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Propulsion Forces as a Function of Intensity for Weightlifting and Vertical Jumping

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ABSTRACT

Garhammer, J. and R. Gregor. Propulsion forces as a function of intensity for weightlifting and vertical jumping. *J. Appl. Sport Sci. Res.* 6(3):129-134. 1992.—*Four Olympic-style weightlifters and six athletes from other sports volunteered to perform maximal and submaximal vertical jumps with countermovement and/or snatch lifts on a Kistler force plate to compare the kinetics of the two activities at different levels of effort. Parameters studied included maximum vertical ground reaction force generated during a snatch lift or jump for both maximal and submaximal efforts and force duration at magnitudes greater than 50, 80 and 90 percent of max during the propulsion phase of each activity. Results indicated that in both activities, as the level of performance (intensity) increased, maximal propulsion force magnitudes generally decreased, whereas the duration of force at higher percentages of maximum increased. Qualitative similarities in the temporal pattern of vertical ground reaction force for each activity were observed in both unweighting and propulsion phases. Use of a double knee bend lifting technique accounted for an unweighting phase during the snatch lifts. Data indicated that the athletes used adjustments in temporal pattern of propulsive force application, rather than an increase in the magnitude of force generated for maximal versus submaximal efforts in both activities. Athletes who require improved jumping ability may benefit from utilizing Olympic lifting movements as part of their strength training program due to the applied overload and the similarities found between the propulsive* force *patterns of each activity.*

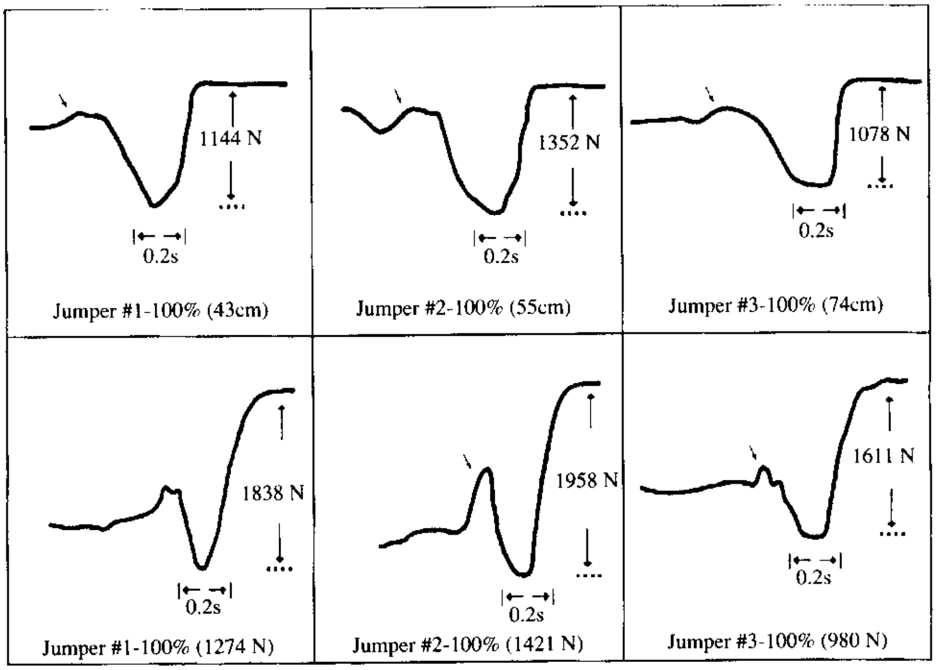
KEY WORDS: Thrust force, snatch lifts, jumps, impulse, force plate.

