DETERMINING VARIABLES OF PLYOMETRIC TRAINING FOR IMPROVING VERTICAL JUMP HEIGHT PERFORMANCE: A META-ANALYSIS

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[1]University Pablo de Olavide, Seville, Spain; [2]Aristotle University of Thessaloniki, Thessaloniki, Greece; [3]Human Performance Laboratory, Department of Kinesiology, University of Connecticut, Storrs, Connecticut; and [4]Research, Studies and Sport Medicine Center, Government of Navarre, Pamplona, Spain

ABSTRACT

Saez Saez de Villarreal, E, Kellis, E, Kraemer, WJ, and Izquierdo, M. Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis. *J Strength Cond Res* 23(2): xxx–xxx, 2009—Plyometric training improves vertical jump height (VJH). However, the effectiveness of plyometric training depends on various factors. A meta-analysis of 56 studies with a total of 225 effect sizes (ESs) was carried out to analyze the role of various factors on the effects of plyometrics on VJH performance. The inclusion criteria for the analysis were a) studies using plyometric programs for lower-limb muscles, b) studies employing true experimental designs and valid and reliable measurements, and c) studies including enough data to calculate ESs. Subjects with more experience in sport obtained greater enhancements in VJH performance ($p < 0.01$). Subjects in either good or bad physical condition benefit equally from plyometric work ($p < 0.05$), although men tend to obtain better power results than women after plyometric training ($p < 0.05$). With relation to the variables of performance, training volumes of more than 10 weeks and more than 20 sessions, using high-intensity programs (with more than 50 jumps per session), were the strategies that seemed to maximize the probability of obtaining significantly greater improvements in performance ($p < 0.05$). To optimize jumping enhancement, the combination of different types of plyometrics (squat jump + countermovement jump + drop jump) is recommended rather than using only 1 form ($p < 0.05$). However, no extra benefits were found to be gained from doing plyometrics with added weight. The responses identified in this analysis are essential and should be considered by strength and conditioning professionals with regard to the most appropriate dose-response trends for optimizing plyometric-induced gains.

KEY WORDS power, effect size, lower limb, training volume, intensity

INTRODUCTION

Plyometrics refers to exercises that are designed to enhance muscle, mainly through the use of jump training. Plyometric exercises constitute a natural part of most sport movements because they involve jumping, hopping, and skipping (i.e., such as high jumping, throwing, or kicking) (4,5,7). Plyometric exercises come in various forms depending on the purposes of a training program. Typical plyometric exercises include the countermovement jump (CMJ), the drop jump (DJ), and the squat jump (SJ). These exercises either can be combined within a training program or can be applied independently. Furthermore, plyometrics can be performed at various intensity levels, ranging from low-intensity double-leg hops to high unilateral-intensity drills. As far as the lower body is concerned, plyometrics includes the performance of various types of body-weight jumping exercises, such as DJ, CMJ, alternate-leg bounding, hopping, and other stretch-shortening cycle (SSC) jumping exercises (12,15,20,24). These exercises are characterized by SSC actions; that is, they start with a rapid stretch of a muscle (eccentric phase) and are followed by a rapid shortening of the same muscle (concentric phase) (12,16,18,19,24,54).

Plyometric training improves strength, muscle power, coordination, and athletic performance (1,6,8,13,21,27,50). Numerous studies on plyometric training have demonstrated improvements in vertical jump height (VJH) (1,11, 21,25,30,33,38,45,50,55,61,63,96,97) ranging from 4.7 to 15% that could be attributed to the enhanced coordination and muscle power after training (1,94). In contrast, a number of authors failed to report significant positive effects of plyometric on VJH (47,66,87), and some even have reported

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negative effects (58). However, the characteristics of a training program that achieves better gains are not clear (5,10,21,30,38).

The effects of plyometric training may differ depending on various subjects' characteristics, such as training level (21,48,56,63,67), gender (17,95), age (17,44,68), sport activity, or familiarity with plyometric training (11,20,21,26,27,35,90,91). Research studies that combine these variables in different ways sometimes lead to conflicting results (30,33,58,60,63,64, 66,75,82,83,87,98). Other factors that seem to determine the effectiveness of plyometric training are program duration and training volume. Research studies have used numerous combinations of duration, intensity, and volume characteristics (1,11,21,26,42,48,52,56,59,60,66,72,74,75,83,84,88,92, 96,97); therefore, the optimal combination of these factors for maximum achievement remains unclear.

Research findings on the ideal box height to optimize plyometric training are also conflicting (5,8,16,54,57). Some authors suggest optimum DJ heights less than (5,14,16,54) or more than 60 cm (89), because one may optimize maximal power output. Furthermore, inconclusive results also arise from studies that have used additional weight during plyometric exercises to maximize muscle power gains (21,33, 50,60,63,66,70,72,82,83,84). Plyometric exercises also have been successful when combined with other types of training such as electrostimulation or aerobics (25,47,60,72,83).

Despite the advantages of plyometric training, the principal issue of determining the optimal elements of a plyometric program remains inconclusive. Identification of the role of the various elements of a plyometric training program with regard to their effectiveness can be achieved with the use of meta-analysis: a method that allows us to overcome the problems of small sample size and low statistical power. Meta-analysis is a quantitative approach in which individual study findings addressing a common problem are statistically integrated and analyzed (46). Because meta-analysis can effectively increase the overall sample size, it also can provide a more precise estimate of the effect of plyometrics on VJH. In addition, meta-analysis can account for the factors partly responsible for the variability in treatment effects observed among different training studies (1,11,21,47,58,66,87). Thus, the purpose of this study was to examine the influence of various factors on the effectiveness of plyometric training using a meta-analysis approach.

METHODS

In the present study, the meta-analysis was performed in different steps, grounded in previous recommendations (79).

