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Relationships of isometric mid-thigh pull variables to weightlifting performance

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***Aim*. The purpose of this study was to evaluate the relationship between weightlifting performance (snatch, clean and jerk, and total) and variables obtained from the isometric mid-thigh pull (IMTP).**
***Methods*. Twelve weightlifters, ranging from novice to advanced, performed the IMTP 10 days after a competition. Correlations were used to evaluate relationships between variables of the IMTP and absolute and scaled competition results.**
***Results*. Unscaled competition results correlated strongly with IRFD (0-200ms: r=0.567-0.645, 0-250ms: r=0.722-0.781) while results correlated weakly with Peak IRFD (5ms window, r=0.360-0.426). Absolute peak force values correlated very strongly with absolute values for the competition performance (r=0.830-0.838). Force at 100ms, 150ms, 200ms and 250ms also correlated strongly with competition results (r=0.643-0.647, r=0.605-0.636, r=0.714-0.732, r=0.801-0.804). Similar findings were noted for allometrically scaled values.**
***Conclusion*. Measures of average IRFD probably represent a more relevant variable to dynamic performance than does Peak IRFD (5ms). Maximum isometric strength also is likely to have a strong role in weightlifting performance.**

Key words: Muscle strength - Resistance training - Athletic performance.

Multijoint isometric testing represents one facet of performance monitoring, allowing the sport scientist and coach to evaluate a number of variables, such as isometric peak force (IPF) and isometric rate of force development (IRFD). Furthermore, the strength of relationship between isometric and dynamic tests appears to depend on a number of factors including: similarity of joint position between isometric test with a dynamic movement [1, 2] and if the choice of joint angles in the isometric test that are most similar to the position of greatest force production in the dynamic test.[2, 3] Multijoint isometric test variables also appear to have good reliability and strong relationships with variables of dynamic movements requiring large magnitudes of force,[4] including dynamic tests of strength and explosive strength and weightlifting movements.[5] Based on these criteria and characteristics, the isometric mid-thigh pull (IMTP), as first described by Haff *et al.*[1] appears to be a valid and reliable isometric monitoring test for weightlifters.

The IMTP is a compound, closed-chain isometric test designed to approximate the body position at the beginning of the second pull of the snatch and clean,[1] as the second pull has been shown to have the highest forces and velocities of any part of the lifts.[6] Certain variables of the IMTP have been shown to correlate well with various dynamic tests. For example, isometric peak force (IPF) correlates well with dynamic mid-thigh pulls of varying loads,[1, 4] multijoint lower body 1-RMs,[5] shotput and discus performance,[2] sprint cycling[7] and weightlifting performance.[8, 9] Some authors have found significant

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correlations with IMTP peak force and the power snatch in non-weightlifter athletes as well.[2] Thus, the use of isometric peak force as a valuable measure of maximum strength and its relation to dynamic movements appears well founded.

However, a factor that is unclear deals with the degree of relationship among variables using absolute values of isometric force production *versus* relative values. For example, stronger relationships have been noted for comparisons of dynamic versus isometric variables when the values are scaled by body mass or scaled allometrically for both sprint cycling [7] and weightlifting.[9] Another confounding factor is the use of net forces [10, 11] in which the body weight is removed from the meaurement versus total forces.[1, 7, 9] Furthermore there are differences in pulling technique with some researchers [10, 11] using a pull from just above the knee and others using a mid-thigh pull.[1, 4, 5, 7-9]

In addition, evidence supporting a relationship between dynamic performance and isometric rate of force development (IRFD) has not been consistent, with only one study finding strong correlations between weightlifting performance [8] and others showing mixed or weak correlations.[1, 7, 12] Part of the reason for this discrepancy may be the manner in which IRFD is calculated (peak *versus* average). Peak IRFD has been typically calculated as an "instantaneous" value using a small window of time (*e.g.* 2-5 ms) rather than calculated as an average over a time period (*e.g.* average IRFD 0-250 ms).[13, 14]

It was the purpose of this study to evaluate the relationship of dynamic weightlifting performance with measures obtained from the IMTP, considering 1) varying methods of scaling isometric force; 2) net *versus* total IPF; and 3) two different methods of measuring IRFD.

Materials and methods

Experimental approach to the problem

In this study, we evaluated the relationships between competition performance of weightlifters in a meet and IMTP variables obtained in a testing session 10 days postcompetition. The postcompetition testing was used as not all of the weightlifters participated in the pre-competition testing. However, previous data from our laboratory (unpublished) shows very strong correlations (r≥0.94) among weightlifters (and other athletes), between isometric data collected pre and postcompetition as much as four months apart.

