BIOMECHANICS OF LIFTING

CINEMATOGRAPHICAL EXAMINATION OF POWERLIFTING AIDS IN SQUATTING

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Six experienced weight-lifters were compared in powerlifting squats with and without lifting aids. Lifting aids were commercial, competitive elastic lifting suits and knee wraps. Subjects were filmed with a 16mm Locam camera at 50 fps while performing 3 trials of 3 repetitions maximum under the two lifting conditions.

Squats were divided into four phases (2 for descent, 2 for ascent) by trunk to hip and thigh to leg rotations. Postural torques about the hip and the knee were estimated from digitized images. Inertial torques were discounted as modulating contributors to performance due to their invariance across the lifting conditions.

Phasic comparisons revealed no significant differences ($p < .05$) across subject conditions suggesting that temporal components of powersquatting were not affected by lifting aids. Dependent sample comparisons of weights lifted and torques estimated revealed significant increases ($p < .05$) for all lifters using lifting aids. Average improvement in weights lifted was 12.94% over maximum unassisted lifts.

Use of competitive powerlifting aids significantly assisted subjects in lifting greater weights, but did not influence lifting technique. Caution is expressed in the use of such aids for untrained athletes due to increased loads on the joints.

Introduction

The importance of maximizing muscular strength and power to improving athletic performance has been well documented in recent years (Dunn, et al, 1984; Garhamm, 1981; Stone and Garhammer, 1981; Wathen and Shutes, 1982). It has been widely accepted that the best way to increase the strength of a muscle is to subject it to maximal or near maximal loads, and to progressively increase those loads as muscular strength increases (Hay, et al, 1983; Yess, 1982).

Powerlifting is one sport in which the extent of strength and power development largely determines the success of the athlete. As strength and power outputs increase, there is also an increase in the amount of weight that can be lifted (Stone and Garhammer, 1981). This ultimately is the goal of all powerlifters, who are always looking for ways to increase their maximum weight in each of the three powerlifting events. In addition to proper training methods used to help increase the amount of weight lifted, equipment is allowed in hopes of enhancing performance.

In this study, the powerlifting squat was investigated under current powerlifting rules. Due to the steady increase in women powerlifters during the last decade, both men and women were employed as subjects. The primary equipment used for the squat are knee wraps, a lifting belt and a lifting suit. The effects that knee wraps and the lifting suit had on the squat were of primary interest.

The use of powerlifting aids to enhance performance is widely accepted among powerlifters. Do the lifting suit and knee wraps actually increase the amount of weight that a person can lift, or do they simply give a placebo effect to those who use them? If these aids do indeed help, then what percent increase in weight can one expect? Furthermore, how do these powerlifting aids affect torques observed at the hip and knee joints?

This study examined torque production at the hip and knee joints while performing the squat with and without powerlifting aids (lifting suit and knee wraps). The relationship of torques observed between the hip and knee joints were also examined to help understand how increases or decreases in torques observed at one joint affect torques observed at the other joint. Variations in the amount of weight lifted with and without these aids were also investigated. Because the ultimate goal in powerlifting is to successfully lift a maximum amount of weight, it was hoped that the results of this study would help lifters understand the role of powerlifting aids in performing the squat.

Subjects

This study was limited to three males and three females, all of whom were competitive powerlifters (see Table 1). All subjects had previously used the powerlifting suit and knee wraps in training and competition.

Limitations

Data were collected according to the sequence of subjects' training: (a) first, without powerlifting aids; (b) second, with powerlifting aids.

Safety concerns limited the number of repetitions each subject performed both with an without powerlifting aids. Ideally, a one repetition maximum (1 RM) was desired for both unaided and aided lifts, since the 1 RM is performed in competition. However, none of the subjects would agree to a 1 RM without powerlifting aids. All subjects instead agreed to a 3 RM, the lowest common number of repetitions that all subjects would perform with and without powerlifting aids.

Due to individual preferences, lifting suits and knee wraps varied among the subjects. For the lifting suits, subjects two, four and six used the "Elite"; subject one used the "Brute Force"; subject five used the "Inzer"; and subject three used the "Z-10". For the knee wraps, subjects one, three and four used the "Superwrap 10," and subjects two, five and six used the Superwrap 2". Furthermore, subject 2 preferred to use loose to moderate tightness (instead of the normal tightly wrapped knee wraps and tight fitting suit) in her knee wraps and suit, thus possibly affecting the amount of weight that she lifted.