Experimental Approach to the Problem

Search of Scientific Literature. A search was performed using key words in the English and French languages (e.g., jump training, drop jump, depth jump, stretch-shortening cycle, plyometric, plyometrics, training of power, plyometric training, pliometrique, entrainement pliometrique). These key words were introduced in the databases ADONIS, ERIC, SPORTSDiscus, EBSCOhost, MedLine, and PubMed. Moreover, manual searches of relevant journals and reference lists obtained from articles were conducted. The present meta-analysis includes studies published in journals that have presented original research data on healthy human subjects. No age, gender, or language restrictions were imposed during the search stage.

Study Selection. Research studies implementing plyometric training programs for lower-limb muscles were used. Investigations involving training of the upper-limb muscles as well as summaries or abstracts were rejected. A total of 70 studies were initially identified.

The next step was to select studies with respect to their internal validity. Selection was based on the recommendations of Campbell and Stanley (23) and included 1) studies involving a control group, 2) randomized control studies, 3) studies using instruments with high reliability and validity, and 4) studies with minimal experimental mortality. Fifty-six studies were selected after having completed all quality conditions (1,2,4,7,9–11,21,22,25–38,43,47,48,50,51–53,56,58–60,62–63,65–67,69–72,75,76,78,80–84,87,92,96–98) (Table 1).

Identification of the Independent Variables. Each study was read and coded independently by 2 investigators using different moderator variables. Because of the high number of variables that may affect training effectiveness, independent variables were grouped into the following areas: 1) subject characteristics: variables included age (years), body mass (kg), height (cm), years of experience, group size, level of fitness, sports level, and type of sport activity; 2) program exercises: variables included combination with other types of exercise, intensity of session, types of plyometric exercises, and resistance; 3) program elements: variables included duration of the session, frequency of weekly sessions, program duration, total number of sessions, drop height, number of jumps per session, number of exercises per session, and rest intervals between series of exercises; and 4) outcome measurements: the type of power test used to identify gains in SJ, CMJ, DJ, or Sargent jump. The coding agreement between investigators was determined by dividing the variables coded the same by the total number of variables. A mean agreement of 0.90 is accepted as an appropriate level of reliability in the coding procedure (74). Mean agreement was 0.91 in our study. Each coding difference was scrutinized by both investigators and was resolved before the analysis.

Calculation of Effect Size. Effect size (ES) is a standardized value that permits the determination of the magnitude of the differences between groups or experimental conditions (85). Gain ESs were calculated using Hedges and Olkin's g (46), using Formula [1]: $g = (M_{\text{post}} - M_{\text{pre}})/SD_{\text{pooled}}$, where M_{post}

TABLE 1. Summary of characteristics of all studies meeting the inclusion criteria.

