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Force-Time Dependent Characteristics of Dynamic and Isometric Muscle Actions

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Reference Data

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ABSTRACT

Eight trained men were used to compare isometric and dynamic force-time variables. Subjects performed maximum isometric and dynamic pulls at 80% (DP80), 90% (DP90), and 100% (DP100) of their current 1-RM power clean from a standardized postion on a 61.0- × 121.9-cm AMTI force plate. Isometric peak force showed moderate to strong correlations with peak force during DP80, DP90, and DP100 (r = 0.66, 0.77, and 0.80, respectively). Isometric rate of force development showed moderate to strong correlations with dynamic peak force during DP80, DP90, and DP100 (r = 0.65, 0.73, and 0.75, respectively) and was strongly correlated with peak dynamic rate of force development during DP80, DP90, and DP100 (r = 0.84, 0.88, and 0.84, respectively). This suggests that the ability to exert both isometric and dynamic peak force shares some structural and functional foundation with the ability to generate force rapidly.

Key Words: rate of force development, peak force, power

Introduction

Force-time curve analysis has been used to evaluate skeletal muscle function (4, 15). Force-time characteristics (Figure 1) such as the rate of force development (RFD) and maximal force (MF) have been widely investigated with respect to skeletal muscle fiber type (2), age (2, 3, 7), gender (15), and fatigue (12, 20).

An important performance variable is the ability to generate high RFD (16, 21). The quantification of the RFD has been typically associated with the use of isometric testing (1, 3, 8–10, 21, 22). The highest isometric rates of force development (IRFD) are found in male power athletes who employ explosive exercises of varying loads in their training (12). Explosive exercises tend to enhance the ability to generate high IRFD (9, 12, 24), while exercises that are not explosive generate slow IRFD (11, 12, 17). Endurance athletes typically generate slow IRFD due to training that involves slow contraction velocities with low loads (12). The quality of physical performances that occur in less than 250 ms is most dependant on IRFD (16, 24). When heavy loads are encountered and performance lasts longer than 250 ms, MF becomes the most important factor (16, 4). Some studies have reported a significant relationship between some parameters of isometric and dynamic muscle actions (13, 17, 18). However, other studies have reported that IRFD is not related to dynamic activities with high dynamic rates of force development (DRFD) such as sprinting (14, 21) and jumping (23).

The purpose of this study was to examine the force-time characteristics and intercorrelation of various aspects of dynamic and isometric muscle actions, which are represented by the midthigh clean pull (CP), countermovement jump (CMJ), and static vertical jump (SJ).

Methods

Subjects and Instrumentation

Eight men with at least 2 years of training experience with dynamic explosive exercises (power cleans, snatches, snatch-and-clean pulls) were tested. The subjects' height, weight, age, and maximal power clean were: 179.9 ± 1.4 cm; 95.1 ± 4.4 kg; 27.0 ± 2.9 yrs; and 114.7 ± 8.0 kg. All subjects completed an informed consent form prior to participation in the study.

All lifts were performed on a custom built isometric rack (Sorinex Inc., Irmo, SC) which allows the bar to be fixed at any desired height above the floor using a combination of pins and hydraulic jacks. The isometric rack was placed over a 61- × 121.9-cm AMTI forceplate (Advanced Mechanical Technologies, Newton, MA) which sampled

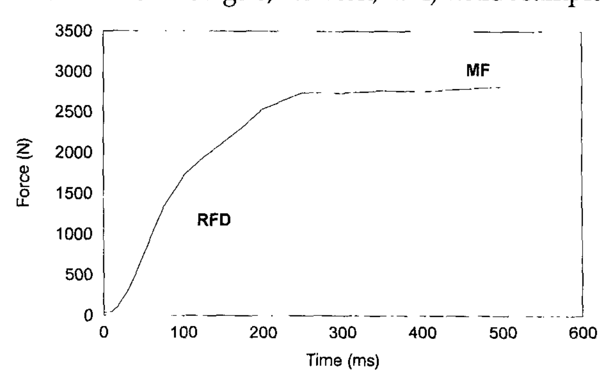

Figure 1. Force-time curve characteristics.

at a rate of 500 Hz. Several variables from the vertical force component (Fz) were calculated from ground reaction force data over the entire sampling period. Force/rate of change was the difference between two adjacent force samples divided by the intersample time interval (0.002 sec). Vertical velocity of the center of mass (CM) was calculated from the principle that net force × time = the product of mass and change in velocity. Thus the change in vertical velocity of the CM during a computer sampling interval equaled the net vertical force on the body multiplied by the intersample time period divided by the mass. The net force was taken as the vertical force platform reading minus weight.