Subjects

Athletes participating were male (N.=10) and female (N.=2) intermediate to advanced level weightlifters (N.=12; BdM, 91.1±20.1 kg; Ht, 173.6±7.7 cm). A performance classification table by Takano [15] was used to categorize the performance level of each lifter; although this sample contained USA National and Collegiate National level weightlifters their performance fell below the classification of "Master of Sport" and were therefore considered sub-elite. All athletes were familiar with testing protocols, and had read and signed informed consent documents pertaining to the long-term athlete monitoring program. All documents and testing procedures were in accordance with the guidelines of the University's Institutional Review Board.

Testing procedures

Scheduling

Ten days after a weightlifting competition each lifter participated in testing procedures used regularly as part of a performance monitoring program. Subjects completed a typical low volume active rest workout during the ten days prior to testing. Table I represents an example training week during active rest. Active rest is designed to allow lifters to recuperate and recover from the prior training cycle and competition; as such, total fatigue during this phase of training is intended to be low.

Hydration and anthropometrics

Athletes entered the laboratory in the morning at 7:00 AM and were evaluated for hydration using a refractometer (PAL-10s, Atago USA Inc, Bellevue, WA) as hydration status may have a detrimental effect on strength and power.[16] Athletes not hydrated were not allowed to begin testing until evidence of moving toward hydration was achieved (*i.e.* urine specific gravity of ≤1.020). Body mass was assessed with a calibrated digital scale to the nearest 0.1kg (Tanita BF-350,

TABLE I.—*Active rest training performed by lifters.*

Monday and Friday		Wednesday	
Overhead squats	3x3@65-80%	Power Snatch	3x5 at 50-60%
Lunge with press	3x3@65-80%	Snatch Grip Shoulder Shrugs	3x5 at 65-80%
Incline press	3x3@65-80%	Cleans	3x3 at 50-60%
Front raise with plate	3x5@65-80%	Straight Leg Deadlift	3x5 at 65-80%

All intensity prescriptions are noted as percentage of 1-RM. All prescribed exercise sets/reps are followed by a down set at 50-60% of the load used. Additional low volume mid-section training was performed on Tuesdays and Thursdays.

Arlington Heights, IL). Athlete height was measured using a stadiometer to the nearest 0.5 cm.

Warm-up procedures

Warm-ups were standardized among participants. Each subject began with 30 jumping jacks, then performed 3 sets of 5 repetitions of dynamic clean-grip pulls from mid-thigh (hang position), with approximately 60 seconds between sets. Males performed this exercise with 60 kilograms, while females used 40 kilograms.[13]

Isometric mid-thigh pull testing

Procedures for the IMTP have been reported previously.[9] In our laboratory, the IMTP was performed standing on a 91.4x91.4 cm (Rice Lake Weighing Systems, Rice Lake, WI) inside of a custom designed power rack that allows fixation of the bar at any height. Athletes were secured to the bar using lifting straps and athletic tape, utilizing a clean grip, then were instructed to assume a body position very similar to the start of the second pull of the snatch and clean.[13, 17, 18] Knee angle was assessed using a hand-held goniometer to verify that knee angle fell between 125-135°; hip angle was approximately 175°.[13] Once body position was stabilized (verified by watching the athlete and force trace), the athlete was given a countdown. Minimal pre-tension was allowed to ensure that there was no slack in the subject's body prior to initiation of the pull. Each athlete performed two warm up attempts, one at 50%, and one at 75% of the athlete's perceived maximum effort. Subjects then performed 2-3 maximal isometric mid-thigh pulls. The test attempt was terminated if a consistent decrease or plateau in peak force was observed. A third trial was only used if a difference of ≥250N was observed between the first two trials.[13] Athletes were instructed to pull as "fast and hard" as possible, and received loud, verbal encouragement.[19]

Ground reaction forces were measured only in the vertical direction. IPF and force at 100 ms, 150 ms, 200 ms and 250 ms was measured (ICCα: 0.944, 0.838, 0.887, 0.935, 0.944, respectively). IRFD was calculated as 0-100 ms, 0-150 ms, 0-200 ms and 0-250 ms (ICCα: 0.885, 0.92, 0.954, 0.947, respectively), as the length of the second pull of weightlifting movements has been estimated to be approximately 100-200ms.[18, 20] Peak IRFD (PIRFD) using a 5 ms window (ICCα: 0.966) was measured. Unless otherwise stated, all force values reported were gross values, as the force plates were not offset for the weight of the lifter on the force plate.

Analog data from the force plate were amplified and conditioned (low-pass at 16 Hz) using a Transducer Techniques amplifier and conditioning module (Temecula, California). An analog to digital converter (DAQCard-6063E, National Instruments, Austin, TX) collected at 1000 Hz and analysis using custom Labview software (National Instruments, Austin, TX). The digitized signal was filtered using a 4^{th} order Butterworth low-pass filter at 100Hz.