Authors	Gr	Year	Treatm	*n*	G	Age	W	H	Exp	KPly	Fit	VJG	ES	Freq	D wk	Int	BH	No. J	No. E	Tply	R	JL	Test
Adams et al.	E	1987	Plyo	38	M	13	–	–	Nat	N	G	0.6	0.06	3	10	Low	56	30	1	DJ	–	N	S
Adams et al.	E	1992	Plyo	48	M	23	–	–	NR	N	N	3.81	0.63	2	6	H	50	75	3	DJ	120	N	S
Adams et al.	E	1992	Ply+WT	48	M	23	–	–	NR	N	N	10.67	1.76	2	6	H	50	75	3	DJ	120	N	S
Anderst et al.	E	1994	Plyo	20	M	–	–	–	NR	N	N	8.4	0.38	3	12	Low	40	10	2	C+D	–	N	CMJ
Bauer et al.	E	1990	Plyo	37	B	23.3	73.7	173	NR	N	N	2.7	0.3	3	8	Mod	–	–	1	SJ	–	N	S
Bauer et al.	E	1990	Ply+Sw	37	B	21.3	69.5	174	NR	N	N	5	0.56	3	8	Mod	–	–	1	SJ	–	N	S
Bauer et al.	E	1990	Ply+WT	37	B	25	71.4	172	NR	N	N	4.1	0.31	3	8	Mod	–	–	1	SJ	–	N	S
Berger	E	1963	Ply+aer	89	M	16	–	–	NA	N	N	−0.99	0.37	3	7	Low	–	10	1	SJ	–	N	S
Blakey et al.	E	1987	Ply+WT	31	M	19.5	–	–	NR	Y	G	11.11	0.72	3	8	Mod	110	30	1	DJ	–	N	–
Blakey et al.	E	1987	Ply+WT	31	M	19.5	–	–	NR	Y	N	11.43	0.37	3	8	Mod	40	30	1	DJ	–	N	–
Blattner et al.	E	1979	Plyo	48	M	17	–	–	NA	N	B	5.2	1.05	3	8	Mod	86	30	1	DJ	–	NR	S
Blattner et al.	C	1979	–	48	M	17	–	–	NA	N	B	0.71	0.02	–	–	NR	–	–	–	–	–	NR	–
Brown et al.	E	1986	Plyo	26	M	15	67.9	180.8	Nat	N	G	7.3	1.34	3	12	Low	45	30	3	DJ	60	N	CMJ
Brown et al.	C	1986	–	26	M	15	67.9	180	Nat	N	G	3.7	0.55	–	–	NR	–	–	–	–	–	NR	CMJ
Clutch et al.	E	1983	Ply+WT	12	M	20.9	77.7	179	NA	N	N	3.35	1.4	2	4	Low	30	40	1	DJ	120	N	CMJ
Clutch et al.	E	1983	Ply+WT	12	M	20.9	77.7	179	NA	N	N	2.97	1.11	2	4	Low	75	40	1	DJ	120	N	CMJ
Clutch et al.	E	1983	Ply+WT	32	M	21.2	87.5	183	Nat	Y	G	2.85	0.27	2	16	Low	75	40	1	DJ	120	N	S
Clutch et al.	E	1983	Ply+WT	32	M	21.2	87.5	183	Reg	Y	G	3.88	0.47	2	16	Low	75	40	1	DJ	120	N	S
Cornu et al.	E	1997	Plyo	19	M	22.3	–	–	Reg	Y	G	7.19	0.41	1	7	Mod	40	450	5	S+D	–	N	–
Cornu et al.	C	1997	–	19	M	26	–	–	NA	N	B	−4.93	0.13	–	–	NR	–	–	–	–	–	NR	–
Cossor et al.	E	1999	Plyo	38	M	11.7	47.4	159.1	Nat	N	E	1.2	0.18	3	20	Mod	–	450	15	C	–	N	CMJ
Cossor et al.	C	1999	–	38	M	11.7	44	154.7	Nat	N	E	3	0.6	3	20	Mod	–	450	15	C	–	N	CMJ
Chimera et al.	E	2004	Ply+aer	20	F	20	59.7	165.6	Nat	N	G	1	0.46	2	6	Mod	46	150	5	C	120	N	DJ
Delecluse et al.	E	1995	Plyo	78	M	20	70.2	177	NA	N	N	0.21	0.37	2	9	Low	–	50	5	C	–	N	–
Delecluse et al.	C	1995	–	78	M	20	70.2	177	NA	N	N	0.04	0.07	–	–	NR	–	–	–	–	–	NR	–
Di Brezzo et al.	E	1988	Plyo	8	F	14	–	–	NR	N	N	2.28	0.64	3	5	Low	12	–	2	C	–	N	S
Diallo et al.	E	2001	Plyo	20	M	12.3	41.2	153.1	Reg	N	N	3.4	0.76	3	10	Mod	20	250	3	DJ	–	N	CMJ
Diallo et al.	C	2001	–	20	M	12.6	39.2	147.4	Reg	N	N	0	0	–	–	NR	–	–	–	–	–	NR	CMJ
Duke et al.	E	1992	Ply+WT	10	M	16	–	–	Reg	N	G	6.35	0.11	3	6	H	–	300	4	C	–	N	S
Fatouros et al.	E	2000	Plyo	41	M	21.1	83.4	178	NA	N	B	6	2.25	3	12	H	30	150	5	C	–	N	S
Fatouros et al.	E	2000	Ply+WT	41	M	20.1	79.9	178	NA	N	B	8.6	2.57	3	12	H	30	150	5	C	–	N	S
Fatouros et al.	C	2000	–	41	M	20.5	80.8	181	NA	N	B	0.4	0.22	–	–	NR	–	–	–	–	–	NR	S
Ford et al.	E	1983	Plyo	50	M	17	–	–	NA	N	N	3.12	0.36	3	10	Low	60	15	1	DJ	30	Y	DJ
Fowler et al.	E	1995	Ply+WT	18	M	22.7	77.5	181.5	Reg	Y	G	4	0.76	4	3	H	–	50	2	SJ	–	Y	CMJ
Fry et al.	E	1991	Ply+WT	14	F	19.6	64.3	171.9	Nat	N	E	3.3	0.53	2	12	Mod	–	–	7	C	–	N	S
Gauffin et al.	E	1988	Plyo	54	M	20	–	–	Nat	N	E	3	0.39	3	10	Low	–	30	1	CMJ	–	N	CMJ
Gauffin et al.	C	1988	–	54	M	20	–	–	Nat	N	E	−0.09	0.11	–	–	NR	–	–	–	–	–	NR	–
Gehri et al.	E	1998	Plyo	28	B	19.3	56.76	174.4	NA	N	N	1.65	0.17	2	12	Mod	–	32	1	CMJ	60	N	CMJ
Gehri et al.	E	1998	Plyo	28	B	19.3	56.76	174.4	NA	N	N	2.4	0.4	2	12	Mod	–	32	1	CMJ	60	N	DJ
Gehri et al.	E	1998	Plyo	28	B	20	65.28	174.1	NA	N	N	2.13	0.2	2	12	Mod	40	32	1	DJ	60	N	CMJ
Gehri et al.	E	1998	Plyo	28	B	20	65.28	174.1	NA	N	N	2.79	0.44	2	12	Mod	40	32	1	DJ	60	N	DJ