For the jump tests, the mass and weight used were those of the jumper. For the weight lifting trials, the mass and weight used were those of the lifter + barbell. Absolute velocity at the end of each sampling interval was determined by adding the velocity change over the interval to the preinterval absolute velocity, which was zero at the start of the movement. The vertical position change over each interval was calculated as absolute velocity multiplied by the time interval. Position changes were added in succession, beginning with the position at the start, to yield absolute vertical position at the end of each interval. Instantaneous power was calculated as vertical force × concurrent vertical velocity. After all these variables were established for the entire movement, each variable's peak and time of peak were determined.

All subjects completed a warm-up of static stretches that focused on the muscle groups to be used in testing, and 5 power cleans at 30–50% of their current 1-RM power clean. Prior to the isometric test they performed 3 isometric pulls. As part of the vertical jump test warm-up they performed 3 practice CMJ and SJ.

Tests

All subjects participated in 2 isometric clean pulls from midthigh. This movement was chosen because it corresponds to the portion of the clean and snatch in which the highest velocities and forces are generated (6). Once placed in position, knee and hip angles (144 ± 5°; 145 ± 3°) were measured in order to reproduce the same position on each trial. Subjects were then strapped to the bar using standard lifting straps and athletic tape. They were instructed to pull as fast and hard as possible. When the aim of testing is to record maximal force and rate of force development, these instructions produce optimal results (1). Subjects then had 3 min rest between trials.

The dynamic midthigh pull test used an Olympic bar, plates, and the adjustable rack upon which the bar rested before each lift. Subjects completed 3 pulls at 80, 90 and 100% of their 1-RM power clean (114.7 ± 8.0 kg). The lifter's position was established using the knee and hip angles determined by goniometry during the isometric portion of the test. Subjects used standard lifting straps during all dynamic trials. They were then instructed to pull as fast and hard as possible. Again, they rested 3 min between trials.

All subjects completed 6 vertical jumps (3 CMJ, 3 SJ). All vertical jumps were executed with hands on hips (10). SJs were initiated from a leg and hip position representative of the pull position used in the isometric and dynamic tests. The first 2 CMJ and SJ were practice trials and thus were not analyzed. The 3rd CMJ and SJ trial were performed on a 61- × 121.9-cm AMTI force plate.

Analyses

Force-time curves were analyzed during isometric and dynamic actions. The isometric variables analyzed were isometric rate of force development (IRFD) and isometric peak force (IPF). The dynamic lifting variables analyzed were dynamic peak force (DPF), dynamic rate of force development (DRFD), dynamic peak power (DPP). The vertical jump variables examined were vertical displacement during jumps (VD), vertical jump peak force (VJPF), vertical jump rate of force development (VJRFD).

Pearson product-moment correlation coefficients were used to determine the relationships between isometric and dynamic time-dependant variables. Paired *t*-tests were used to determine whether there were significant difference between multiple isometric trials, with an alpha of $p < 0.05$, and 2 × 3 ANOVAs were used to compare selected force-time variables during isometric pulls, dynamic pulls, and vertical jumps. When differences were found, a Tukey studentized range test was used as the post hoc test, with alpha set at $p < 0.05$.

Results

Force-time dependent variables were analyzed during isometric and dynamic actions. Performance characteristics are listed in Table 1.

When correlating the two isometric trials, it was determined that IPF and IRFD had Pearson product moment values of $r = 0.93$ and 0.92, respectively. The multiple isometric trials were not significantly different. The combination of strong correlations and lack of significant difference suggests good test-retest reliability. The correlations achieved between force-time variables for the isometric and dynamic midthigh clean pull and the static

Table 1
Performance Characteristics (*N* = 8)

