Can Resistance Training Enhance the Rapid Force Development in Unloaded Dynamic Isoinertial Multi-Joint Movements?

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BRIEF REVIEW

CAN RESISTANCE TRAINING ENHANCE THE RAPID FORCE DEVELOPMENT IN UNLOADED DYNAMIC ISOINERTIAL MULTI-JOINT MOVEMENTS? A SYSTEMATIC REVIEW

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ABSTRACT

Van Hooren, B, Bosch, F, and Meijer, K. Can resistance training enhance the rapid force development in unloaded dynamic isoinertial multi-joint movements? A systematic review. *J Strength Cond Res* 31(8): 2324–2337, 2017—The objectives of this systematic review were to (a) evaluate whether resistance training can improve the rapid force development in unloaded dynamic isoinertial multi-joint movements and (b) investigate whether these effects differ between untrained/recreationally trained and well-trained individuals. Four electronic databases were screened for studies that measured the effects of resistance training on rapid force development in unloaded dynamic isoinertial multi-joint movements. Twelve studies with a total of 271 participants were included. 10/26 (38%) and 6/14 (43%) of the measures of rapid force development in unloaded dynamic isoinertial multi-joint movements significantly improved following training in the untrained/recreationally trained and well-trained individuals, respectively. Additionally, 7/14 (50%) and 3/12 (25%) of the measures significantly improved during a countermovement and squat jump in the untrained/recreationally trained individuals and 4/6 (67%) and 2/8 (25%) significantly improved during a countermovement and squat jump in the well-trained individuals, respectively. These findings indicate that resistance training has a limited transfer to rapid force development in unloaded dynamic isoinertial multi-joint movements, especially for well-trained individuals and in movements without a countermovement. Furthermore, rapid force development has likely a limited transfer from movements with countermovement to movements without a countermovement and from bilateral movements to unilateral movements. Therefore, it is important to specifically mimic the actual sport movement in order to maximize the transfer of training and testing.

KEY WORDS rate of force development, muscle slack, co-contractions, explosive sport performance, high-intensity sport performance, transfer of training

INTRODUCTION

During most sport situations, there is limited time to develop force and the capability to rapidly develop force is therefore of paramount importance for successful sport performance. Resistance training is one of the training modalities that is used to improve rapid force development. However, the effects of resistance training on rapid force development are usually assessed in movements with external load (17,27,29,34,35,42,43,50,56,58,66,68), while there usually is hardly any or no external load during the actual sports performance.

Transfer of Loaded Movements to Unloaded Movements

The transfer between a movement performed with external load in a test or training and the actual sport performance may be limited when there is no large external load in the actual sport performance. Indeed, only very small to moderate correlations have been found between 5 and 10 m sprint performance and several measures of rapid force development in a loaded countermovement jump (CMJ) among students (42,43). In another study, several measures of the rapid force development during a loaded CMJ could not differentiate between faster and slower professional rugby union players (29). Furthermore, only very small to moderate correlations were found between the rapid force development during a loaded squat jump (SJ) or loaded CMJ and 30 m sprint performance in a study among competitive individuals (66). In contrast, in the only study that compared the transfer of both loaded and unloaded jumps with an isoinertial movement, a stronger

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correlation was found between several sprint distances and the rate of force development in a loaded CMJ compared to the rate of force development in an unloaded SJ and CMJ (50). These findings are in contrast with the idea that the addition of external load results in a reduced transfer to isoinertial movements. However, the latter study used skeleton athletes and since skeleton involves pushing against an external load (maximum 43 kg for men) this may explain the higher correlations for the loaded jumps in this study. It should be noted though that there are also other differences between sprinting and a loaded CMJ. For example, sprinting is an unilateral activity, while vertical jumping is usually performed bilaterally. Differences in the mechanisms of force production between bilateral and unilateral movements such as a higher need for stability, alterations in the force-velocity relationship and interhemispheric inhibition may also reduce the transfer between these movements (11,52,62). Additionally, while rapid force development is frequently measured in a movement with (a large) countermovement (14,29,42,43,46,47,50,66), in many sports situations there is usually no time to perform a large countermovement. Since the countermovement may take up muscle slack (which is represented by the delay between muscular contraction and recoil of the tendinous tissues) and allow an increased time to build-up activation and a thus active state (63,64), a movement involving a (large) countermovement may also limit the transfer to movements with a small or no countermovement.

Although there are some discrepancies and other factors that may influence the transfer, these findings suggests that loaded movements generally have a limited transfer to unloaded movements (i.e., not involving external load such as barbells, weights, chains, elastic bands, etc.). Training with an external load may therefore also have a less pronounced transfer to movements without external load that commonly assumed.

The aim of this systematic review is therefore to determine whether training with external load (i.e., resistance training) can improve the rapid force development in movements with no, or hardly any external load such as a CMJ or SJ, performed with body mass only. To answer this question, we conducted a systematic literature search to identify studies that investigated changes in rapid force development in unloaded, dynamic, isoinertial, multi-joint movements following resistance training.

Delimitations

For this review, resistance training was defined as a training intervention of at least 4 weeks involving an external load provided by barbells, weights, chains or elastic bands. Furthermore, rapid force development was defined as the force developed during the first 300 ms after onset of force development because this time frame reflects the time available for force development in several athletic events (70).