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Gehri et al.	C	1998	–	28	B	19.8	59.21	170.5	NA	N	N	−0.86	0.08	–	–	NR	–	–	–	–	–	NR	CMJ
Gehri et al.	C	1998	–	28	B	19.8	59.21	170.5	NA	N	N	0.18	0.02	–	–	NR	–	–	–	–	–	NR	DJ
Häkkinen et al.	E	1985	Plyo	10	M	27.1	74.7	176.3	NA	Y	G	7.6	1.67	3	24	H	–	200	3	S+C+D	–	N	SJ
Häkkinen et al.	E	1985	Plyo	10	M	27.1	74.7	176.3	NA	Y	G	4.8	1.32	3	24	H	–	200	3	S+C+D	–	Y	SJ
Häkkinen et al.	E	1985	Plyo	10	M	27.1	74.7	176.3	NA	Y	G	6.9	1.68	3	24	H	–	200	3	S+C+D	–	N	CMJ
Häkkinen et al.	E	1985	Plyo	10	M	27.1	74.7	176.3	NA	Y	G	5.2	1.42	3	24	H	–	200	3	S+C+D	–	Y	CMJ
Häkkinen et al.	E	1985	Plyo	10	M	27.1	74.7	176.3	NA	Y	G	7.8	1.59	3	24	H	20	200	3	S+C+D	–	N	DJ
Häkkinen et al.	E	1985	Plyo	10	M	27.1	74.7	176.3	NA	Y	G	8.3	1.82	3	24	H	60	200	3	S+C+D	–	N	DJ
Häkkinen et al.	E	1985	Plyo	10	M	27.1	74.7	176.3	NA	Y	G	9	1.79	3	24	H	100	200	3	S+C+D	–	N	DJ
Herrero et al.	E	2006	Plyo	40	M	20.8	79.7	179	NA	N	N	−0.4	0.12	2	4	H	–	100	–	C	180	N	CMJ
Herrero et al.	E	2006	Ply+EMS	40	M	21.4	80.2	179	NA	N	N	2.5	0.36	4	4	H	–	100	–	C	180	N	CMJ
Hewett et al.	E	1996	Ply+WT	20	B	15	62.74	169.5	Nat	N	N	3	0.54	3	6	Mod	–	–	7	C	30	N	CMJ
Holcomb et al.	E	1996	Plyo	51	M	16	84.1	183	NA	N	G	4.7	0.54	3	8	Mod	–	72	1	CMJ	–	N	CMJ
Holcomb et al.	E	1996	Plyo	51	M	16	83.2	185	NA	N	G	6.1	0.84	3	8	Mod	40	72	3	DJ	–	N	CMJ
Holcomb et al.	C	1996	–	51	M	16	73.6	181	NA	N	G	1.2	0.15	–	–	NR	–	–	–	–	–	NR	CMJ
Holtz et al.	E	1988	Plyo	6	M	17	–	–	Nat	N	G	5.07	0.42	2	10	Low	–	–	–	–	–	N	S
Hunter et al.	E	2002	Plyo	50	M	24	82.93	182	Reg	N	N	3.7	0.7	2	10	Mod	30	60	6	C+D	60	Y	DJ
Hunter et al.	E	2002	Plyo	50	M	24	82.93	182	Reg	N	N	3.5	0.63	2	10	Mod	60	60	6	C+D	60	Y	DJ
Hunter et al.	E	2002	Plyo	50	M	24	82.93	182	Reg	N	N	2.3	0.42	2	10	Mod	90	60	6	C+D	60	Y	DJ
Hunter et al.	E	2002	Ply+St	50	M	24	82.93	182	Reg	N	N	4.9	0.85	2	10	Mod	–	60	6	C+D	60	Y	CMJ
Hunter et al.	E	2002	Ply+St	50	M	24	82.93	182	Reg	N	N	3.5	0.62	2	10	Mod	30	60	6	C+D	60	Y	DJ
Hunter et al.	E	2002	Ply+St	50	M	24	82.93	182	Reg	N	N	3.5	0.68	2	10	Mod	60	60	6	C+D	60	Y	DJ
Hunter et al.	E	2002	Ply+St	50	M	24	82.93	182	Reg	N	N	3.4	0.63	2	10	Mod	90	60	6	C+D	60	Y	DJ
Hunter et al.	C	2002	–	50	M	24	82.93	182	Reg	N	N	0.03	0.05	–	–	NR	–	–	–	–	–	NR	DJ
Irmischer et al.	E	2004	Plyo	28	F	24	65.3	170	NA	N	N	5	0.88	2	9	Low	–	175	5	C	180	N	S
Kotzamanidis	E	2006	Plyo	30	M	11.1	49.6	156.8	NA	N	N	7.97	1.32	2	10	Mod	20	80	–	C	180	N	SJ
Kramer et al.	E	1983	Ply+WT	28	F	21.3	66.5	170	Nat	Y	E	2.2	0.23	3	9	Mod	30	–	4	S+D	–	N	S
Luebbers et al.	E	2003	Plyo	38	M	–	–	–	NR	N	N	1.9	0.22	3	4	H	–	272	4	C	30	N	CMJ
Luebbers et al.	E	2003	Plyo	38	M	–	–	–	NR	N	N	2.6	0.38	3	7	H	–	155	4	C	30	N	CMJ
Lyttle et al.	E	1996	Plyo	39	M	23.9	79.1	182.3	Reg	N	G	3.8	0.37	2	8	Mod	–	40	1	SJ	–	N	CMJ
Lyttle et al.	E	1996	Ply+WT	39	M	23.8	72.5	178.4	Reg	N	G	5.6	0.43	2	8	Mod	20	10	1	DJ	.–	N	CMJ
Lyttle et al.	C	1996	–	39	M	20.6	74.2	177.3	Reg	N	G	0.2	0.02	–	–	NR	–	–	–	–	–	NR	CMJ
Maffiuletti et al.	E	2002	Ply+EMS	20	M	21.8	80.5	190.7	Reg	Y	E	5.2	0.8	3	4	Mod	40	50	2	C+D	180	N	CMJ
Maffiuletti et al.	C	2002	–	20	M	22.3	75.2	180.6	Reg	Y	E	0.2	0.02	–	–	NR	–	–	–	–	–	NR	CMJ
Martel et al.	E	2005	Ply+Sw	19	F	15	64	167	Nat	N	G	3.7	0.69	2	6	Mod	–	–	–	C	30	N	S
Martel et al.	C	2005	–	19	F	14	57	164	Nat	N	G	1.3	0.2	–	–		–	–	–	–	–	–	S
Matavulj et al.	E	2001	Plyo	33	M	15.5	–	–	Int	N	E	4.8	1.13	3	6	Mod	50	30	1	DJ	180	N	CMJ
Matavulj et al.	E	2001	Plyo	33	M	15.5	–	–	Int	N	E	5.6	1.32	3	6	Mod	100	30	1	DJ	180	N	CMJ
Matavulj et al.	C	2001	–	33	M	15.2	–	–	Int	N	E	0	0	–	–	NR	–	–	–	–	–	NR	CMJ
Miller	E	1982	Plyo	24	F	–	–	–	NA	N	B	5	0.72	1	8	Mod	50	50	1	DJ	–	N	NR
Miller	C	1982	–	24	F	–	–	–	NA	N	B	0	0	–	–	NR	–	–	–	–	–	–	NR
Miller et al.	E	2002	Plyo	40	B	21.5	72.2	171.1	NA	N	B	1.5	0.05	2	8	Mod	–	100	5	C	–	N	S
Miller et al.	E	2002	Ply+Sw	40	B	22	74.2	170.8	NA	N	B	3.7	0.1	2	8	Mod	–	100	5	C	–	N	S
Miller et al.	C	2002	–	40	B	23	79.8	177.8	NA	N	B	1.8	0.04	–	–	NR	–	–	–	–	–	NR	S
Newton et al.	E	1999	Plyo	16	M	19	84	189	Nat	Y	E	3.9	0.81	2	8	Low	30	36	3	S+C+D	–	N	CMJ
Newton et al.	C	1999	–	16	M	19	84	189	Nat	Y	E	0.01	0.01	–	–	NR	–	–	–	–	–	NR	CMJ
Polhemus et al.	E	1980	Ply+WT	27	M	26	–	–	NR	N	N	3	0.72	3	6	Mod	25	35	2	S+D	60	Y	S

