§
	0.6 m	94 ± 15$^{\S,\#}$	93 ± 12$^{\S,\#}$	86 ± 17$^{\S,\#}$

Note: § – significantly different ($p < 0.01$) from 0.2 m drop jump; $^{\#}$ – significantly different ($p < 0.01$) from 0.4 m drop jump; ^{a} – significantly different ($p < 0.05$) from unloaded jump; ^{b} – significantly different ($p < 0.05$) from loaded jump (5% BM)

We presume that this situation occurred in a loaded drop jump from 0.6 m, where a subject wore a weight vest of 10% BM, as GRF_2 values (approximately 4500 N) were not significantly different from GRF_2 generated after a 0.4 m drop jump with a vest of the same weight.

Walsh et al. [31] reported that increasing the drop height from 0.2 m to 0.6 m led to a change in GRF_{max} by the same value as jumps from 0.2 m but performed very quickly (contact time = 0.14 s) and jumps performed much more slowly (contact time = 0.21 s). Nevertheless, we are inclined to believe that changing the drop height is a more predictable and therefore more practical way of regulating the intensity of these exercises than manipulating an athlete's performance technique, which is difficult to control in training conditions. Moreover, the assumption concerning the regulation of drop jump intensity by using time differentiation is controversial because a basic principle of plyometric exercises states that it is imperative that exercises be performed at an optimal velocity and force as only then will the values of parameters in question (i.e. power and vertical jumping ability) be the highest. It was interesting that this statement was borne out in the research results of Walsh et al. [31].

In view of the aforementioned considerations, the parameter that may depict the drop jump intensity more exactly is the rate of force development (RFD). This parameter includes GRF as well as time, which is the key element due to the specificity of plyometric exercises [13]. This assumption was confirmed in the research carried out by Jansen and Ebben [15], who did not observe any changes in GRF_{max} even when plyometric exercises and their performance conditions did differ. However, the rate of eccentric force development measured from 0 to GRF_1 (E-RFD_1) differentiated the above-mentioned jumps, similarly to our study results. Moreover, we noted that the rate of eccentric force development measured from 0 to GRF_2 (E-RFD_2) increased significantly together with raising the drop height. Similar observations were made by Lin et al. [18].

We would like to emphasise the fact that to provide a full description of intensity it is best to make use of a group of parameters. The group should include parameters that characterise the first (GRF_1, E-RFD_1) and the second force peak (GRF_2, E-RFD_2). Distinguishing between these groups makes it possible to determine intensity and thus facilitates the assessment of loads, which is an extremely important piece of information as far as prevention and effectiveness in plyometric training are concerned. For instance, it was found that in a drop jump the hip joint absorbed 19% of GRF_1, while in the case of GRF_2 it was as much as 49% [1]. Also, Butler et al. [5] believe that knee stiffness is related to landing on the toes, while ankle stiffness depends on landing on the heels.

Exercise intensity control through body mass changes turned out to be ineffective. Only 5 out of 24 possible value changes of the analysed parameters (GRF_1, GRF_2, E-RFD_1, E-RFD_2) occurred. They mainly related to 0.6 m loaded drop jumps (both 5 and 10% BM). It is worth highlighting that in loaded drop jumps with additional 5% BM subjects obtained higher values than in jumps with 10% BM, which shows even more explicitly the limitations concerning drop jump intensity control through body mass changes. Other limitations are mentioned by Jansen and Ebben [15], who claim that loaded drop jumps are usually performed from low heights, which prevents a rapid acceleration brought about by gravity. Therefore, they classify these exercises as mid-intensity ones.

Fowler et al. [11] observed that 0.26 m loaded drop jumps (8.5 kg) revealed higher GRF_{max} than those performed without any additional loads from the same height. Nonetheless, we suppose that apart from body mass, this difference may have stemmed from too heavy loads or insufficient strength of the lower extremities. Brown et al. [3] found that increasing the body mass of recreational athletes resulted in a more extended lower extremity position with decreased knee flexion velocity at landing. In this case higher values of GRF are discernible than in a 'soft' landing, where we can observe increased flexion of particular joints in the lower extremities with their increased flexion velocity.

CONCLUSIONS

To sum up, drop height changes in drop jumps make it possible to manipulate the intensity of this group of exercises, while body mass changes do not. Both groups of parameters (E-RFD and GRF) measured during the contact of the toes and then the heels with the ground ought to be applied in order to determine exercise intensity. Further research is needed to systemise plyometric exercises according to their intensity. Moreover, the problem of determining relations of intensity parameters measured in the eccentric and concentric phase ought to be dealt with. If these theoretical and practical problems can be solved, it will be possible to optimise previous programmes of plyometric training.

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