Variable	Isomet. pull	DP100	DP90	DP80	CMJ	SJ
Peak force (N)	2847.14 ±255.77	2723.96 ±162.86	2682.88 ±173.01	2671.04 ±163.74	1516.26 ±108.93	2161.44 ±126.25
RFD (N · s^{-1})	29693.11 ±3069.87	38178.14 ±3161.44	43126.28 ±3693.11	46306.89 ±3291.59	24037.50 ±4341.37	46660.03 ±4955.74
Peak power (W)		2404.10 ±251.02	2422.70 ±251.90	2440.23 ±236.90	5125.63 ±314.59	3702.91 ±351.68
Vertical displacement (m)					0.47 ±0.03	0.28 ±0.03
Time of peak RFD (ms)	68.00 ±9.71	65.50 ±7.36	67.25 ±4.57	70.75 ±10.95	149.00 ±25.10	62.00 ±4.26
Time of PF (ms)	222.25 ±23.51	136.50 ±9.16	127.50 ±8.52	119.75 ±9.80	291.75 ±25.77	101.50 ±8.96

Table 2
Correlations (*r*) Between Isometric & Dynamic Midthigh Pulls

Dynamic pull	At 100% RFD	At 100% PF	At 90% RFD	At 90% PF	At 80% RFD	At 80% PF
Peak force (N)	0.75*	0.80*	0.73*	0.77*	0.65*	0.66
RFD ($N \cdot s^{-1}$)	0.84*	0.36	0.88*	0.30	0.84*	0.45
Peak power (W)	0.41	0.70	0.52	0.72	0.54	0.53

Isometric PF (N) and RFD ($N \cdot S^{-1}$) = 0.68. RFD = rate of force development; PF = peak force. *Significant at $p < 0.05$

Table 3
Correlations (*r*) Between Isometric & Vertical Jump Variables

Vertical jump	Isomet. RFD	Isomet. PF	Isomet. RFD	Isomet. PF
	Countermvmt.		*Static mvmt.*	
PF (N)	0.44	0.53	0.57	0.76*
RFD ($N \cdot s^{-1}$)	0.21	–0.13	–0.18	–0.46
Peak power (W)	0.62	0.47	0.76*	0.47
Vertical disp. (m)	0.07	–0.35	0.82*	0.56

*Significant at $p < 0.05$

Table 4
Correlations (*r*) Between Dynamic Midthigh Pulls & Vertical Jump Variables

Dynamic pull	Countermovement vertical jump PF	RFD	Disp.	PP	Static vertical jump PF	RFD	Disp.	PP
At 80%								
Peak force (N)	.80*	.21	.12	.63	.18	–.04	.56	.50
RFD ($N \cdot s^{-1}$)	.31	.11	.12	.34	–.17	–.25*	.78	.53
Peak power (w)	.67	.16	.09	.42	.08	.03	.58	.43
At 90%								
Peak force (N)	.78*	.17	.15	.70*	.21	–.14	.58	.55
RFD ($N \cdot s^{-1}$)	.36	.48	.27	.53	.09	.08*	.75	.68
Peak power (W)	.67	–.07	.01	.49	.10	–.10	.51	.38
At 100%								
Peak force (N)	.80*	.21	.07	.67	.28	–.14	.62	.62
RFD ($N \cdot s^{-1}$)	.23	.32	–.09	.21	.03	–.05*	.88	.70*
Peak power (W)	.63	–.11	–.14	.32	.03	–.19	.47	.30

*Significant at $p < 0.05$

and countermovement vertical jump are listed in Tables 2, 3 and 4. In examing the PF values, no significant difference was found between the isometric, dynamic pulls at 80, 90, and 100%. However, the PF generated during the CMJ and SJ was significantly lower than the isometric and all dynamic midthigh clean pulls. Peak force tended to increase as the resistance increased from the 80% dynamic trial to the isometric trial.

The rates of force development during the isometric test were significantly lower than those achieved during the SJ and dynamic pulls at 80 and 90% of max power-clean performance. However, both CMJ and dynamic pulls at 100% of 1-RM power-clean rates of force development did not differ significantly from achieved IRFD values. As well, RFDs achieved during the 80, 90, and 100% trials did not differ significantly. But the RFDs achieved during CMJ and SJ were significantly different.

The time at which maximal RFD occurred for isometric, dynamic pull at 80, 90, and 100%, and SJ tests, were significantly different. However, the time to maximal RFD during the CMJ was significantly longer than the other test measures. The time at which PF occurred was significantly later during the isometric and CMJ trials when compared to all dynamic pulls and the SJ. The time to PF during all dynamic pulls and the SJ trial did not differ significantly. However, the time to peak force was significantly longer during the CMJ than the isometric trial.