Unloaded Movements. Unloaded movements were defined as movements that did not involve any other load than body mass. Some studies used a linear position transducer to measure rapid force development and this position transducer applies a pulling force, which could be interpreted as a loaded movement. However, the resistance provided by a linear position transducer is small (12) and therefore, movements performed with a linear position transducer were also considered unloaded.

Dynamic Movements. Assessments of rapid force development were only included when they were performed in dynamic movements because both multiple and single-joint isometric assessments of rapid force development have a limited transfer to dynamic rapid force development (4,21,22,25,27,34–36,48,55,66) or dynamic movements (21,40,66).

Isoinertial Movements. Most movements are characterized by acceleration and deceleration of a constant mass (i.e., isoinertial) and not by moving a changing mass at a constant velocity (i.e., isokinetic). Hence, the transfer between isokinetic and isoinertial movements is limited (67) and therefore, only assessments of rapid force development in isoinertial movements were included.

Multi-Joint Movements. Finally, most movements are the result of complex coordinative patterns among multiple-joints (7,32) and it has been shown that single-joint training can disrupt these coordination patterns, hereby limiting the transfer to multi-joint movements (16,39). Therefore, single-joint isoinertial assessments of rapid force development were also excluded.

The Effects of Training Experience

It has previously been hypothesised that resistance training can also result in a decreased capability to rapidly develop force and this negative effect of resistance training may be more pronounced in well-trained individuals compared to untrained and recreationally trained individuals because most of the positive adaptations following resistance training may already be well developed in well-trained individuals (63). Negative adaptations such as a reduced capability to quickly build-up activation and a reduced capability to co-activate muscles may negatively influence the capability to rapidly develop force. In contrast, for untrained and recreationally trained individuals, the positive adaptations following training may mask the negative influence(s) of resistance training. Therefore, a second aim is to investigate the degree to which training experience influences changes in rapid force development following resistance training. A subdivision is made for studies that used untrained and recreationally trained individuals and studies that used well-trained individuals.

METHODS

Search Strategy

A systematic review of the literature was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocol (PRISMA-p) 2015 guidelines (44,51). One researcher (B.V.H.) searched the electronic databases from Google Scholar, Web of Science, MEDLINE (via EBSCOhost) and PubMed between January 14, 2016 and January 15, 2016. Relevant studies published anytime up to January 15, 2016 were included. The following combination of keywords and Booleans was used: ("rate of force development" OR "explosive strength" OR "rapid force production" OR "rapid force development" OR "explosive force production" OR "explosive force development" OR "time to peak force" OR "starting strength") AND ("vertical jump" OR "countermovement jump" OR "squat jump" OR "jump squat" OR "squat" OR "overhead throw") AND ("resistance training" OR "weightlifting" OR "ballistic training" OR "external load" OR "strength training" OR "elastic bands" OR "chains").

Inclusion Criteria

Eligibility criteria for study inclusion were: (a) written in English, (b) published in a peer-reviewed journal, (c) intervention duration of minimum 4 weeks, (d) intervention that involved an external load such as a barbell, weights, chains, elastic bands, (e) healthy participants aged between 16 and 65, (f) measurement of the rapid force development in unloaded dynamic isoinertial multi-joint movements, (g) measurement of the rapid force development in the first 300 ms after onset of force development, (h) measurement of the rapid force development by "time to peak force" or "time to produce a certain percentage of peak force" or "force at a certain amount of ms" or "starting strength" or "rate of force development" or closely related concepts such as "maximum rate of force development" or "relative rate of force development." Forward citation and reference lists of retrieved full-text articles were examined to identify additional articles that were not found by the initial search. Only full-text articles were included so that the methods could be assessed.

Literature Selection

Studies were screened for eligibility in 2 consecutive phases. Phase one consisted of screening for (a) duplicates, (b) title, and (c) abstract. Phase 2 consisted of screening the full article using the inclusion criteria. Full-text was obtained for all articles that appeared to meet the inclusion criteria or when there was uncertainty.

Data Extraction

Data extraction was done by one author (B.V.H.) using a standardized form. Extracted data from each article included study identification information, sample size, sex, age, training experience, frequency and duration of the training intervention, type of training method, test movement, measure of rapid force development and information required to assess the risk of bias of the study. Data to calculate the effect size were also extracted for meta-analysis. Initially, 6 studies that met the inclusion criteria did not provide enough information to calculate the effect size (13,15,30,38,39,46) and 4 authors did also not provide this data after multiple requests. Therefore, a meta-analysis was not undertaken, but effect sizes were calculated when possible.