Data analysis

Competition results (snatch, clean and jerk, and total) were scaled using several common procedures: scaling to body mass (load•bodymass^{-1}), allometric scaling (load•bodymass$^{-0.67}$) and the Sinclair Total.[21, 22] Allometric scaling takes into consideration the fact that increases in body mass do not translate to a linear increase in performance.[21] The Sinclair total is a polynomial method used to compare weightlifters across body weights, by calculating what the lifter's theoretical total would be if he or she were in the 105+ (male) or a 75+ (female) weight category, given the lifter's current skill level.[22] It is recalculated every

E II.—*IMTP Performance Results.*

Subject	Mean±SD	1	2	3	4	5	6	7	8	9	10	11	12
: Force	5576±1147	3713	3773	4943	5208	5349	5349	5428	5655	6400	6817	7115	7157
e at 100ms (N)	2672±622	1362	1713	2590	2849	2865	2853	3067	2657	3319	3321	3240	2233
e at 150ms (N)	3581±848	1735	2411	3189	4180	3757	3746	4290	3523	4463	4019	4521	3132
e at 200ms (N)	4044±907	2174	2653	3342	4232	4334	4323	4911	4218	4580	4552	5302	3901
e at 250ms (N)	4260±943	2284	2730	3608	4126	4539	4522	4876	4619	4803	5017	5494	4496
0-100ms ·S-1)	14292±5782	5894	8597	15485	20018	17509	17432	15691	8475	21142	11661	22554	7051
0-150ms ·S-1)	15582±5450	6418	10383	14318	22216	17620	17573	18612	11428	21724	12428	23578	10691
0-200ms ·S-1)	14002±4102	7007	8996	11506	16920	16099	16065	17066	12045	16877	11986	21590	11867
0-250ms ·S-1)	12066±3174	6047	7508	10267	13114	13702	13649	13513	11239	14392	11449	18038	11872
: Force (allo)	278±50	218.6	237.8	253.4	279.4	313.4	258.2	241.5	216.6	327.2	278.8	337.5	371.9
e at 100ms (allo)	133±27	80.2	108	132.7	152.9	167.8	137.7	136.4	101.8	169.7	135.8	153.7	116.1
e at 150ms (allo)	178±39	102.2	152	163.4	224.3	220.1	180.8	190.8	135	228.2	164.4	214.4	162.8
e at 200ms (allo)	201±39	128	167.2	171.3	227	253.9	208.7	218.5	161.6	234.2	186.2	251.5	202.8
e at 250ms (allo)	211±39	134.5	172.1	184.9	221.4	265.9	218.3	216.9	176.9	245.5	205.2	260.6	233.7
: Force (SCBM)	62.4±12	53.1	59.7	57.4	64.7	75.8	56.7	50.9	42.4	74	56.4	73.5	84.8
e at 100ms CBM)	29.8±6.5	19.5	27.1	30	35.4	40.6	30.3	28.8	19.9	38.4	27.5	33.5	26.5
e at 150ms CBM)	40.0±9.4	24.8	38.2	37	51.9	53.3	39.7	40.2	26.4	51.6	33.2	46.7	37.1
e at 200ms CBM)	45.1±9.4	31.1	42	38.8	52.6	61.5	45.9	46.1	31.6	53	37.7	54.8	46.2
e at 250ms CBM)	47.4±9.4	32.6	43.2	41.9	51.3	64.4	48	45.7	34.6	55.5	41.5	56.8	53.3
: RFD over 5 ms ndow (N·S-1)	33231±13296	29486	19448	22075	31049	24830	24830	28885	52837	58717	20319	48350	37951

allometrically scaled; SCBM: Scaled to body mass.

Olympic year based on world record totals. The current Sinclair total (ST) is calculated as follows for male lifters under 173.961kg and female lifters under 125.441kg:[23] Note: If the lifter's bodyweight is greater than either of the aforementioned cutoffs, then Sinclair Total is the same as the non-adjusted total:

Male: $ST=total \bullet 10^{AX^2}$, where $X=\log_{10}$(body weight 173.961^{-1}) and A=0.784780654

Female: $ST=total \bullet 10^{AX^2}$, where $X=\log_{10}$(body weight 125.441^{-1}) and A=1.056683941

Statistical analysis

Descriptive statistics were calculated for all data and presented individually for each athlete and as means and standard deviations (*SD*s). Relationships between IMTP variables and competition results (absolute and adjusted) were analyzed using Pearson's *r* ($P=0.05$; significant *r*-value: ≥0.576). In order to assess relative strength of the correlations, calculated r-values were evaluated using a scale modified by Hopkins:[24] 0.0-0.1 Trivial, 0.1-0.3 Small (Weak), 0.3-0.5 Moderate, 0.5-0.7 Large (Strong), 0.7-0.9 Very Large (Very Strong), and 0.9-1 nearly perfect. The Predictive Analytics SoftWare (PASW, version 18) was used for the analyses (SPSS: An IBM company, New York, NY). Cronbach's alpha was used to assess reliability of IMTP variables.