Poole et al.	E	1987	Plyo	75	B	21.6	76.27	173.4	Nat	N	G	2.37	0.45	3	10	Mod	75	40	1	DJ	–	N	S
Poole et al.	E	1987	Plyo	75	B	18.7	69.54	170.1	Nat	N	G	2.09	0.41	2	10	Mod	75	40	1	DJ	–	N	S
Poole et al.	C	1987	Plyo	75	B	21.1	75.64	174.8	Nat	N	G	0.58	0.13	–	–	NR	–	–	–	–	–	N	S
Potteiger et al.	E	1999	Plyo	19	M	21.3	–	185	NR	N	N	2.7	1.17	3	8	H	–	320	4	SJ	30	N	CMJ
Potteiger et al.	E	1999	Ply+aer	19	M	21.3	–	185	NR	N	N	3.1	1.06	3	8	H	–	320	4	SJ	30	N	CMJ
Rimmer et al.	E	2000	Plyo	32	M	24	83	177	NR	N	G	0.05	0.44	2	8	H	–	117	4	C	180	N	–
Rimmer et al.	C	2000	–	32	M	24	83	177	NR	N	G	0.01	0.2	–	–	NR	–.	–	–	–	–	NR	–
Sáez-Sáez de Villarreal et al.	E	2008	Plyo	42	M	22.3	75.6	174.7	NA	N	N	0.55	0.11	1	7	H	60	60	1	DJ	60	N	CMJ
Sáez-Sáez de Villarreal et al.	E	2008	Plyo	42	M	23.1	80.1	176.6	NA	N	N	4.6	0.75	2	7	H	60	60	1	DJ	60	N	CMJ
Sáez-Sáez de Villarreal et al.	E	2008	Plyo	42	M	21.8	72.68	175.5	NA	N	N	5.16	0.82	4	7	H	60	60	1	DJ	60	N	CMJ
Sáez-Sáez de Villarreal et al.	C	2008	–	42	M	23.6	78.56	180.3	NA	N	N	0.31	0.07	–	–	–	–	–	–	–	–	N	CMJ
Scoles	E	1978	Plyo	26	NR	–	–	–	NA	N	B	3	0.12	2	8	Low	75	20	1	DJ	–	N	S
Scoles	C	1978	–	26	NR	–	–	–	NA	N	B	1	0.09	–	–	NR	–	–	–	–	–	N	S
Schmidtbleicher et al.	E	1988	Plyo	9	M	21	–	–	NR	Y	NR	2.2	0.56	4	4	Low	–	60	1	SJ	300	N	SJ
Schmidtbleicher et al.	E	1988	Plyo	9	M	21	–	–	NR	Y	NR	3.5	0.43	4	4	Low	32	60	1	DJ	300	N	DJ
Schmidtbleicher et al.	E	1988	Plyo	9	M	21	–	–	NR	Y	NR	3.7	0.48	4	4	Low	40	60	1	DJ	300	N	DJ
Schmidtbleicher et al.	E	1988	Plyo	9	M	21	–	–	NR	Y	NR	3.8	0.44	4	4	Low	48	60	1	DJ	300	N	DJ
Schmidtbleicher et al.	E	1988	Plyo	9	M	21	–	–	NR	Y	NR	2.7	0.36	4	4	Low	56	60	1	DJ	300	N	DJ
Siegler et al.	E	2003	Ply+WT	34	F	16.5	61.46	167.4	Nat	N	N	1.72	0.33	3	10	Low	–	50	3	C	–	N	S
Siegler et al.	C	2003	–	34	F	16.3	58	166.7	Nat	N	N	0.73	0.7	–	–	NR	–	–	–	–	–	NR	S
Spurrs et al.	E	2003	Ply+aer	17	M	25	72.4	178	NR	N	E	5	0.69	3	6	NR	–	90	4	C	–	N	CMJ
Spurrs et al.	C	2003	–	17	M	25	72.4	178	NR	N	E	−1	0.21	–	–	NR	–	–	–	–	–	NR	CMJ
Steben	E	1981	Plyo	160	B	15	–	–	NA	N	B	10	1.23	5	7	Low	25	15	1	DJ	–	N	SJ
Turner et al.	E	2003	Plyo	21	B	31	65.4	170	Reg	N	N	2	0.24	3	6	Low	–	70	6	C	–	N	CMJ
Turner et al.	C	2003	–	21	B	27	71.5	174	Reg	N	N	0	0	–	–	NR	–	–	–	–	–	NR	CMJ
Wagner et al.	E	1997	Plyo	60	M	17.5	–	–	Reg	N	N	0.05	0.09	3	6	H	30	80	4	C	–	N	S
Wagner et al.	C	1997	–	60	M	17.5	–	–	NA	N	B	0.01	0.01	–	–	NR	–	–	–	–	–	NR	S
Wilson et al.	E	1993	Plyo	64	NR	22.1	71.6	174	NR	Y	N	3.7	0.51	2	10	Mod	20	60	2	DJ	180	N	CMJ
Wilson et al.	C	1993	–	64	NR	24.1	76.1	173	NR	Y	N	0.08	0.08	–	–	NR	–	–	–	–	–	NR	CMJ
Wilson et al.	E	1996	Plyo	45	M	20.5	81.1	181	Reg	N	G	10.4	0.89	2	8	Mod	20	40	2	DJ	180	N	CMJ
Wilson et al.	C	1996	–	45	M	24.5	75.9	175	Reg	N	G	3.3	0.42	–	–	NR	–	–	–	–	–	NR	CMJ
Witzke et al.	E	2000	Plyo	56	F	14.6	61	164.3	NA	N	B	12	0.55	3	36	Mod	–	120	6	C	–	N	–

Treatm = treatment; Plyo = plyometric; Ply+aer = aerobic; Ply+WT = weight training; Ply+EMS = electrostimulation; Ply+Sw = in water; Ply+St = stretching; JL = jump loaded; Y = yes; N = no.