Procedures

Cinematography

A Locam 16 mm high speed camera was used for filming all lifters from a left sagittal view. All lifters were filmed at 50 frames per second. Filming started approximately one second before each lifter began the squat descent to attain the desired frame rate. Filming ceased at the completion of the squat ascent. Camera position was 10 meters from and perpendicular to the plane of motion. Identification markers were placed over the joint centers of the hip and knee of all lifters.

Data Collection

To control differences in technique due to fatigue, all lifters were filmed during two sessions that were one week apart. Since many powerlifters perform the squat only once per week, this provided an appropriate time period. During the first session, the lifters performed their 3 RM without the use of powerlifting aids. During the second session, the lifters performed their 3 RM with the use of powerlifting aids. During both sessions, lifting belts of maximum thickness and width (according to powerlifting rules) were used. For each session, all lifters were filmed performing three separate trials at their 3 RM.

Data Reduction

Cinematographic Data

Bar, hip and knee positions were digitized using an optical pointer interfaced to an IBM PC microcomputer. The following surface areas were digitized every second frame of film:

1) bar — left end of the center of the bar
2) left hip — head of the greater trochanter
3) left knee — center of axis of rotation of the knee.

In addition, a reference point was digitized to synchronize the coordinate system for all film frames. The data were scaled to real distance values using a .36 meter reference measure filmed as part of the filming arrangement.

To aid in the film analysis, the squat was divided into four phases (see Figure 1). The descent of the lift consisted of phases 1 and 2, while the ascent consisted of phases 3 and 4. They were as follows:

1) phase 1 — start of descent to 135 degree relative knee angle.
2) phase 2 — 135 degree relative knee angle to minimum thigh position.
3) phase 3 — minimum thigh position to 135 degree relative knee angle.
4) phase 4 — 135 degree relative knee angle to completion of ascent.

Relative knee angle was the angle formed between the posterior thigh and leg at the knee joint. The minimum thigh position was the lowest portion of descent, based upon the powerlifting definition of the squat.

Statistical Analysis

To test differences in weight lifted between the two conditions, a one-tailed t-test with dependent samples was used. To test differences in absolute and relative torques, a 2-way Anova with planned comparisons was applied to the cinematographic data. Each phase between the two conditions was compared to each other. A Pearson Product Moment Correlation test was used during both conditions to test torque correlations at the hip and knee joints. The .05 level of significance was utilized for all tests.

Results and Discussion

Weight Comparisons

All subjects significantly increased the amount of weight that was lifted when powerlifting aids were used (see Table 2). There was an average increase of 12.94 percent in the amount of weight that was lifted. A graphical representation is given in Figure 2.

Mean Absolute Torques

During the condition without powerlifting aids (see Table 3), mean absolute torques at the knee increased from phase 1 to phase 2, then decreased during the remaining two phases. Mean absolute torques at the hip increased for the first 3 phases, then decreased in the remaining phase.

During the condition with powerlifting aids (see Table 4), mean absolute torques at the knee similarly increased during the first 2 phases, and decreased in the remaining 2 phases. Mean absolute torques at the hip increased during the first 3 phases, and decreased during the final phase.

When comparing torques between the two conditions, it was found that torques were higher at every phase (both at the knee joint and hip joint) when powerlifting aids were utilized. A graphical representation is given in Figure 3.

Mean Relative Torques

Relative torques during both conditions had a pattern similar to absolute torques (see Tables 5 and 6). Relative torques were computed as (torque/wt) x 100. They represent "normalized scores" relative to the weight lifted. A graphical representation is given in Figure 4.

Mean Distances

Mean perpendicular distances from the joints to the force-line of the weight, the moment of the force, were found to be similar during both conditions (see Figure 5). The distances form the hip joint to the force-line of the weight were almost identical during all phases, while the distances from the knee joint to the force-line of the weight varied slightly during phases 2 and 3 (see Table 7).

Mean Time

Mean total time needed to complete a repetition was almost half a second less when powerlifting aids were used (see Table 8). This is in spite of the fact that both conditions represented the subjects 3 RM, and more weight was lifted when powerlifting aids were used. Times were very similar during the middle phases (2 and 3), while varying more at the extremes (1 and 4).

Statistical Analysis

A one-tailed t-test with dependent samples was used to determine the significance of the difference in weight lifted between conditions. It was concluded that there was a significant difference in weight lifted for each subject.