INTRODUCTION

Coaches of Olympic-style weightlifters are in general agreement that the most rational technique for executing the competitive lifts include phases that can be characterized as jumping vertically with the barbell. During this jumping phase of a lifting movement the propulsive force (vertical ground reaction force) primarily developed by dynamic activation of leg, hip and shoulder girdle muscles (8), is transferred to the barbell by keeping the arms and torso straight, via isometric contraction of appropriate muscles, so they act like rigid links. Similarities in lower extremity and torso movements during the propulsion phase of a standing vertical jump and snatch or clean lift can be seen by viewing these activities from a position perpendicular to the sagittal plane of motion. The starting position, including joint angles at the hip, knee and ankle, are also comparable for skilled performers. Numerous kinetic evaluations of vertical jumping have been published (4, 11, 14, 15, 17). Less common are kinetic data on the performance of competitive Olympic-style weightlifting (1, 6, 7, 9, 10). Only one kinetic comparison of these two activities has been found (3). The purpose of this paper is to compare vertical ground reaction forces exerted during vertical jumps and snatch lifts for both maximal and submaximal efforts.

METHODS

The vertical force-time histories of four male Olympic weightlifters performing snatch lifts on a Kistler force plate (model 9251A) were compared with those of nine male athletes executing standing vertical jumps with a countermovement on the same force plate. Three of these nine were experienced Olympic lifters and two of these lifters were among the subjects who performed snatch lifts on the plate.



Jumper #1-100% (43cm)
Jumper #2-100% (55cm)
Jumper #3-100% (74cm)
Jumper #1-100% (1274 N)
Jumper #2-100% (1421 N)
Jumper #3-100% (980 N)

Figure 1: Vertical ground reaction forces for vertical jumps and snatch lifts (right foot only on the force plate for snatch lifts). Time advances left to right and the zero force level is at the right end of each curve when contact with the plate was lost (higher ground reaction forces deflected the curve lower). Arrows indicate unweighting phases ($\overline{X}$ ± SD).

Each athlete performing vertical jumps was permitted three maximal effort trials (after warm up exercises), followed by three trials to jump and touch a mark at 70 percent of his best maximal effort. Jump height was recorded from a chalk mark on a vertical scale made by the index and middle finger of the subject's "reach" arm. The subjects performing snatch lifts warmed up with increasingly heavy lifts until a maximum was reached for that day. The maximum lift and the next heaviest warm up lift were analyzed.

Force-time histories for both activities were registered on a Grass chart recorder (model 7B) connected directly to the force plate charge summing amplifiers. Force curves were digitized (HP 9864A system interfaced with an HP 9830A programmable calculator) to permit analysis of the force magnitude and durations. Parameters compared included maximum vertical force generated for each level of effort in a snatch lift or vertical jump and duration of the vertical force at levels above 50, 80 and 90 percent of its maximum value for the different levels of effort in each activity. These latter parameters relate to the rate of propulsion force rise and fall and the impulse generated during the propulsion phase of each activity.

RESULTS

Figure 1 shows tracings of representative ground reaction force-time histories for three jumps and three snatch lifts. Note the "unweighting" phase in each pattern just prior to the propulsion phase. Jumper No. 3 and lifter No. 3 were the same subject.

The average maximum vertical force generated by each of the subjects during maximal and submaximal (70 percent) efforts in the vertical jump, and their sport of primary participation, are listed in Table 1. Data from three trials were averaged for each subject at each level of jumping effort. Also shown for each subject are the average time intervals during which the vertical force was greater than 90, 80 and 50 percent of the maximum value during the propulsion phase of each effort. Five of the six athletes with the highest jumps registered lower average maximum force values for maximal effort, compared to submaximal effort jumps, as did two of the three athletes with the lowest jumps. All but one subject increased the duration of force at magnitudes greater than 90, 80 and 50 percent of maximum force for a given effort level when comparing maximal to submaximal jumping efforts.

Group averages and standard deviations for the maximum force and the duration of the different levels of force are listed at the bottom of Table 1 for both maximal and submaximal efforts. These group averages indicate that force durations at the different percentages of maximum force increased, while the magnitude of maximum force decreased for maximal versus submaximal effort jumps.