Gr = group; E = experimental; C = control; G = gender; M = men; F = women; B = both; W = weight (kg); H = height (cm); Kply = knows plyometric; N = no; Y = yes; T = test; S = Sargent.

Exp = experience; Nat = national; Reg = regional; NA = no athlete; Int = international; Fit = fitness; E = elite; G = good; N = normal; B = bad; NR = not reported.

Tply = type of plyometric training; C = combined; SJ = squat jump; DJ = drop jump; CMJ = countermovement jump; S+D = SJ + DJ; C+D = CMJ + DJ; S+C+D = SJ + CMJ + DJ; R = rest (s); VJG = vertical jump gains (cm).

Freq = frequency (d·wk^{-1}); D wk = duration weeks; Int = intensity; H = high; Mod = moderate; BH = box height (cm); No. J = number of jumps; No. E = number of exercises.

is the mean for the post test and M_{pre} is the mean for the pretest, and SD_{pooled} is the pooled *SD* of the measurements. [2]:

$$SD_{\text{pooled}} = \frac{(M_{\text{post}} - M_{\text{pre}})}{\sqrt{((n_1 - 1)SD_1^2 + (n_2 - 1)SD_1^2)/(n_1 + n_2 - 2)}}$$

In those cases for which mean and *SD* values were not available, ESs were calculated using *F,t,* or *p* values, as outlined by Rosenthal (77). For correlational studies, *r* values were converted to *g* using Formula [3]:

$$g = \frac{r}{\sqrt{1 - r^2}} \sqrt{\frac{df\,(n_1 + n_2)}{n_1 \times n_2}}$$

Correction of Effect Size. It has been suggested (77,79,85) that ES should be corrected for the magnitude of the sample size of each study. Therefore, correction was performed using Formula [4]: $1 - 3\,/\,(4m - 9)$, where $m = n - 1$, as proposed by Hedges and Olkin (46).

Statistical Analyses

To examine the effect of the categorical independent variables on the ES, an analysis of variance (ANOVA) was used (39,77,86). In the case of quantitative independent variables (e.g., age, height, duration of the treatment in weeks, number of jumps per session) a Pearson (*r*) correlation test was used to examine the relationships between ESs and variable values (77). Statistical significance was set at $p \le 0.05$ for all analyses. The scale used for interpretation was the one proposed by Rhea (73), which is specific to strength training research and the training status of the subjects to evaluate the relative magnitude of an ES. The magnitudes of the ESs were considered either trivial (<0.35), small (0.35 − 0.80), moderate (0.80 − 1.50), or large (>1.5).

RESULTS

The analysis showed that the average ES of the plyometric training group (0.84; $n = 107$; 3.90 cm) was significantly higher ($p < 0.05$) compared with the ES of controls (0.13; $n = 44$; 0.84 cm). The Pearson test showed a negative correlation between sample size ($r = -0.221$, $p = 0.05$) and ES.

With regard to subject characteristics, the results indicate a significant correlation coefficient for age ($r = 0.240$) and years of experience ($r = 0.575$) with the magnitude of the ES (Table 2). The ANOVA showed a significant ($p < 0.05$) gender effect and sport level ($p < 0.05$) on ES (Table 2). No other significant effects were found.

The ANOVA showed a significant effect regarding the intensity of a session ($p < 0.05$) and the type of plyometric exercise ($p < 0.05$). According to the reported data, in these athletes, a post hoc analysis also indicated that maximal gains were obtained with the combined use of SJs, CMJs, and DJs during a training session, showing significantly higher gains ($p < 0.05$) compared with other plyometric exercises. No differences in ESs were found among the different combinations of plyometric training or among programs with and without added resistance (Table 3).

The results show a positive relationship ($p < 0.05$) between program duration ($r = 0.452$), number of sessions ($r = 0.515$), and number of jumps per session ($r = 0.391$) with plyometric training effect (Table 4). No differences in ES ($p > 0.05$) were found among the different power tests (Table 5).

DISCUSSION

The results of this investigation support previous narrative reviews (12,61) that have concluded that plyometric training seems to be an effective training method for the improvement of vertical jumping ability (ES = 0.84; i.e., plyometric group). Thus, the reported VJH enhancement of >7% (i.e., 3.90 cm) resulting from plyometric training could be of practical relevance for trained athletes in sports aiming at achieving optimum jumping performance. In addition, several studies focusing on plyometrics have demonstrated that a significant increase in VJH of 10% was accompanied by a respective increase in sport-specific jumping (12,61). The present meta-analysis offers robust quantitative evidence to this conclusion, together with a precise estimate of the effects of plyometric training on jump height in particular types of vertical jumps. Furthermore, the results of this study provide valuable information concerning the importance of controlling some determinant variables for the improvement of jumping performance.

It is well known that sample size influences the power to detect real and significant effects (46). The typical sample size in almost all previous studies on plyometrics ranged from 8 to 12 subjects per group. The present results show a low negative correlation between sample size and training gains. It seems that the greater the sample size, the worse the ES. Most studies used small sample sizes, and therefore a generalization of their findings would be inappropriate. Therefore, one may suggest that studies using large sample sizes are necessary to better illustrate the effects of plyometric training.

Plyometric training requires appropriate technical ability as well as optimum levels of muscle strength and joint coordination. For this reason, subjects with low fitness levels or less experienced individuals are expected to benefit less from such training (3,49). However, the results of the present meta-analysis indicate equal ESs for subjects of various fitness levels (Table 2). These results might indicate that when subjects can adequately follow plyometric exercises, the training gains are independent of fitness level.

Furthermore, our results suggest that higher enhancements after plyometric training can be observed in athletes competing at the international level compared with those gains reached in athletes at the regional level (Table 2). This is further supported by a moderate correlation coefficient between years of experience and ES (Table 2) and suggests that plyometric training is essential for top-level and experienced athletes. Plyometrics improve SSC use with reduced energy

TABLE 2. Analysis for independent variables of subject characteristics.