Results

Results show strong relationships between IPF (unscaled and scaled) and weightlifting performance.

TABLE III.—*Competition performance.*

Subject	1	2	3	4	5	6	7	8	9	10	11	12	Mean±SD
Sex	F	F	M	M	M	M	M	M	M	M	M	M	
Body Mass (kg)	70	63.2	86.2	133	107	80.5	94.3	70.5	86.5	121	96.8	84.4	91.1±20.9
Snatch (kg)	58	48	77	95	72	88	120	89	97	100	125	110	89.9±23.3
C&J (kg)	75	55	100	125	93	110	153	120	120	137	150	145	115.3±30.4
Total (kg)	133	103	177	220	165	198	273	209	217	237	275	255	205.2±53.5
Snatch (allo)	3.47	3.02	4.04	3.66	3.24	4.78	5.85	5.3	5.04	4.11	6.07	5.74	4.52±1.08
Snatch (SCBM)	0.85	0.76	0.93	0.72	0.69	1.11	1.29	1.29	1.15	0.83	1.34	1.31	1.02±0.252
C&J (allo)	4.48	3.46	5.25	4.82	4.18	5.97	7.46	7.15	6.24	5.63	7.29	7.57	5.79±1.39
C&J (SCBM)	1.1	0.87	1.2	0.95	0.89	1.39	1.65	1.74	1.42	1.14	1.61	1.73	1.31±0.33
Sinclair Total	158	128	213	226	180	245	312	280	259	248	314	306	239.0±61.0

Allo: allometrically scaled; SCBM: Scaled to body mass.

TABLE IV.—*Correlations between IMTP variables not offset for body mass and weightlifting performance0.*

	Snatch (Absolute)	C&J (Absolute)	Total (Absolute)	Snatch (Allo)	Snatch (SCBM)	C&J (Allo)	C&J (SCBM)	Total Sinclair	Total (SCBM)	Total (Allo),
Peak Force	0.830*	0.838*	0.838*	0.644*	0.483	0.666*	0.507	0.775*	0.502	0.662*
Force at 100 ms (N)	0.646*	0.643*	0.647*	0.436	0.282	0.444	0.292	0.592*	0.279	0.436
Force at 150 ms (N)	0.636*	0.605*	0.621*	0.471	0.334	0.449	0.317	0.588*	0.317	0.455
Force at 200 ms (N)	0.732*	0.714*	0.724*	0.523	0.362	0.518	0.362	0.666*	0.357	0.519
Force at 250 ms (N)	0.801*	0.801*	0.804*	0.563	0.385	0.579*	0.405	0.731*	0.395	0.574
Peak Force (Allo)	0.622*	0.597*	0.610*	0.794*	0.799*	0.783*	0.792*	0.737*	0.802*	0.793*
Force at 100 ms (Allo)	0.469	0.436	0.452	0.572	0.561	0.550	0.542	0.571	0.541	0.551
Force at 150 ms (Allo)	0.438	0.380	0.407	0.571	0.575	0.520	0.529	0.536	0.542	0.536
Force at 200 ms (Allo)	0.566	0.516	0.540	0.685*	0.673*	0.649*	0.644*	0.663*	0.652*	0.661*
Force at 250 ms (Allo)	0.668*	0.638*	0.653*	0.767*	0.739*	0.754*	0.761*	0.769*	0.734*	0.759*
Peak Force (SCBM)	0.397	0.363	0.379	0.719*	0.808*	0.696*	0.788*	0.580*	0.805*	0.710*
Force at 100 ms (SCBM)	0.300	0.257	0.277	0.547	0.614*	0.515	0.584*	0.468	0.589*	0.521
Force at 150 ms (SCBM)	0.279	0.215	0.244	0.540	0.613*	0.482	0.559	0.436	0.577*	0.501
Force at 200 ms (SCBM)	0.379	0.323	0.348	0.650*	0.719*	0.605*	0.680*	0.547	0.694*	0.620*
Force at 250 ms (SCBM)	0.468	0.429	0.448	0.732*	0.791*	0.707*	0.771*	0.645*	0.780*	0.717*
RFD 0-100 ms ($N\cdot S^{-1}$)	0.461	0.376	0.414	0.538	0.515	0.460	0.443	0.497	0.542	0.478
RFD 0-150 ms ($N\cdot S^{-1}$)	0.494	0.405	0.445	0.536	0.497	0.453	0.420	0.511	0.436	0.478
RFD 0-200 ms ($N\cdot S^{-1}$)	0.645*	0.567	0.603*	0.627*	0.550	0.560	0.492	0.638*	0.502	0.580*
RFD 0-250 ms ($N\cdot S^{-1}$)	0.781*	0.722*	0.751*	0.719*	0.612*	0.675*	0.576	0.767*	0.580*	0.688*
PRFD 5 ms window ($N\cdot S^{-1}$)	0.426	0.360	0.390	0.306	0.218	0.245	0.162	0.335	0.175	0.267