A 2-way Anova with planned comparisons was applied to the absolute and relative torque variables. The statistical analyses were limited to comparing each phase of each condition to one another. It was found that there were significant differences in both absolute and relative torques throughout all phases.

A Pearson Product Moment Correlation test was used for both conditions to test torque correlations at the hip and knee joints. An inverse correlation was found both with ($r = -.31$) and without ($r = -.45$) powerlifting aids.

The .05 level of significance was used for all tests.

Discussion

By the use of powerlifting aids, all six subjects increased the amount of weight they could lift. Five of the six subjects increased their weight lifted approximately 10-18 percent, while the remaining subject increased by less than 6 percent. This smaller increase could have been due to individual preferences: (a) this subject preferred knee wraps that were not wrapped very tightly; and (b) this subject preferred a "loose fitting" suit. The other five subjects preferred tight fitting suits and tightly wrapped knee wraps.

While mean absolute torques were greater with powerlifting aids than without them, primarily due to the increase in weight, a similar pattern was shown in both conditions. Torques increased at the knee during phases 1 and 2 and decreased during phases 3 and 4. Torques increased at the hip throughout phases 1, 2, and 3 and decreased during the last phase. This implied that the subjects' technique during their ascent differed from their technique during their descent, otherwise phases 2 and 3 would be the same, as would phases 1 and 4. This seems reasonable given gravitational influence in lifting verses lowering a load. Furthermore, the decrease in knee torques and the increase in hip torques from phases 2 to 3 suggest that the hips were slightly back, thus increasing forward trunk lean. Therefore, the perpendicular distance from the hip to the force line of the weight increased, while the distance from the knee to the force line of the weight decreased.

Relative torques represent a percent score relative to the amount of weight lifted. If lifting technique remained constant during both conditions (i.e., perpendicular distances relative to the weight and hip/knee joint were constant), then these scores should also remain constant. Despite the fact that significant differences in relative torques were found, these scores and the moment of force scores were similar between both conditions.

Perpendicular distances relative to the weight and joints were used to determine how technique differed between the 2 conditions. These distances were nearly identical in all 4 phases at the hip joint and 2 of the 4 phases at the knee joint. The variances in the remaining 2 phases at the knee (2 and 3) were thought to be inaccuracies due to: (a) the difficulty in locating the knee joint when knee wraps were utilized, and (b) the covering of the knee by the large disks of weight on the bar. Furthermore, differences in standard deviation scores were greatest during these 2 phases at the knee. Therefore, technique was assumed to be similar between the 2 conditions, implying that the increase in weight lifted during the second condition was primarily due to the powerlifting aids.

Mean percents of time during the two conditions indicated that without powerlifting aids, a little over 50 percent of the time involved phases 2 and 3, and almost 50 percent involved phases 1 and 4. With powerlifting aids, almost 60 percent of the time consisted of phases 2 and 3, and only 40 percent of the time involved phases 1 and 4. It is interesting that the only real variances between both conditions in the amount of time were at phases 1 and 4 (the beginning and ending of the squat), since time was almost identical during phases 2 and 3. This may suggest that the subjects were more cautious, and thus performed the movement more slowly, without powerlifting aids during the beginning and ending phases.

Summary

In conclusion, the use of powerlifting aids during the squat caused an increase in the amount of weight that could otherwise be lifted. Indeed, this is the ultimate goal in competitive powerlifting. Concurrent to this weight increase comes a greater load on lower extremity joints. For these competitive lifters, the loads were manageable without any apparent changes in lifting technique.

Table 1

<u>Description of subjects</u>

Subject	Age	Wt N(lbs)	Ht cm	sex	Class
1	25	823(185)	170	F	I
2	29	801(180)	183	F	Master
3	26	894(201)	178	M	I
4	43	819(184)	173	M	Master
5	25	632(142)	170	M	II
6	20	516(116)	152	F	II

	Age	Wt N(lbs)	Ht cm
Range	20-43	516-894(116-201)	152-183
Mean	28.00	748(168)	171.00
SD	7.90	142.88(32.19)	10.58

Table 2

<u>Comparisons of Weight Lifted--- N(lbs)</u>

Subject	WOPA	WPA	D	Percent Increase
1	1202(270)	1402(315)	200(45)	16.67
2	1535(345)	1624(365)	89(20)	5.80
3	2136(480)	2336(525)	200(45)	9.38
4	2114(475)	2403(540)	289(65)	13.68
5	1335(300)	1513(340)	178(40)	13.33
6	712(160)	846(190)	134(30)	18.75

Average Percent Increase	SD
12.94	4.73

Note. WOPA = without powerlifting aids.