Effect Size Calculation

To allow comparison of the effect magnitude between studies, effect sizes were calculated for each study (when possible) by subtracting the pre-test mean from the post-test mean and dividing this by the standard deviation of the pre-test (49). When a repeated-measures design was used, the effect size was calculated from baseline to the latest time point, excluding a detraining period. Effect sizes rather than percentage changes where calculated because effect sizes take into consideration the variance of strength improvements, whereas percentage changes do not. Effect sizes were interpreted using the scale proposed by Rhea (49) because the commonly used Cohen scale does not accurately reflect the relative magnitude of an effect in strength training research (49). In the Rhea scale, an effect size is considered <0.50, trivial; 0.50–1.25, small; 1.25–1.9, moderate; and >2.0, large for untrained individuals, <0.35, trivial; 0.35–0.80, small; 0.80–1.50, moderate; and >1.5, large for moderately trained individuals and <0.25, trivial; 0.25–0.50, small; 0.50–1.0, moderate; and >1.0, large for well-trained individuals (49). This classification means that effect sizes are interpreted differently based on the sample's training experience. Individuals will be classified as untrained when they have not been consistently training for 1 year; moderately trained when they have been training for 1–5 years and well-trained when they have been training for at least 5 years (49). Note that this classification does not account for the skill level of the individual. For example, participation in (inter)national championships (i.e., elite athlete) does not necessarily indicate that an individual is well-trained. Elite or sub-elite athletes can still be relatively untrained when they have only been training for 1 year. Similarly, individuals who have been training for at least 5 years are not necessarily elite athletes when they do not participate in (inter)national championships. Furthermore, although the individual may have been training for 6 years, it is well possible that the exercises in the training program are novel to the individual. Therefore, this classification does also not consider whether the individual is experienced with the stimulus employed in the study (10).

Risk of Bias Assessment

After the literature search and examination, the full-text of relevant articles was retrieved and a risk of bias assessment was performed independently by 2 authors (B.V.H. and K.M.). Disagreements was resolved by discussion before the scores were merged into a spreadsheet. Since most risk of bias assessments such as the Delphi scale, PEDro scale and Cochrane scale are designed for healthcare interventions, a modified risk of bias assessment screening scoring system designed for exercise training studies was adopted (9). We added one additional point (i.e., point 2) to this scale because we considered this an important aspect related to the risk of bias of the study. In addition, we omitted the point related to the practically useful assessment, since studies that did not include a useful assessment (e.g., static or isokinetic test) were not included in this review. Therefore, a 10-item scale (range 0–20) was used:

1. Clear inclusion criteria;
2. Clear description of the participants training experience;
3. Random allocation of the participants to groups;
4. Clearly defined intervention;
5. Similarity test at baseline for all groups;
6. Use of a control group that did not perform resistance training;
7. Clearly defined outcome variables;
8. Adequate familiarisation period;
9. Appropriate between-group statistical analysis;
10. Point measures of variability.

The score for each criterion were rated as follows: 0 = clearly no/not reported; 1 = maybe; and 2 = clearly yes. Although we acknowledge that some aspects may be more important than others, each aspect was given equal weight and the resulting scores were considered <10, poor; 10–15, moderate; >15, good, and 20, excellent.

Results

Search Results

The initial literature search yielded 604 records through the electronic databases (Figure 1). After the removal of 229 duplicates, 375 records were retrained for the review. Title and abstract screening resulted in the exclusion of 311 and 35 records, respectively. Finally, after screening 29 records for inclusion/exclusion criteria, 22 records were rejected, with the reason being isometric/static assessment of rapid force development ($n = 10$), no assessment of rapid force development ($n = 8$), no English language ($n = 1$), investigation of acute effects ($n = 1$), elderly participants ($n = 1$) and tests with external load ($n = 1$). Forward citation and screening of references yielded 5 more relevant records and therefore, 12 records were included in the systematic review.

Study Characteristics

A total of 12 studies has investigated the effects of resistance training on rapid force development in unloaded dynamic isoinertial multi-joint movements. Untrained or recreationally trained individuals were used in 9 studies (13–16,26,33,36,38,39). A total of 271 participants, of which

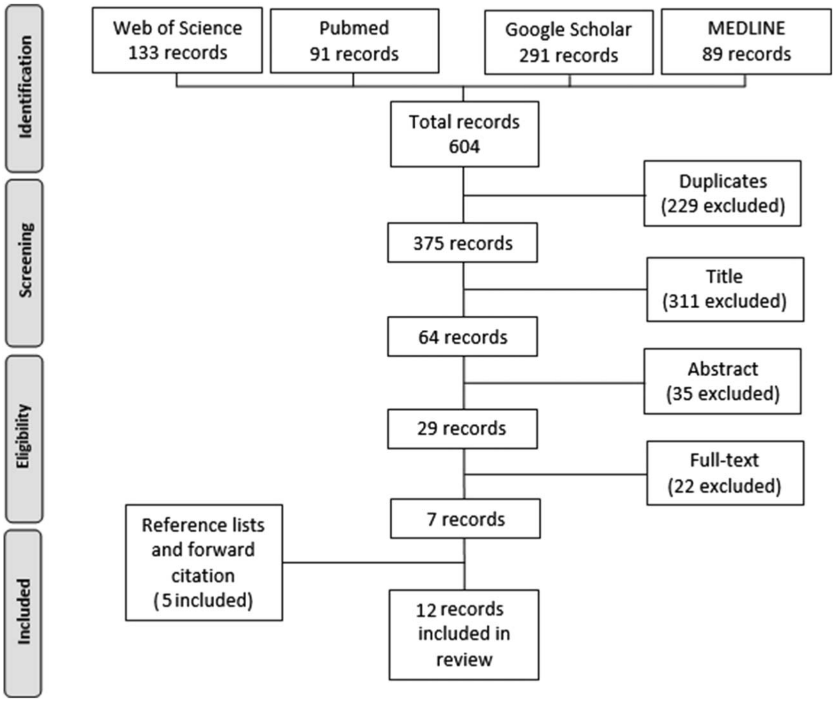

Figure 1. Flow chart of the systematic literature search.