*designates significance at P≤0.050. Allo: Allometrically scaled; SCBM: Scaled to body mass.

Peak IRFD (5 ms window) was not strongly related (r=0.360-0.426) to weightlifting results; however, average IRFD (particularly for 0-250 ms) values did correlate strongly (Table IV). Performance and competition data can be found in Tables II, III. Correlations between IMTP force values not offset and offset for body weight are found in Tables IV, V, respectively. Correlations between competition results and IMTP IRFD measures are also shown in Table V. Correlations between IRFD measures and forces are found in Table VI.

LE V.—*Correlations between IMTP variables offset for body mass and weightlifting performance.*

	Snatch (Absolute)	C&J (Absolute)	Total (Absolute)	Snatch (Allo)	Snatch (SCBM)	C&J (Allo)	C&J (SCBM)	Total Sinclair	Total (SCBM)	Total (Allo),
Force	0.816*	0.814*	0.818*	0.712*	0.585*	0.725*	0.601*	0.799	0.600*	0.725*
e at 100 ms (N)	0.581*	0.558	0.570	0.532	0.447	0.519	0.437	0.603	0.432	0.518
e at 150 ms (N)	0.581*	0.534	0.557	0.535	0.451	0.496	0.417	0.588	0.423	0.507
e at 200 ms (N)	0.710*	0.676*	0.693*	0.604*	0.486	0.584*	0.472	0.692	0.472	0.590*
e at 250 ms (N)	0.801*	0.789*	0.797*	0.657*	0.516	0.660*	0.524	0.777	0.518	0.660*
Force (Allo)	0.584*	0.557	0.571	0.787*	0.808*	0.773*	0.798*	0.713	0.809*	0.784*
e at 100 ms (Allo)	0.409	0.370	0.388	0.571	0.591*	0.543	0.565	0.536	0.567	0.547
e at 150 ms (Allo)	0.395	0.333	0.361	0.569	0.593*	0.514	0.543	0.510	0.558	0.531
e at 200 ms (Allo)	0.524	0.470	0.495	0.658*	0.694*	0.644*	0.660*	0.639	0.670*	0.658*
e at 250 ms (Allo)	0.628*	0.594*	0.611*	0.770*	0.763*	0.752*	0.750*	0.748*	0.755*	0.759*
Force (SCBM)	0.397	0.363	0.379	0.719*	0.808*	0.696*	0.788*	0.580*	0.805*	0.710*
e at 100 ms (SCBM)	0.300	0.257	0.277	0.547	0.614*	0.515	0.584*	0.468	0.589*	0.521
e at 150 ms (SCBM)	0.279	0.215	0.244	0.540	0.613*	0.482	0.559	0.436	0.577*	0.501
e at 200 ms (SCBM)	0.379	0.323	0.348	0.650*	0.719*	0.605*	0.680*	0.547	0.694*	0.620*
e at 250 ms (SCBM)	0.468	0.429	0.448	0.732*	0.791*	0.707*	0.771*	0.645*	0.780*	0.717*

gnates significance at P≤0.05. Allo: Allometrically scaled; SCBM: Scaled to body mass.

LE VI.—*Correlations between select IMTP variables, offset and not offset for body mass0.*