	Subject characteristics							
Independent variables	Average (cm) ± *SD*	*F*	Level	ES	*SD*	*n*	*r*	*p*
Age (y)						116	0.24	0.01*
Mass (kg)						79	0.221	
Height (cm)						81	0.209	
Years of experience						15	0.575	0.05*
Group size						122	−0.079	
Previous experience		*F*(1,121) = 2.15	*p* = 0.145					
Familiarized	4.18 ± 2.13			0.81	0.58	30		
Not familiarized	3.80 ± 2.37			0.64	0.54	92		
Fitness		*F*(3,121) = 1.97	*p* = 0.102					
Bad	3.36 ± 2.88			0.8	0.99	18		
Normal	3.15 ± 1.78			0.54	0.33	49		
Good	5.07 ± 2.45			0.84	0.57	37		
Elite	4.35 ± 2.00			0.7	0.35	13		
Gender		*F*(2,121) = 6.56	*p* = 0.000*					
Men	4.45 ± 2.35			0.82*	0.6	84		
Women	2.82 ± 1.12			0.5	0.18	7		
Both	2.62 ± 1.94			0.36	0.27	26		
Sport level		*F*(3,121) = 5.26	*p* = 0.001*					
International	5.20 ± 0.56			1.22*	0.13	2		
National	3.22 ± 1.65			0.55	0.4	18		
Regional	3.62 ± 2.77			0.47	0.32	32		
No athletes	4.28 ± 2.30			0.94	0.73	44		
Sport activity		*F*(10,121) = 0.75	*p* = 0.68					
Track and field	4.22 ± 2.69			0.46	0.34	6		
Volleyball	4.27 ± 1.49			0.64	0.24	8		
Basket	3.68 ± 2.56			0.76	0.63	9		
Basket + volleyball	3.46 ± 0.73			0.63	0.12	8		
Body building	4.47 ± 3.51			0.73	0.49	14		
Rowing	2.15 ± 0.07			0.31	0.11	4		
Aerobics + body building	1.60 ± 2.25			0.86	0.43	3		
Swimming	4.12 ± 2.36			0.46	0.19	7		
Soccer	2.66 ± 0.75			0.51	0.18	5		
Physical education	4.93 ± 1.93			0.84	0.52	35		
American football	0.60 ± 0.01			0	–	1		

*$p < 0.05$; ES = effect size.

consumption and higher power output, and they require high levels of coordination. These features are essential aspects of top-level athletes and optimal performance.

An interesting finding in this study is that men demonstrated higher gains compared with women (Table 2). The reasons for this difference are not clear. It could be suggested that men demonstrate higher power output and better coordination than women. However, the large difference in sample sizes between men and women and the small number of ESs available may account for this observation.

The results show similar ESs for various sport activities. Each sport has its own characteristics, and therefore specific plyometric training exercises have been applied. This confirms previous suggestions (81) that plyometric training should be performed in conditions very similar to competition to achieve sport-specific gains.

In the present study, VJH improvements are not higher when plyometrics are combined with other types of exercise (Table 3). This emphasizes the unique characteristics of plyometric training in terms of improving VJH. However, it

TABLE 3. Analysis of variance results on the differences of effect size (ES) between various elements of plyometric training independent variables of program elements.

	Program exercises					
Independent variables	Average (cm) ± *SD*	*F*	Level	ES	*SD*	*n*
Combination with other types of exercise		$F(5,121) = 0.318$	$p = 0.926$			
Plyometric	3.74 ± 2.29			0.68	0.51	78
Plyometric + resistance force	4.37 ± 2.45			0.76	0.63	17
Plyometric + electrostimulation	6.25 ± 1.48			0.94	0.19	3
Plyometric + aerobic exercises	3.77 ± 3.76			0.75	0.29	4
Plyometric + flexibility	3.82 ± 0.71			0.69	0.1	4
Plyometric in water	4.35 ± 0.91			0.33	0.32	3
Intensity of session		$F(2,111) = 12.79$	$p = 0.000$*			
High	5.07 ± 2.93			1.22*	0.73	21
Moderate	3.90 ± 1.78			0.57	0.29	47
Low	3.18 ± 2.18			0.56	0.4	36
Type of plyometric exercises		$F(6,104) = 5.79$	$p = 0.000$*			
Combined	3.23 ± 2.56			0.56	0.71	18
SJ	3.33 ± 2.24			0.54	0.22	9
CMJ	2.91 ± 1.05			0.4	0.17	7
DJ	3.97 ± 2.35			0.66	0.43	45
SJ + DJ	2.60 ± 0.56			0.47	0.34	2
CMJ + DJ	4.41 ± 1.89			0.66	0.19	11
SJ + CMJ + DJ	5.96 ± 2.00			1.46*	0.38	11
Resistance		$F(2,111) = 0.929$	$p = 0.45$			
Added weight	3.71 ± 0.78			0.84	0.43	16
Hydraulic machines	3.00 ± 0.98			0.38	0.17	2
Weightless	3.94 ± 2.49			0.67	0.53	86

*$p < 0.05$. SJ = squat jump; CMJ = countermovement jump; DJ = drop jump; Ply = plyometric.

should be mentioned that when plyometrics were combined with electrostimulation, higher ESs were observed.

The results of this investigation suggest that when the intensity is high during a session, there is a greater improvement in VJH performance (Table 3). The present results show that a combination of SJs, CMJs, and DJs demonstrates a higher ES compared with the use of a single type of exercise (Table 3). It is well documented (17,54,65,81,89,99) that VJH is higher during DJs, followed by CMJs and then SJs. This is mainly because of the different characteristics of movement and, thus, different use of SSC characteristics. For these reasons, the combination of various exercises may result in higher VJH gains compared with the performance of each exercise alone.