WPA = with powerlifting aids.

D = difference in weight lifted.

Table 3

Mean Absolute Torques (Nm)--- WOPA

	Phase 1	Phase 2	Phase 3	Phase 4
Knee				
Max	245.87	270.18	274.11	195.92
SD	80.06	139.17	144.72	65.36
Min	5.45	52.69	29.53	10.96
SD	9.67	36.38	41.07	18.41
Ave	106.86	160.37	125.04	88.74
SD	33.82	88.70	57.49	35.54
Hip				
Max	298.18	420.73	492.84	361.61
SD	117.69	130.83	188.60	264.04
Min	49.45	247.86	207.13	26.48
SD	51.22	99.51	106.22	34.88
Ave	168.35	339.36	375.90	214.66
SD	49.41	109.51	144.34	160.92

Note. WOPA = without powerlifting aids.

Table 4

Mean Absolute Torques (Nm)--- WPA

	Phase 1	Phase 2	Phase 3	Phase 4
Knee				
Max	294.67	376.61	345.20	226.03
SD	116.13	176.49	155.68	72.04
Min	19.53	169.25	64.41	6.38
SD	41.18	114.63	71.10	10.31
Ave	143.59	260.00	201.14	94.30
SD	65.65	153.88	105.41	28.34
Hip				
Max	384.81	540.79	569.50	456.43
SD	156.37	209.81	262.63	328.24
Min	81.56	314.60	344.66	72.94
SD	102.38	144.47	161.00	71.16
Ave	208.50	425.42	448.04	261.09
SD	127.11	171.03	191.71	191.66

Note. WPA = with powerlifting aids.

Table 5

Mean Relative Torques (normalized for weight lifted)---WOPA

	Phase 1	Phase 2	Phase 3	Phase 4
Knee				
Max	16.86	17.00	17.83	13.61
SD	3.71	5.70	5.86	3.37
Min	.38	3.44	2.01	1.30
SD	.64	2.75	3.06	2.48
Ave	7.35	9.97	8.42	6.54
SD	1.69	4.95	3.76	3.47
Hip				
Max	20.66	28.93	33.50	23.96
SD	7.13	5.05	7.15	12.83
Min	4.81	17.08	15.20	2.60
SD	7.56	5.24	8.58	4.82
Ave	12.71	23.31	25.66	14.45
SD	7.72	4.26	5.93	9.14

Note. WOPA = without powerlifting aids.

Table 6

Mean Relative Torques (normalized for weight lifted)---WPA

	Phase 1	Phase 2	Phase 3	Phase 4
Knee				
Max	18.21	22.41	21.38	14.13
SD	6.10	9.86	9.50	4.89
Min	1.40	9.22	4.25	.55
SD	2.71	6.71	4.65	.86
Ave	8.83	15.55	12.50	5.89
SD	4.12	8.79	6.92	1.98
Hip				
Max	22.73	31.86	32.87	25.56
SD	3.89	4.15	4.98	8.99
Min	5.55	18.30	19.93	4.30
SD	6.78	3.42	3.74	3.94
Ave	12.53	24.93	25.98	14.39
SD	6.25	3.02	3.04	6.67

Note. WPA = with powerlifting aids.

Table 7

Mean Perpendicular Distances (cm) from Weight to Joints

		Phase 1	Phase 2	Phase 3	Phase 4
WOPA					
	Knee	7.37	9.99	8.44	6.55
	SD	1.69	4.96	3.77	3.48
	Hip	12.74	23.37	25.72	14.49
	SD	7.74	4.27	5.94	9.16
WPA					
	Knee	8.85	15.59	12.53	5.91
	SD	4.13	8.81	6.94	1.98
	Hip	12.56	24.99	26.04	14.43
	SD	6.27	3.03	3.04	6.69

Note. WOPA = without powerlifting aids.

WPA = with powerlifting aids.