	Peak Force	Force at 100 ms (N)	Force at 150 ms (N)	Force at 200 ms (N)	Force at 250 ms (N)	RFD 0-100 ms (N·S-1)	RFD 0-150 ms (N·S-1)	RFD 0-200 ms (N·S-1)	RFD 0-250 ms (N·S-1)	PRFD 5 ms window (N·S-1)	Force at 100 ms (N; Offset)	Force at 150 ms (N; Offset)	Force at 200 ms (N; Offset)	Force at 250 ms (N; Offset)	Force at 250 ms (N)
Force	1														
e at 100 ms (N)	0.705*	1													
e at 150 ms (N)	0.691*	0.967*	1												
e at 200 ms (N)	0.778*	0.930*	0.959*	1											
e at 250 ms (N)	0.872*	0.909*	0.908*	0.977*	1										
0-100 ms (N·S-1)	0.337	0.753*	0.806*	0.687*	0.574	1									
0-150 ms (N·S-1)	0.419	0.775*	0.871*	0.772*	0.656*	0.970*	1								
0-200 ms (N·S-1)	0.564	0.802*	0.895*	0.885*	0.797*	0.893*	0.950*	1							
0-250 ms (N·S-1)	0.729*	0.845*	0.908*	0.933*	0.895*	0.821*	0.879*	0.970*	1						
D 5 ms window (N·S-1)	0.485	0.309	0.387	0.406	0.433	0.248	0.342	0.390	0.453	1					
Force (N; Offset)	0.986*	0.659*	0.660*	0.735*	0.824*	0.369	0.444	0.574	0.733*	0.462	1				
e at 100 ms (N; Offset)	0.621*	0.947*	0.940*	0.861*	0.813*	0.877*	0.874*	0.852*	0.862*	0.232	0.626*	1			
e at 150 ms (N; Offset)	0.623*	0.915*	0.972*	0.901*	0.829*	0.887*	0.939*	0.928*	0.915*	0.336	0.629*	0.964*	1		
e at 200 ms (N; Offset)	0.743*	0.904*	0.956*	0.978*	0.937*	0.773*	0.851*	0.941*	0.969*	0.372	0.733*	0.902*	0.948*	1	
e at 250 ms (N; Offset)	0.864*	0.896*	0.915*	0.971*	0.981*	0.656*	0.731*	0.856*	0.942*	0.410	0.848*	0.861*	0.881*	0.971*	1

gnates significance at P≤0.050. Allo: Allometrically scaled; SCBM: Scaled to body mass.

Discussion

This is the first study to the authors' knowledge evaluating average IRFD over a given time period with the IMTP in athletes and comparing it to instantaneous RFD values (5 ms window). Average isometric RFD appears to have a strong relationship with performance. IRFD (0-250 ms) showed very strong relationships to unscaled snatch, clean and jerk and total, as well as with performance scaled in a variety of ways. IRFD (0-200 ms) also showed strong correlations with unscaled and scaled performance though not as strong as IRFD 0-250ms. Interestingly, IRFD from 0-100 ms and 0-150 ms only correlated moderately but not significant statistically, with performance results, despite more closely matching the reported time characteristics of the second pull (lasting approximately 100-200 ms) than IRFD from 0-250 ms. One possible reason for this time frame discrepancy is that during the snatch and clean the bar is already moving as the second pull is initiated, muscles have already gained greater tension and the bar has some momentum. In the present study the athletes used an isometric pull and forces had to be built over a longer period. Another possible reason for the discrepancy is that the re-bend of the knees just prior to the second pull probably utilizes the stretch shortening cycle, adding the contribution of non-contractile elements of the quadriceps muscles and the reflex activation of alpha motor neurons to the development of force during the second pull;[25] in contrast, the isometric pull is performed such that no countermovement is allowed, thus minimizing or eliminating the contribution of the stretch shortening cycle.

While PIRFD appears to be reliable (ICCα=0.800-0.966), as shown in our study and others,[4, 7, 8, 26, 27] it does not appear to be consistently correlated with dynamic performance.[4, 8, 27] Haff *et al.*[26] evaluated PIRFD (measured over a 5ms window) in six elite female weightlifters and found that it was only correlated significantly with competition total (r=0.80), while snatch (r=0.79) and clean and jerk (r=0.69) relationships to PIRFD were very strong but not significant. Also using PIRFD over a 5ms window, Stone *et al.*[27] found a very low, non-significant correlation to snatch 1-RM in collegiate throwers. Kawamori *et al.*[4] found that weak, non-significant relationships existed between isometric mid thigh pull PIRFD (2 ms) and jump performance and dynamic mid-thigh pull peak force and peak power. In the present study, weak non-significant relationships of PIRFD to performance were noted, agreeing with previous observation[27]. Other authors have also reported relatively weak non-significant relationships of dynamic performance (power cleans and split jerks) with PIRFD in non-weightlifter athletes, but it is not clear what methods were used to calculate the PIRFD values.[10, 11] The present study showed strong, significant relationships of IRFD (0-200 ms) with snatch and total, and IRFD (0-250 ms) with snatch, clean and jerk, and total, indicating these may be better variables for monitoring performance of weightlifting movements than PIRFD.