TABLE 1. Risk of bias assessment.*

Study	Clear inclusion criteria	Clear description of the participants training experience	Random allocation of the participants to groups	Clearly defined intervention	Similarity test at baseline for all groups	Use of a control group	Clearly defined outcome variables	Adequate familiarisation period	Appropriate between-group statistical analysis	Point measures of variability	Total
Jakobsen et al. (33)	0	0	0	1	0	2	2	0	2	2	9
Newton et al. (46)	2	2	2	1	0	1	1	0	2	0	11
Harrison et al. (30)	0	0	2	2	0	2	2	0	2	0	10
Haff et al. (26)	0	0	2	1	1	0	2	0	1	2	9
Kraemer et al. (36)	1	0	2	2	0	0	2	2	1	2	12
Lamas et al. (38)	1	1	2	2	0	2	2	2	2	0	14
Cormie et al. (13)	0	0	2	2	1	2	2	2	2	2	15
Cormie et al. (15)	0	0	2	2	1	2	2	2	2	2	15
Cormie et al. (14)	0	0	2	2	1	2	2	2	2	2	15
Leirdal et al. (39)	0	0	1	1	1	0	2	2	1	0	8
Dalen et al. (16)	0	0	1	1	1	0	2	2	1	2	10
Newton et al. (47)	1	0	0	0	0	0	2	0	0	2	5

*0 = clearly no/not reported; 1 = maybe; and 2 = clearly yes.

TABLE 2. Improvements in rapid force development in unloaded dynamic isoinertial multi-joint movements in untrained and recreationally trained individuals.*

Study	Total sample size	Age (y)	Years of training experience; classification	Frequency; duration of resistance training	Type of training	Results				
						Group	Test	Measure	Effect size (Rhea)	p
Jakobsen et al. (33)	94 males	37.8 ± 7.7	Not reported; untrained	×2 per wk; 12 wk	Heavy resistance training	HRG ($n = 8$)	Unloaded CMJ	RFD	1.35; moderate	≤0.05
						CG ($n = 10$)	Unloaded CMJ	RFD	−0.25; trivial	≥0.05
Lamas et al. (38)	40 males	Not reported	>2 y resistance training; recreationally active	×3 per wk; 8 wk	Resistance or power training	STG ($n = 14$)	Unloaded CMJ	RFD	–	≥0.05
							Unloaded SJ	RFD	–	≤0.05
						PTG ($n = 14$)	Unloaded CMJ	RFD	–	≥0.05
							Unloaded SJ	RFD	–	≤0.05
						CG ($n = 12$)	Unloaded CMJ	RFD	–	≥0.05
							Unloaded SJ	RFD	–	≤0.05
Cormie et al. (14)	32 males	23.4 ± 4.4	Not reported; weaker individuals	×3 per wk; 10 wk	Heavy back squats or ballistic jump squats	WPG ($n = 8$)	Unloaded jump squat	Total RFD	10.06; large	≤0.05
								Eccentric RFD	8.9; large	≤0.05
							Unloaded SJ	Total RFD	0.88; small	≥0.05
						WSG ($n = 8$)	Unloaded jump squat	Total RFD	1.85; moderate	≥0.05
								Eccentric RFD	2.76; large	≤0.05
							Unloaded SJ	Total RFD	1.71; moderate	≤0.05
						CG ($n = 8$)	Unloaded jump squat	Total RFD	−0.07; trivial	≥0.05
								Eccentric RFD	−0.12; trivial	≥0.05
							Unloaded SJ	Total RFD	−0.16; trivial	≥0.05
Cormie et al. (15)	24 males	Not reported	Not reported; weaker individuals	×3 per wk; 10 wk	Ballistic jump squats	WPG ($n = 8$)	Unloaded jump squat	RFD	10.28; large	<0.05
						CG ($n = 8$)	Unloaded jump squat	RFD	−0.07; trivial	≥0.05
Cormie et al. (13)	24 males	23.9 ± 4.8	Not reported; relatively weak individuals	×3 per wk; 10 wk	Heavy back squats (HSG) or ballistic jump squats (BSG)	HSG ($n = 8$)	Unloaded jump squat	RFD	1.54; moderate	≤0.05
						BSG ($n = 8$)	Unloaded jump squat	RFD	10.28; large	≤0.05
						CG ($n = 8$)	Unloaded jump squat	RFD	−0.07; trivial	≥0.05

(continued on next page)