Table 8

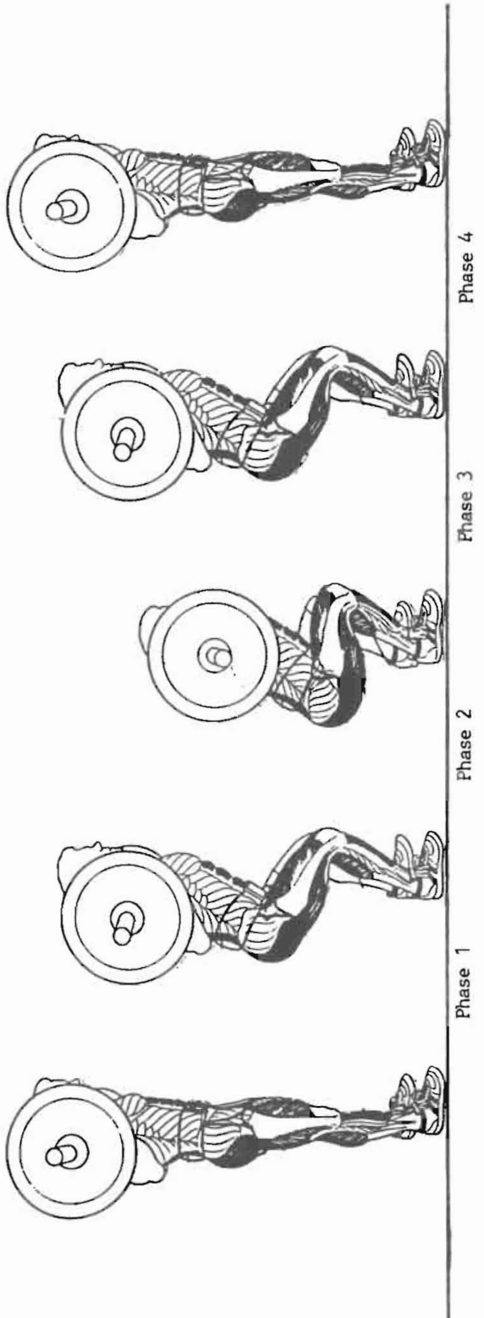
Mean Time (s) and Percents

		Phase 1	Phase 2	Phase 3	Phase 4
WOPA					
	Time	.68	.79	.95	.87
	SD	.19	.28	.36	.40
	Percent	20.88	23.93	28.63	26.56
	SD	6.67	8.86	9.94	12.36
WPA					
	Time	.54	.73	.93	.62
	SD	.10	.05	.26	.26
	Percent	19.12	26.09	32.92	21.87
	SD	2.31	3.50	8.41	8.85

Total Time (WOPA)	Total Time (WPA)
3.29	2.82

Note. WOPA = without powerlifting aids.

WPA = with powerlifting aids.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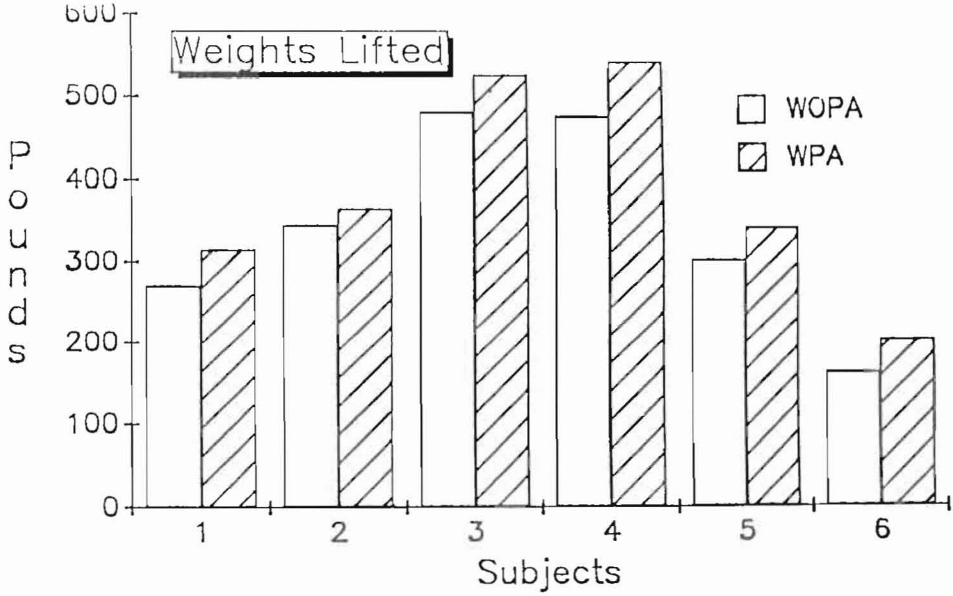
Phase 3
Phase 4