Table 2 lists the values obtained during the snatch lifts for the force and time variables presented in Table 1 for vertical jumps. If a lifter also participated in the jumping part of this study, his average jump values are repeated

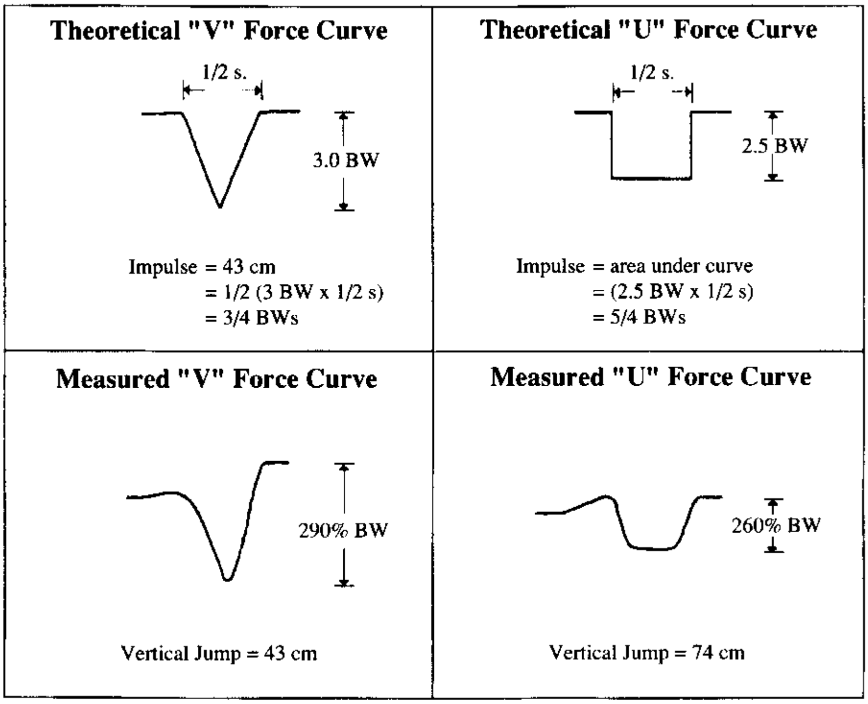


Figure 2: Theoretical thrust force versus time curves compared to selected experimentally measured curves ($\overline{X} \pm SD$).

from Table 1 for easy comparison. Two of the three lifters evaluated at different levels of effort registered lower maximal force for the 100 percent lift, compared to the submaximal lift. Durations of vertical ground reaction force were again found to be greater at magnitudes above 90, 80 and 50 percent of maximum force at a given level of effort when comparing maximal and submaximal lifts. Group averages and standard deviations for the duration of force above the three percentages of maximum are listed at the bottom of Table 2 for the three athletes who performed both maximal and submaximal snatch lifts. These averages also indicate that force durations at higher percentages of maximum force were increased for maximal compared to submaximal lifts.

Thrust Force is also listed in Table 2. It is defined as the difference between static system weight (i.e., jumper's body weight or lifter plus barbell weight) and the maximum vertical force generated during the activity. Values for thrust force were similar for the two athletes who performed both jumps and snatch lifts. For these subjects, thrust force differences ranged from 100 to 200 N, whereas maximal force differences for the same trials ranged from 1,000 to 1,500 N.

DISCUSSION

Figure 2 depicts two theoretical possibilities for force-time patterns along with two similar but experimentally measured patterns. The vertical momentum developed by a system depends on the magnitude of the vertical impulse applied. If a jumper or lifter produced the "V" pattern as shown in Figure 2 the impulse calculated is 0.75 body-weight-seconds. If, however, the "U" shaped pattern were generated, the resulting impulse is 1.25 body-weight-seconds for an equal propulsion duration, even though the maximum force achieved was lower (2.5 versus 3.0 times body weight). Thus, a greater maximum force generated during the propulsion phase of one of these activities does not assure a greater impulse or better result compared to that resulting from a lower maximum force effort. The time course of the force generation is also very important. The measured patterns in Figure 2 and data from Table 1 show that jumper VC (body weight = 819 N, max force = 2.91 x body weight) generated a "V" shaped force-time curve for a 43 cm jump, while jumper JG (body weight = 811 N, max force = 2.63 x body weight) generated a lower maximum force "U" pattern for a 74 cm jump, which agrees with the theoretical example.