Kraemer et al. (36)	17 males	21.3 ± 1.4	Not reported; moderately trained	×4 per wk; 8 wk	Resistance and sprint/plyometric training	ASG ($n = 8$)	Unloaded CMJ	Time to 50% peak force	0.03; trivial	≥0.05
							Unloaded CMJ	Time to 75% peak force	0.10; trivial	≥0.05
						MSG ($n = 9$)	Unloaded CMJ	Time to 50% peak force	0.03; trivial	≥0.05
							Unloaded CMJ	Time to 75% peak force	−0.05; trivial†	≥0.05
Haff et al. (26)	36 males and females	19.9 ± 0.4	Not reported; collegiate track and field athletes	×3 per wk; 6 wk	Traditional resistance training, weightlifting and sprint training	CrG ($n = 15$)	Unloaded SJ	Peak RFD	1.4; moderate	≥0.05
								Time of peak RFD	0.08; trivial	≥0.05
						PG ($n = 21$)	Unloaded SJ	Peak RFD	0.2; trivial	≥0.05
								Time of peak RFD	0.01; trivial	≥0.05
Leirdal et al. (39)	16 men, 6 females	23.2 ± 6.9	Not reported; generally trained sport science students (recreationally active individuals)	×3 per wk; 5 wk	Squat with plantar flexion or squat without plantar flexion and plantar flexion separately	Tsingle ($n = 11$)	Unloaded SJ	RFD	–	≥0.05
						Tmulti ($n = 11$)	Unloaded SJ	RFD	–	≥0.05
Dalen et al. (16)	10 males, 3 females	20.3 ± 1.6	Not reported; sport science students (recreationally active individuals)	×3 per wk; 5 wk	Ballistic squat with plantar flexion or ballistic squat without plantar flexion and plantar flexion separately	MultiJ ($n = 7$)	Unloaded SJ	Time to peak force	0.47; trivial	≤0.05, but significant increase and thus slower
						SingleJ ($n = 6$)	Unloaded SJ	Time to peak force	2.64; large	≥0.05

*HRG = heavy resistance training group; CG = control group; STG = strength training group; PTG = power training group; WPG = weaker power training group; WSG: weaker strength training group; HSG = heavy squat group; BSG = ballistic jump squat group; ASG = athletic shoe group; MSG = meridian elyte shoe group; CrG = creatine supplementation group; PG = placebo group; Tsingle = single joint training group; Tmulti = multi joint training group; MultiJ = multi joint group; SingleJ = single joint group; RFD = rate of force development; CMJ = countermovement jump; SJ = squat jump.

†A decrease in the time to peak force is indicative of an improved rapid force development.

Table 3. Improvements in rapid force development in unloaded dynamic isoinertial multi-joint movements in well-trained individuals.*

Study	Total sample size	Age (y)	Years of training experience; classification	Frequency; duration of resistance training	Type of training	Results				
						Group	Test	Measure	Effect size	p
Cormie et al. (14)	32 males	23.4 ± 4.4	Not reported; stronger individuals	×3 per wk; 10 wk	Ballistic jump squats	SPG ($n = 8$)	Unloaded jump squat	Total RFD	3.05; large	≤0.05
								Eccentric RFD	2.76; large	≤0.05
							Unloaded SJ	Total RFD	0.98; moderate	≥0.05
Cormie et al. (15)	24 males	Not reported	Not reported; stronger individuals	×3 per wk; 10 wk	Ballistic jump squats	SPG ($n = 8$)	Unloaded jump squat	RFD	3.63; large	≤0.05
Harrison et al. (30)	15 males	20.5 ± 2.8	Not reported; professional and semi-professional rugby players	×2 per wk; 6 wk	Resisted sprint training	RS ($n = 8$)	Unloaded SJ on sledge apparatus	mRFD	–	≥0.05
								Starting strength	–	≤0.05
								Time to peak RFD	–	≥0.05
						CG ($n = 7$)	Unloaded SJ on sledge apparatus	mRFD	–	≥0.05
								Starting strength	–	≥0.05
								Time to peak RFD	–	≥0.05
Newton et al. (46)	16 males	19 ± 2	>2 y of resistance training and 5 y of volleyball training; NCAA division I volleyball players	×4 per wk; 8 wk	Traditional and ballistic training or traditional training only	TBG ($n = 8$)	Unloaded CMJ	mRFD	–	≥0.05
							Unloaded SJ	mRFD	–	≤0.05
						TG ($n = 8$)	Unloaded CMJ	mRFD	–	≥0.05
							Unloaded SJ	mRFD	–	≥0.05
Newton et al. (47)	14 females	20 ± 1.2	Not reported; NCAA Division 1 volleyball players	×2 per wk; 11 wk	Volleyball practice and 7 wk traditional resistance training followed by 4 wk ballistic resistance training.	NCAA volleyball players	Unloaded SJ	Time to peak force	−0.43; small†	≥0.05
							Unloaded SJ	mRFD	0.23; trivial	≥0.05
							Unloaded CMJ	mRFD	1.04; large	≤0.05

*SPG = stronger power training group; RS = resistance training; CG = control group; TBG = traditional and ballistic training group; TG = traditional resistance training group; RFD = rate of force development; mRFD = maximum rate of force development; CMJ = countermovement jump; SJ = squat jump.

†A decrease in the time to peak force is indicative of an improved rapid force development.