In addition, the results of this study indicate that isometric peak force has a strong relationship to weightlifting performance in weightlifters. Absolute IPF values obtained from IMTP testing correlated strongly with absolute values for the snatch, clean and jerk, and total. This agrees with Stone *et al.*[9] who found that IPF was strongly correlated to snatch (r=0.83) and clean and jerk (r=0.84) in elite male and female weightlifters. Haff *et al.*[8] also found high correlations between IPF and best results in the the snatch (r=0.93) and total (r=0.80) in elite female weightlifters; IPF and maximum clean and jerk were also strongly correlated, although non-significantly (r=0.64). The strong relationships between unscaled competition results and absolute peak force in our study also indicate that stronger athletes (regardless of body mass) tend to have higher competition results. Furthermore, the Sinclair total and allometric scaling of competition results also showed a very strong relationship to absolute and scaled peak force which indicates that maximum strength is an important factor even when bodymass is accounted for, agreeing with Stone *et al.*[9]

Using the IMTP, several studies indicate that non-weightlifter athletes with higher IPF values also perform better in the weightlifting movements.[10, 11, 27] In collegiate throwers, Stone *et al.*[27] demonstrated that IPF was nearly perfectly correlated to 1-RM snatch (r=0.94-0.98). McGuigan *et al.*[11] showed near perfect (r=0.97) correlation between IMTP peak force and power clean in college wrestlers. McGuigan & Winchester [10] also found strong correlations between IMTP peak force and split jerk 2-RM (r=0.72) as well as with power clean (r=0.71) in collegiate football players.

Isometric PF values from the IMTP have been found to relate to other dynamic measures of performance. Over the course of an 8 week training period, Stone *et al.*[27] found strong, statistically significant relationships between IPF and shotput performance (r=0.67-0.75) and weight throw performance (r=0.70-0.79). In sprint cyclists, Stone *et al.*[7] found moderate, significant relationships between isometric peak force and split times (r= -0.49 to -0.55), countermovement jump height (r=0.66) and static jump height (r=0.67). Cyclists were grouped by peak force values obtained in the IMTP into the strongest (N.=6) and weakest (N.=6), which revealed statistically significant differences in 25m sprint time, Wingate test peak power, and countermovement peak power. Because there are strong relationships between the IMTP and dynamic performances, the use of the IMTP as an effective monitoring device is strengthened.

It is interesting to note that the correlations found between offset force values (body weight is removed, yielding net forces) and weightlifting performance did not differ greatly from correlations between non-offset values (body weight is not removed, yielding gross values) and weightlifting performance. While there was a general trend toward slightly lower r-values for offset values and weightlifting performance, the difference between corresponding r-values were not very large. It is also important to note that correlations between non-offset and corresponding offset IMTP values (*e.g.* offset force at 100ms with non-offset force at 100ms) had very large, significant relationships (r=0.947-0.986). The prior two facts indicate that in terms of relationships, particularly for allometrically scaled values, with other performance variables it probably does not matter if the force plate measurement is or is not offset for body mass when using the IMTP. However, this is a study with a small sample size and only a preliminary look at this idea, therefore more research should be conducted to reach definitive conclusions.

Conclusions

Ideally, testing and monitoring should minimally affect training while simultaneously providing enough data to gauge the progression of the athlete. The IMTP represents a viable monitoring test for weightlifters of different levels, as it is able to provide diverse measures of strength and explosiveness that are strongly related to their performance. Furthermore, this is possible without the significant interruption of training of other tests, such as 1-RM testing, that often require considerably more time, may take multiple tests to obtain the diversity of information, and potentially create a greater fatigue level. This study also affirms the findings of past research that emphasizes the importance of maximal strength on performance.

The method of calculating IRFD appears to be important as PIRFD (5 ms) shows weak relationships to weightlifting performance compared to various measures of average IRFD. Additionally, although total forces have slightly better correlations with other variables, net (offset) versus total forces (not offset) both show good correlations with most performance variables measured, particularly when allometrically scaled. However, the small sample size population limit the generalizability of these findings; therefore additional research should be undertaken to further investigate the relationships of variables found in the study.

References

1. Haff GG, Stone MH, O'Bryant H, Harman E, Dinan, C, Johnson R *et al.* Force-time dependent characteristics of dynamic and isometric muscle actions. J. Strength Cond Res 1997;11:269-72.
2. Stone MH, Sands WA, Stone ME. Principles and Practice of Strength-Power Training. Champaign, Il: Human Kinetics; 2007.
3. Murphy AJ, Wilson GJ, Pryor JF, Newton RU. Isometric assessment of muscular function: the effect of joint angle. J Appl Biomech 1995;11:205-15.
4. Kawamori N, Rossi SJ, Justice BD, Haff EE, Pistilli EE, O'Bryant HS *et al.* Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. J Strength Cond Res 2006;20:483-91.
5. Nuzzo JL, McBride JM, Cormie P, McCaulley GO. Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. J Strength Cond Res 2008;22:699-707.
6. Garhammer J. A review of power output studies of olympic and power lifting: methodology, performance prediction and evaluation tests. J Strength Cond Res 1993;7:76-8.
7. Stone MH, Sands WA, Carlock J, Callan S, Dickie D, Daigle K *et al.* The importance of isometric maximum strength and peak rate-of-force development in sprint cycling. J Strength Cond Res 2004;18:878-84.
8. Haff GG, Carlock JM, Hartman MJ, Kilgore JL, Kawamori N, Jackson RJ *et al.* Force-time curve characteristics of dynamic and isometric muscle actions of elite women olympic weightlifters. J Strength Cond Res 2005;19:741-8.
9. Stone MH, Sands WA, Pierce KC, Carlock J, Cardinale M, New-