The specific effects of plyometrics on VJH in the different types of vertical jumps could be of particular importance. It has been suggested that plyometric training is more effective in improving vertical jump performance in SSC jumps because it enhances the ability of subjects to use the elastic and neural benefits of the SSC (95). This also could be attributed to differences in the use of SSC characteristics (17,54). An SJ mainly consists of a concentric (push-off) phase, whereas a CMJ involves an eccentric and concentric phase (15). The results of our study support these suggestions. Specifically, our data indicate that plyometrics produce somewhat greater (although not significantly) positive effects in the fast SSC jumps (i.e., DJ) than in the concentric-only jumps (i.e., SJ) or even the slow SSC jumps (i.e., CMJ). Keeping the specificity of contraction-type training in mind (i.e., SSC muscle function), greater positive effects of plyometric training on DJs and CMJs than on SJs can be expected. However, to explain the difference in the effects of plyometric training between DJs and CMJs, we should take into account the biomechanical differences between the slow and fast SSC jumping exercises (12). Several authors (12,99) have shown a substantial difference in the mechanical output and jumping performance between slow SSC vertical jumps such as CMJs and fast SSC vertical jumps such as DJs. For these authors, the jumping technique (i.e., corporal position, movement amplitude, and ground-contact time) represents one of the most important factors to be considered when designing plyometric programs. However, in many of the studies included in this review, the researchers did not consider the

TABLE 4. Pearson correlation coefficients (*r*) between various program elements and training gains.

Training program variables	*n*	*r*	*p*
Duration of session (min)	18	−0.084	
Frequency of sessions per week	116	0.126	
Program duration (wk)	109	0.452	0.01*
Number of sessions	109	0.515	0.01*
Drop height (cm)	67	−0.141	
Change in jump height (cm)	20	−0.108	
Number of jumps per session	99	0.391	0.01*
Number of exercises per session	102	0.058	
Rest between sets (s)	50	−0.02	

*$p < 0.05$.

above-mentioned factors when describing their plyometric programs. Therefore, it remains unclear whether the jumping technique is responsible for the somewhat greater gains observed in VJH.

Some research studies have shown that plyometric training with additional weights (vests, bars on the back, etc.) demonstrated higher gains (11,35,40,41,52), whereas others (21,34,50,60,63,66,70,72,82–84) have reported the opposite. The results of the meta-analysis indicate no differences among training conditions (Table 3). This suggests that using additional weights in training does not cause significant gains in performance. It could be suggested, then, that training with additional loads might increase not only resistance but also contact time. However, the longer the contact time, the less effective the SSC (13). Therefore, training effects using additional weights are not guaranteed.

Volume and frequency are very important parameters to take into account for an optimum plyometric training program design. The results showed that training for 10 weeks is more beneficial than similar programs of shorter duration. Similarly, treatment with more than 20 sessions increases VJH, whereas performance of more than 50 jumps per session seemed to result in the most beneficial volume (Table 4). These figures are compatible with previous recommendations (30,35,89,98). However, in agreement with previous studies (78), a short-term plyometric training program with a moderate training frequency and volume of jumps (2 d·wk^{-1}, 840 jumps) produced similar enhancements in jumping performance but greater training efficiency compared with high training frequency (4 d·wk^{-1}, 1680 jumps). Conceptually taken on the whole, the present data indicate that increasing the number of jumps in previously moderately trained men does not seem to be the best stimulus for improving vertical jump performance during short-term training periods compared with high jump-training volumes. These results also suggest that there is a minimum training volume threshold over which further increases in volume are no longer advantageous. It is also likely that in previously physically active subjects within the context of a short-term plyometric training cycle of 7 weeks, jumping performance training can be improved only by 50% or by a high-volume jumping program (e.g., 28 sessions of plyometric training [1680 DJs] performed for 4 sessions per week during a 7-week training period).

The results indicate a nonsignificant ES for drop height on VJH gains (Table 4). This agrees with previous studies (8,14,93) suggesting that the height of the jump is not crucial for improving power in jump training. Therefore, jumping from a lower height allows performance of more repetitions per session and improves trainability of jumping performance with less injury risk.

In conclusion, the present study demonstrates that plyometric training significantly improves VJH. The estimated improvements in VJH as a result of plyometrics could be considered as practically relevant–for example, an

TABLE 5. Analysis for independent variables of outcome measurement.

	Outcome measurement					
Independent variables	Average (cm) ± *SD*	*F*	Level	ES	*SD*	*n*
Power test		$F(3,121) = 0.731$	$p = 0.572$			
Squat jump	4.51 ± 2.41			0.79	0.52	19
Countermovement jump	4.27 ± 2.23			0.74	0.43	40
Drop jump	4.21 ± 2.00			0.71	0.48	18
Sargent jump	3.06 ± 2.26			0.57	0.69	44

*$p < 0.05$. SJ = squat jump; CMJ = countermovement jump; DJ = drop jump; ES = effect size.

improvement in VJH of >7% (i.e., 3.90 cm) could be of high importance for trained athletes in sports relying on jumping performance. According to our results, subjects with more experience in sport obtained the greatest enhancements in VJH. On the other hand, subjects in both good and bad physical condition benefit equally from plyometric work, although men obtain better power results than women after plyometric training. A training volume of more than 10 weeks (with more than 20 sessions), using high intensities (with more than 50 jumps per session), is the strategy that will maximize one's probability of obtaining significant improvements in performance. It is also probable that there is a minimum training volume threshold over which further increases in volume may no longer be advantageous. Another important conclusion is that it is more beneficial to combine different types of plyometrics than to use only 1 form, whereas the best combination is SJs + CMJs + DJs. However, there are no extra benefits gained from doing plyometrics with added weight.

PRACTICAL APPLICATIONS

Plyometric training can be recommended as an effective form of physical conditioning for augmenting vertical jump performance; yet, the effects of plyometric training could vary because of a large number of variables, such as training program design, subject characteristics (gender, age), training level, the specific sport activity, familiarity with plyometric training, program duration, and training volume or intensity. These conclusions are essential and should be taken into account by strength and conditioning professionals, who must consider the most appropriate plyometric training approach based on the fundamental movement patterns, technique, volume, frequency, intensity, energy system requirements, and potential injury analysis for a given sport. Furthermore, for an individual athlete, initial training status and training experience must be considered, and specific fitness limitations should be stressed. The strength and conditioning coach may take into account the dose-response trends identified in this analysis to prescribe the appropriate level of training.

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