61 can be classified as well-trained, were included in either the experimental group that performed resistance training or the control group. The mean age of the participants ranged from 19 to 37 years. Solely males were included in 8 studies (13–15,30,33,36,38,46), 3 study included both males and females (16,26,39) and one study included females only (47). The participants were described as untrained (33), relatively weak (13), recreationally active (38), sport science students (which are likely recreationally active) (16,39), moderately trained (36), collegiate track-and-field athletes (26), professional and semi-professional rugby players (30), NCAA division I volleyball players (46,47) and weaker or stronger individuals, based on their 1RM back squat (14,15). Training modalities included traditional resistance exercises such as the back squat (13,14,16,33,38,39), ballistic jump squat training (13–15), resisted sprint training (30) or a combination of some of these modalities (e.g., resistance and sprint training or resistance training and volleyball practice) (26,36,46,47). Study durations ranged from 5 to 12 weeks. Rapid force development was measured during a body mass only CMJ/jump squat (13–15,33,38,46,47) and/or SJ (14,16,26,30,38,39,46,47). Rapid force development was assessed using the rate of force development (13–15,26,33,38,39), maximum rate of force development (30,46,47), total rate of force development (14), time to peak/maximum rate of force development (26,30), time to peak force (16,26,47), starting strength (30) and time to produce 50, 75 and 100% of maximal force (36). The time to produce 100% of maximal force (36) and the time to peak force during the SJ (26) and CMJ (47) were excluded as measures of rapid force development since they exceeded the 300 ms time duration set as inclusion criteria.

Risk of Bias Assessment

The mean risk of bias score of the included studies was 11 (range 5–15; Table 1). Therefore, most evidence comes from studies with a moderate risk of bias. Most studies did not clearly describe the inclusion criteria, the training experience of the participants and did not test for similarity at baseline.

Study Findings

Overall, 16 of the 40 (40%) measures of rapid force development were significantly improved following training (11/20 and 5/20 or 55 and 25% for the CMJ and SJ, respectively), indicating that most measures of rapid force development did not significantly improve following resistance training. In the next paragraphs, the results of the studies are subdivided into findings for untrained and recreationally trained individuals and well-trained individuals.

Untrained and Recreationally Trained Individuals. Since only one study used untrained participants, the results of both untrained and recreationally trained individuals are summarized in Table 2. In the 9 studies among untrained and recreationally trained individuals, only 10 of the 26 (38%) measures of rapid force development were significantly improved following training (7/14 and 3/12 or 50% and 25% for the CMJ and SJ, respectively), indicating that most measures of rapid force development did not significantly improve following resistance training.

Well-Trained Individuals. The findings for well-trained individuals are summarized in Table 3. In the 5 studies that included well-trained individuals only 6 of the 14 (43%) measures of rapid force development were significantly improved following training (4/6 and 2/8 or 67% and 25% for the CMJ and SJ, respectively), indicating that most measures of rapid force development did not significantly improve following resistance training, especially in the SJ.

DISCUSSION

The aim of this systematic review was to investigate whether resistance training can enhance the rapid force development in unloaded dynamic isoinertial multi-joint movements. Overall, resistance training resulted in significant improvements in only 16 of the 40 (40%) measures of the rapid force development in unloaded dynamic isoinertial multi-joint movements. These findings suggest that resistance training has a limited transfer to rapid force development in movements that are characterised as unloaded, dynamic, isoinertial and multi-joint (i.e., most sports and daily living movements).

A second aim was to investigate the degree to which training experience influences changes in rapid force development following resistance training. For this purpose, a subdivision was made between untrained or recreationally trained individuals and well-trained individuals. Among untrained and recreationally trained individuals, resistance training resulted in significant improvements in only 10 of the 26 (38%) measures of the rapid force development in unloaded dynamic isoinertial multi-joint movements. In addition, only 7/14 (50%) and 3/12 (25%) of the measures of rapid force development significantly improved in the CMJ and SJ, respectively. Among well-trained individuals, resistance training resulted in significant improvements in only 6 of the 14 (43%) measures of the rapid force development in unloaded dynamic isoinertial multi-joint movements. Additionally, 4/6 (67%) and 2/8 (25%) of the measures of rapid force development significantly improved in the CMJ and SJ, respectively. These findings suggest that resistance training has a better transfer to rapid force development in movements with countermovement for well-trained individuals than for untrained and recreationally trained individuals. However, these findings should be interpreted with caution since there were only a few studies that included well-trained individuals and studies that used well-trained individuals have usually not assessed well-trained elite (world-class) athletes. Additionally, the magnitude of improvement is generally smaller for well-trained individuals (Tables 2 and 3), suggesting that resistance training does indeed lead to less pronounced improvements of rapid force development in unloaded dynamic isoinertial multi-joint movements for well-trained individuals, especially in movements without a countermovement. For example, in a direct comparison between stronger (better trained) and weaker individuals, the magnitude of improvement in rapid force development following training was smaller for the stronger individuals (14,15). In the subsequent paragraphs, we will attempt to explain these findings and provide implications for practice and research.