Weights Lifted
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WOPA
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1
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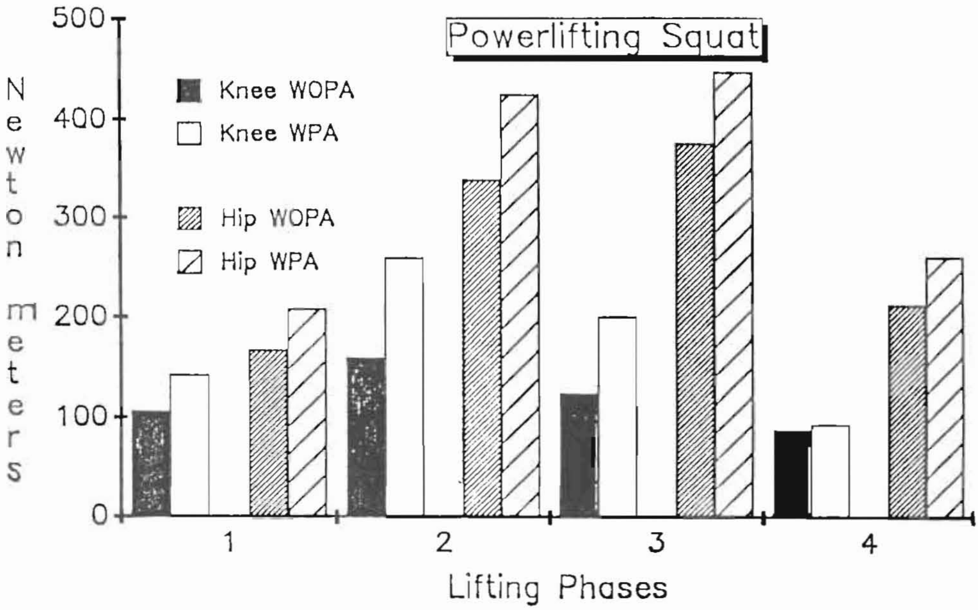
Subjects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400
300
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Knee WOPA
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1
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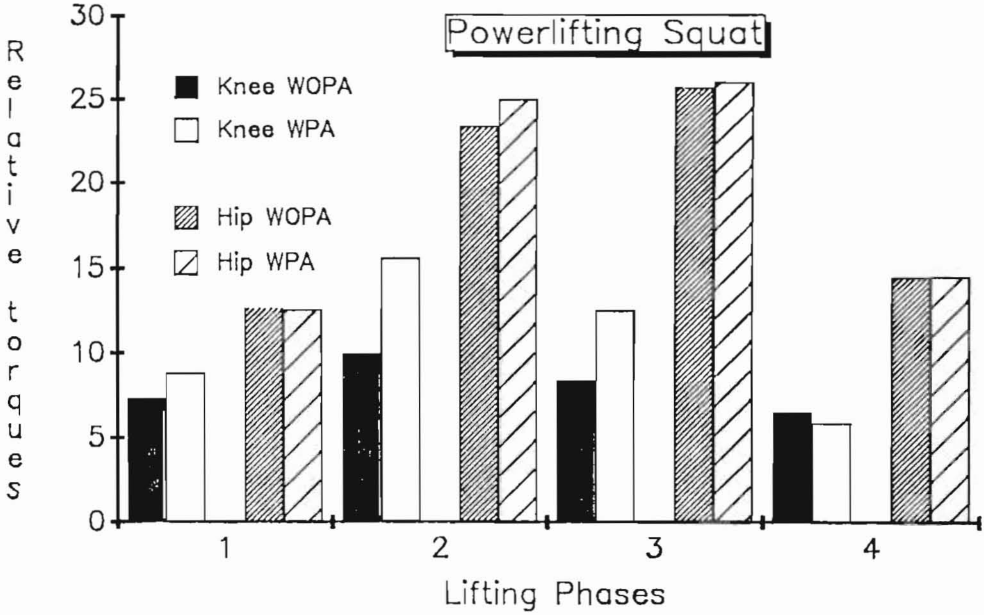
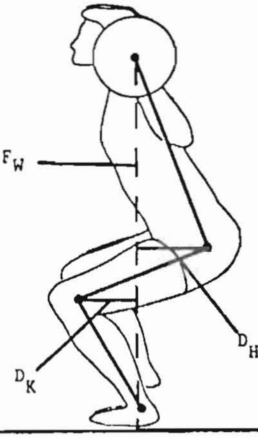
Lifting Phases





F_W--- Force line of weight.

D_H--- Perpendicular distance from hip joint to force line of weight.

D_K--- Perpendicular distance from knee joint to force line of weight.

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