As the duration of force above 90, 80 and 50 percent of its maximum value increases, a force-time curve assumes more of a "U" shape as opposed to a "V" shape. This indicates a more rapid rise and fall of propulsion force. Hunebelle and Damoiseau (12) have noted that poorer jumpers generated triangular ("V" shaped) impulse curves. Force-time graphs and discussions by Desipres (4) and Miller and East (15) indicate that better jumpers exhibit impulse curves with steeper slopes of force rise and fall, resulting in more of a "U" shape. A trend toward lower maximum forces during 100 percent efforts was also noted, again indicating the importance of force duration at higher

Table 1: Subject Information, Jump Heights, Maximum Propulsion Forces and Duration (s) of Forces Above Three Levels of Max with Group Averages ($\overline{X} \pm SD$).

Subject	Sport	Jump(cm)	Max Force (%Bwt)	t>90% Max	t>80% Max	t>50% max
JA	WL	72	293	0.21	0.25	0.29
Bwt =	WL	51	320	0.11	0.16	0.23
822 N						
D J	H J	75	313	0.13	0.25	0.29
Bwt =	H J	52	318	0.11	0.15	0.25
755 N						
MG	D, S P	75	295	0.14	0.21	0.31
Bwt =	D, S P	52	297	0.11	0.15	0.27
1069 N						
D L	SP, D	74	297	0.08	0.12	0.34
Bwt =	SP, D	52	315	0.11	0.13	0.26
1118 N						
J G	W L	74	263	0.17	0.23	0.35
Bwt =	W L	52	287	0.10	0.13	0.27
811 N						
B H	W L	72	248	0.26	0.29	0.43
Bwt =	W L	51	241	0.17	0.23	0.41
906N						
JL	H J	65	334	0.10	0.14	0.21
Bwt =	H J	45	384	0.08	0.11	0.16
779 N						
JR	BB	55	332	0.15	0.23	0.33
Bwt =	BB	39	310	0.14	0.20	0.33
780N						
V C	S C	43	291	0.13	0.17	0.27
Bwt =	S C	30	297	0.09	0.12	0.20
819 N						

Ave Max Force (s.d.) 100%	= 296 (28)
Ave Max Force (s.d.) 70%	= 308 (37)
Average "t" (std. dev.) for 100% effort	= 0.15 (0.06), 0.21 (0.06), 0.31 (.06)
Average "t" (std. dev.) for 70% effort	= 0.11 (0.03), 0.15 (0.04), 0.26 (0.07)

WL-Weightlifting; HJ-High Jump; D-Discus; SP-Shot Put; BB-Basketball; SC-Soccer; Bwt-Body Weight

percentages of maximum force, rather than just the magnitude of maximum force. Nelson and Martin (16) have also pointed out the greater importance of time of force application compared to force magnitude alone. Bosco and Komi (2) have provided evidence that the magnitude of propulsive impulse and the shape (steepness of slope) of the force-time curve for vertical jumps was dependent on the muscle fiber type composition of subjects tested. Muscle fiber type data was not available for the present subjects and could not be used to account for force-time history differences.