Mechanisms of Rapid Force Development

Several mechanisms such as the maximum voluntary contraction strength, muscle-tendon unit stiffness and neural drive influence the capability to rapidly develop force and the contribution of these mechanisms changes throughout the time course of force production (2,20). For example, it has been found that the first 100 ms of rapid force development in isometric and isokinetic movements is primarily influenced by the neural drive to the muscles (20,23,60), intrinsic muscle properties such as fiber type and fascicle length (2,3,6,20) and stiffness of the series elastic element (6). During longer contractions (i.e., >100 ms), rapid force development is increasingly influenced by maximum voluntary contraction strength (2,3,20,28,60), although neural drive (2,20) and the stiffness of the series elastic element also remain important (8,57). Since several studies have found that these mechanisms can be altered by training, it is likely that improvements in these mechanisms are responsible for the significant improvements in rapid force development observed in some studies. For example, the electromyographic activity or rate of increase in electromyographic activity has been found to improve following a wide variety of training modalities such as dynamic ballistic training (24,61) dynamic heavy resistance training (1), isometric contractions with an emphasize on rapid force production (18,59,60) plyometric training (68) and sensimotor training (23,24). However, all of these studies used untrained or recreationally active individuals. It has previously been hypothesized that resistance training has less pronounced beneficial adaptations for well-trained individuals because most of the adaptations such as an increased neural drive or cross-sectional area may already be well developed (63). Negative effects of training with an external load may in such situations be more pronounced.

Time to Build-up Activation and Influence of Muscle Slack. An external load may allow more time to build-up activation because the duration of the movement is likely longer than an unloaded movement. Due to the increased movement time, the athlete is not forced to quickly build-up activation and this capability may therefore not be effectively be trained. Additionally, an external load may take up muscle slack by taking slack out of the fascicles and tendinous tissues, by aligning the muscle-tendon unit and stretching the tendinous tissues, hereby allowing a more rapid force development compared to when no external load is used (19,63,64). This may lead to more muscle slack in movements without external load because the athlete's capability to perform co-contractions and hence take up muscle slack may be reduced as a consequence of the supporting effect of external load (63). Therefore, the potential effects of external load on the capability to quickly build-up activation and on muscle slack may partially explain the less pronounced improvements in rapid force development for the well-trained individuals. In addition, this effect may also explain why the transfer is even more limited in the SJ compared to a CMJ. Specifically, the countermovement during a CMJ allows more time to build-up activation (64), hereby potentially having a similar effect as an external load. However, during the SJ, there is no countermovement that provides the athlete with more time to build-up activation. Furthermore, during a SJ, the athlete may need to create co-contractions to take up muscle slack, whereas the countermovement during a CMJ can reduce the degree of muscle slack (64). Therefore, when rapid force development is assessed during a SJ, the negative effects of an external load may be more pronounced.

Influence of Coordination. Training can also result in a decreased capability to rapidly develop force. For example, Dalen et al. (16) found a large increase in the time to peak force during an unloaded SJ following 3 weeks of separate ballistic squat training without plantar flexion and plantar flexion training in sport science students. In contrast, the group that performed a ballistic squat with plantar flexion showed a trivial increase in the time to peak force. These findings suggest that it is important to specifically mimic the intermuscular coordination patterns of the sports movement to maximise the transfer and to prevent decreases in performance.

The Transfer of Countermovement Training. In addition to the possible influence of muscle slack and intermuscular coordination, another possible explanation for the small amount of significant improvements in rapid force development following resistance training is that the resistance program used to improve rapid force development may have a limited transfer to the test used to measure rapid force development. Moreover, the test used to measure rapid force development may also have limited transfer to actual sport performance. Indeed, several studies have used a movement that involves a countermovement when measuring the rapid force development (14,29,42,43,46,47,50,66), while there is usually no time to perform a large countermovement in the actual sport. For example, an elite 100 m sprinter or an elite swimmer will not first perform a large countermovement after the start signal has been given. The countermovement may take up muscle slack and allow time to build-up activation

(63–65) and hence reduce the transfer between the test and actual sport performance. Therefore, assessment of the rapid force development in a movement involving a countermovement (e.g., vertical countermovement jump or horizontal broad jump) may provide limited information for the rapid sport performance in movements where there is no time to perform a CM.

During the first steps of a sprint, force is primarily generated by a concentric contraction of the contractile element (37) and the countermovements produced by the pendulum motion of the leg may not be large enough to reduce a considerable amount of muscle slack and the duration may not be long enough to allow a full build-up of activation. Therefore, measurement of the rapid force development during a SJ may give a better representation of short acceleration than a CMJ or drop jump. Indeed, a study among national level skeleton athletes found (only) a moderate correlation between the rate of force development in the SJ and the 5 m sprint performance and even a smaller correlation between the rate of force development in a CMJ and the 5 m sprint performance (50).

In summary, although only one study has directly compared the transfer of the rapid force development in a movement involving a countermovement vs. no countermovement, the results suggest that the performance of a countermovement also limits the transfer to movements in which there is no time to perform a large countermovement.

The Transfer of Bilateral Movements to Unilateral Movements. The studies included in this systematic review measured the rapid force development in bilateral movements in which the force production is mainly vertical (e.g., CMJ and SJ), while the force production is both vertical and horizontal in most unilateral movements such as sprinting (29,30,36,41–43,50,54). Differences in the mechanisms of force production between bilateral and unilateral movements may also reduce the transfer between these movements (11,52,62).