ton RU. Relationship of maximum strength to weightlifting performance. Med Sci Sports Exerc 2005;37:1037-43.
10. McGuigan MR, Winchester JB. The relationship between isometric and dynamic strength in college football players. J Sport Sci & Med 2008;7:101-5.
11. McGuigan MR, Winchester JB, Erickson T. The importance of isometric maximum strength in college wrestlers. J Sports Sci Med 2006;5:108-13.
12. Stone MH, O'Bryant HS, McCoy L, Coglianese R, Lehmkuhl M, Schilling B. Power and maximum strength relationships in collegiate throwers. J Strength Cond Res 2003;17:140-7.
13. Kraska JM, Ramsey MW, Haff GG, Fethke N, Sands WA, Stone ME *et al.* Relationship between strength characteristics and unweighted and weighted vertical jump height. Int J Sports Physiol Perform 2009;4:461-73.
14. Khamoui AV, Brown LE, Nguyen D, Uribe BP, Coburn JN, Noffal GJ *et al.* Relationship between force-time and velocity-tmie characteristics of dynamic isometric muscle action. J Strength Cond Res 2011;25:205-10.
15. Takano B. Weightlifting classifications to aid in the planning of training. Takano Athletics Newsletter [Internet] 2010;3(18). Available at: http://www.takanoathletics.com/index.php?optioN.=com_phocadownload&view=category&download=123:volume-3-no-18&id=4:newsletters&Itemid=192&start=20 [cited 2013, Jun 4].
16. Judelson DA, Maresh CM, Anderson JM, Armstrong LE, Casa DJ, Kraemer WJ *et al.* Hydration and muscular performance: does fluid blaance affect strength, power and high-intensity endurance? Sports Med 2007;37:907-21.
17. Gourgoulis V, Aggeloussis N, Antoniou P, Christoforidis C, Mavromatis G, Garas A. Comparitive 3-dimensional kinematic analysis of the snatch technique in elite male and female greek weightlifters. J Strength Cond Res 2002;16:359-66.
18. Kauhanen H, Häkkinen K, Komi PV. A biomechanical analysis of the snatch and clean & jerk techniqes of Finnish elite and district level weightlifters. Scan J Sports Sci 1984;6:47-56.
19. Bemben MG, Clasey JL, Massey BH. The effect of the rate of contraction on the force-time curve parameters of male and female subjects. Res Q Exerc Sport 1990;61:96-9.
20. Escamilla R, Lander J, Garhammer J. Biomechanics of powerlifting and weightlifting exercises. In: Garrett WE, Kirkendall DT, editors. Exercise and Sport Science. Philadelphia: Lippincott Williams and Wilkins; 2000. p. 585-615.
21. Challis JH. The appropriate scaling of weightlifting performance. J Strength Cond Res 1999;13:367-71.
22. Sinclair RG. Normalizing the performances of athletes in Olympic weightlifting. Can J Appl Sport Sci 1985;10:94-8.
23. The Sinclair coefficients for the Olympiad January 1, 2009 to December 31, 2012 for men's and women's Olympic weightliftting [Internet]. International Weightlifting Federation 2009. Available at: http://www.iwf.net/iwf/weightlifting_sport/sinclair.php [cited 2013, Jun 4].
24. A scaled of magnitudes for effect statistics [Internet]. In: Hopkins WG. A new view of statistics. Available at: http://www.sportsci.org/resource/stats/effectmag.html [cited 2013, Jun 4].
25. Isaka T, Okado J, Funato K. Kinematic analysis of the barbell during the snatch movement of elite Asian weightlifters. J Appl Biomech 1996;12:508-16.
26. Haff GG, Jackson RJ, Kawamori N, Carlock JM, Hartman MJ, Kilgore JL *et al.* Force-time curve characteristics and hormonal alterations during an eleven-week training period in elite women weightlifters. J Strength Cond Res 2008;22:433-46.
27. Stone MH, Sanborn K, O'Bryant HS, Hartman M, Stone ME, Proulx C *et al.* Maximum strength-power-performance relationships in collegiate throwers. J Strength Cond Res 2003;17:739-45.

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