The data in Tables 1 and 2 indicate that both jumpers and weightlifters in this study did not increase their performance by increasing the magnitude of force generation, but rather by increasing the rate of force generation and the duration of force at higher percentages of maximum. The countermovement in the vertical jump and second bending (flexion) of the knees during a snatch lift as the bar rises above knee level (double knee bend technique (5) may be performed rapidly enough to store recoverable elastic energy and to elicit a stretch reflex facilitation of the immediately following concentric contraction of knee and hip joint extensor muscles. These sudden stretches occur for both maximal and submaximal efforts. However, higher volitional drive, the speed of movement and/or elastic energy storage and recovery involved with maximal effort may account for the more rapid rise of muscle tension and associated propulsion force for such an effort.

Table 2. Subject and Activity Information, Maximum Propulsion Forces, Thrust Forces and Duration (s) of Propulsion Forces Above Three Levels of Max with Group Averages for Snatch Lifts ($\overline{X} \pm SD$).

Subject	Activity	Effort (%)	Maximum Force (N)	System Weight (N)	Thrust Force (N)	t>90%	t>80%	t>50%
J G	VJ-74 cm	100	2130	811	1319	0.17	0.23	0.35
Bwt =	VJ-52 cm	70	2324	811	1513	0.10	0.13	0.27
811N	SN-980N	100	3222	1811	1411	0.16	0.18	0.32
831N	SN-853N	87	3140	1684	1456	0.12	0.16	0.31
BH	VJ-72 cm	100	2247	906	1341	0.26	0.29	0.43
Bwt=	VJ-51 cm	70	2187	906	1281	0.17	0.23	0.41
906N	SN-1274N	100	3676	2205	1471	0.08	0.12	0.26
931N								
RP	SN-1421N	100	3970	2534	1436	0.13	0.17	0.25
Bwt=	SN-1279N	91	3986	2392	1594	0.12	0.16	0.20
1113N								
G P	SN-1078N	100	3322	1880	1442	0.14	0.18	0.24
Bwt-	SN-1024N	95	3344	1826	1518	0.11	0.15	0.21
802N								
Average "t" (std. dev) for 100% snatch efforts =						0.14	0.18	0.27
						(.02)	(.01)	(.04)
Average "t" (std. dev) for submax snatch efforts =						0.12	0.16	0.24
						(.01)	(.01)	(.06)

VJ-Vertical Jump; SN-Snatch Lift; Bwt-Body Weight day of activity.

The net or "excess" thrust force (maximum vertical force minus static system weight) similarities found for two athletes performing both activities (Table 2) were unexpected. If snatch lifts are considered jumping with a load, then these data suggest that as system weight increases, the muscular forces available for accelerating the system (vertical ground reaction force minus static system weight) remain essentially the same. Data compiled by Nelson and Martin (16) indicate that as the load carried during vertical jumps increased the peak vertical thrust forces increased in such a way as to minimize changes in "excess" thrust force. In their study, height of jumps decreased with increased load, indicating that take-off velocity was inversely related to load, as were lower extremity joint angular velocities.

Results presented by Komi (13) showed that "excess" thrust force increased with load and decreased knee angular velocity during weighted static start vertical jumps in such a way as to form a curve that appears similar to a standard force-velocity curve for muscle contraction. Tihanyi et al. (19) and Tsarouchas and Klissouras (20) have also presented data from weighted vertical jump experiments which indicate that a force-velocity relationship exists for multi-joint activities. Data from the present study cannot be related to a force-velocity curve since joint angular velocities were not measured.

Based on experiments and training camp measurements (18), the majority of skilled weightlifters are excellent performers in the vertical jump. This may be attributable to the high degree of explosiveness (in the sense of mechanical power generated) required for success in the sport (9), and qualitative and quantitative similarities between the lifting movements and the vertical jump, some of which have been presented in this paper. Thus, it is reasonable to recommend the utilization of one or more of the classical weightlifting training movements (i.e., power cleans or snatches, pulls and jerks) in the strength and power development program of other athletes who need to improve jumping skills. One factor in such training methods may be neural learning of optimal motor unit recruitment patterns for the activity, which is needed for rapid increases in propulsion force magnitudes to generate "U" shaped force-time histories, rather than simply increases in muscle strength.

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