Indeed, a study among competitive team sports players found a moderate correlation between the rate of force development in a split squat and 5 m sprint performance and only a small correlation between the rate of force development in a back squat and the 5 m sprint performance among competitive male athletes (54). Furthermore, a study among (inter)national athletes found that the rapid force development during a SJ and drop jump could not predict the sprint performance over 2.5, 5 m and longer distances (41). Finally, a study among recreationally trained individuals did not find significant improvements in several measures of the rapid force development during an unloaded CMJ, while 40 and 60 yards sprint performance did show a significant improvement (36). The findings of these studies suggest that bilateral tests have a limited transfer to unilateral movements, especially for well-trained individuals. However, there are also some studies that did found simultaneous improvements in the rate of force development during an unloaded jump squat and the 5 m sprint performance (13,15). In addition, another study found simultaneous improvements in the initial rate of force development during an unloaded SJ and the 30 m sprint performance (30). However, the last 3 studies used moderately trained individuals and therefore, there is again a trend for untrained and recreationally trained individuals to show positive transfers, while these transfers are (very) limited in well-trained individuals. Based on these findings, the transfer from bilateral movements to unilateral movements appears to be limited, especially for well-trained individuals. Future research should therefore investigate whether bilateral performed resistance training leads to an improved rapid force development in unloaded dynamic isoinertial unilateral multi-joint movements among well-trained individuals.

Limitations

There was a high risk of bias for the training experience (Table 1) and therefore these results should be interpreted with caution. Usually, only a general subdivision is made between untrained and trained individuals. However, large differences may also exist between an elite athlete and a sub-elite athlete, even though they both have been training for a long time. For example, an intervention may have a positive effect on the maximum sprinting speed of professional football player, but a detrimental effect on the maximum sprinting speed of an elite 100 m runner. If the goal is to generalize the results of the intervention to other populations it is therefore important to correctly classify individuals to their training status. Since the effect size were usually smaller, and because there were slightly more significant improvements in rapid force development for the SJ in untrained and recreationally trained individuals compared to the well-trained individuals, it may be expected that the resistance training has less beneficial effects on rapid force development in unloaded dynamic isoinertial multi-joint movements in well-trained elite athletes.

Another limitation is that the results of the included studies were interpreted based on statistically significance, instead of effect sizes and confidence intervals (5,31) as would be possible with a meta-analysis. However, the majority of the studies did not include the information necessary to calculate the effect size and confidence intervals and most authors did also not provide this information after multiple requests. When possible, effect sizes were calculated and reported in Table 2 to give an indication of the magnitude of the effect. It should be noted though that the effect size used in this review it not corrected for changes in the control group whereas other effect sizes are (45). However, studies among (sub)elite athletes usually do not include a control group and therefore it is not possible to calculate an effect size with correction for changes in the control group for these studies. Calculation of an effect size with correction for changes in the control group for untrained and recreationally trained individuals only would allow comparison with (sub)elite athletes (45). Therefore, the adopted calculation of effect size was considered the most appropriate.

Finally, in this systematic review, a training intervention involving external load was classified as resistance training. However, there is a wide range of different resistance training modalities such as ballistic training, hypertrophy training and maximum strength training. Although these modalities may have different effects on the rapid force development, the variety in training programs among studies was too diverse to allow strong conclusions regarding the effects of different training modalities on rapid force development. The results of several studies do however suggest that ballistic resistance training is more effective than traditional resistance training (13,14,47). Interestingly, a study among untrained individuals found that only the group training with external load significantly improved the rate of force development during an unloaded CMJ, while the group that performed technical training did not show a significant improvement (33). This finding suggests that training with external load is necessary to improve the rapid force development in untrained individuals. However, it is well possible that the rate of force development would also have been improved with good technical training, while technical training of moderate or bad quality may not result in an improved rapid force development. The exact details concerning the training program are however usually not reported, which makes it hard to determine the quality of a training program. Future research should therefore provide more details concerning the exact training program. The Consensus on Exercise Reporting Template (CERT) provides more information on the details that should be reported (53).

Practical Applications

The finding that resistance training has a limited transfer to rapid force development in unloaded dynamic isoinertial multi-joint movements has several important implications. First, this finding indicates that current training approaches to improve high-intensity sports performance or prevent injuries by improving rapid force development may not be as effective as commonly assumed. To increase the effectiveness of these approaches, it is important to train more specific to maximize the transfer from training to the sports movement, especially in well-trained individuals. Additionally, it is often assumed that untrained or recreationally trained individuals do not need specific training since any training will result in improvements in performance. However, the findings of this review indicate that specific training is also important to improve rapid force development in these individuals.

There are several aspects that influence the transfer between a movement performed during a test or training and the sports movement. For example, rapid force development has likely a limited transfer from movements with countermovement to movements without a countermovement and from bilateral movements to unilateral movements. Coaches and researchers should therefore consider these factors when designing training programs. Additionally, the addition of external load may also decrease the transfer to unloaded movements. Therefore, special attention should be paid to the effects of external load, since its influence is usually overlooked. Based on these findings, we concur with previous suggestions (69) that it is important to specifically mimic the actual sport movement in order to maximize the transfer between movements, especially for well-trained individuals. However, it should be noted that this does not mean that all training should exactly mimic the competition demands since this may eventually lead to overtraining, an increased risk of injuries and boredom.

Conclusion

Resistance training has a limited transfer to rapid force development in unloaded dynamic isoinertial multi-joint movements (i.e., most sports and daily living movements) and this effect is most pronounced in movements that do not involve a countermovement. Furthermore, the findings also suggest that this transfer is less pronounced in well-trained individuals. It is therefore important to specifically mimic the actual sport movement to maximize the transfer of training and testing.

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