Discussion

The high test reproducibility between isometric trials in this study agrees with Bemben et al. (3), who reported overall reproducibility of maximal force, time to maximal force, and maximal RFD as good. Viitasalo and Komi (19) also reported that force-time measurements in a bilateral leg extension produced good trial-to-trial reproducibility.

The strong to moderate correlation between isometric and dynamic force-time dependant variables does not agree with the data of Wilson et al. (21) and Mero et al. (14). Wilson et al. (21) suggest that isometric tests are not related to dynamic sprint performance. Their isometric and dynamic performance comparisons compare a vertical isometric squat measure to a horizontal dynamic performance (sprinting). Concerning the lack of relationship between IRFD and dynamic sprinting performance reported by Mero et al. (14), they used an isometric knee extension in order to measure IRFD, which may not be a specific test for a running motion. The present study measured the force-time dependant variables during an isometric and dynamic midthigh clean pull. The similarities in the vertical component of these two motions may explain the present correlations.

Jaric et al. (13) used 4 isometric tests to examine the muscle groups that are active during a vertical jump and found that 25% of the variation in kinematic variables in the vertical jump were related to the kinetic parameters of the leg extensors. It can be inferred, then, that vertical jump performance is 25% dependant on kinetic variables (RFD and PF) of the leg extensors. Therefore, significant correlations might be expected between IRFD and jumping performance. The lack of correlation ($r = 0.07$) between isometric IRFD and CMJ performance in the present study disagrees with Viitasalo et al. (18), who reported that CMJ height and IRFD are significantly interrelated. However, this same lack of correlation agrees with Young and Bilby (23) and Wilson et al. (21), who found no relationship between IRFD and CMJ performance. Wilson et al. (21) examined the RFD during a stretch-shortening cycle (SSC) and determined there was no significant relationship to dynamic performance. Also, it was reported that the IRFD and the SSC were poorly correlated ($p = 0.36$).

Conversely, there were strong correlations in the present study between IRFD and SJ performance ($r = 0.82$). Our static vertical jump test was similar to the concentric test used by Wilson et al. (21), which consisted of a concentric-only weighted jump and was determined to be significantly related to dynamic performance. Wilson et al. suggest that the concentric test (SJ) is the most effective jump test.

In the present study, PF occurred within 250 ms in all tests. The ability to generate PF in less than 250 ms suggests that the athletes used a combination of initial RFD and maximal RFD (16). Häkkinen et al. (9) have reported that training with explosive exercises can enhance the ability to generate high RFD. Since all our subjects were trained with explosive exercises, the RFD and time to PF achieved were expected. However, there was a general trend of decreasing RFD and increasing PF as the weight was increased from 80% to the immovable weight represented in the isometric test.

The RFD achieved in the isometric test was significantly less than during the 80 and 90% clean-pull trials. The isometric RFD was less than the RFD during the 100% clean-pull trial but was not significantly different. All dynamic trials exhibited a nonsignificant decrease in RFD as the load lifted increased. As the resistance was increased from 80% to the isometric trials, there was a general shift toward increased PF. However, no significant difference was found between any of the dynamic lifts and the isometric trials. The shift toward increased reliance on PF as heavier loads were encountered supports the data of Schmidtbleicher (16).

The present study seems to suggest that the heavier the mass lifted, the more closely the structural and functional aspects of the neuromuscular system involved in the application of maximal dynamic force overlap those involved in maximal isometric force production. Likewise, the ability to generate high power during weightlifting, especially when using heavier weights, appears to have some common basis with the ability to exert high IPF. These data also suggest that the ability to exert both IPF and DPF shares some structural and functional foundation with the ability to generate force rapidly.

Practical Application

Many sports require high RFD and power output. Häkkinen et al. (10) suggest that dynamic explosive exercise training can enhance the ability to generate high dynamic RFD. Furthermore, training at high power outputs, which also provide high RFDs, can enhance dynamic performance variables better than typical heavy weight training. The present study suggests—at least in clean pulls—that the relative intensity of explosive exercises should be 80% or less. It supports the data of Garhammer (5) which suggests that 80% of the 1-RM for the snatch and clean produce the highest power outputs. Therefore, to best utilize the clean pull to bring about adaptations in peak power and DRFD, one should employ relative training intensities of ~80%.

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