Is the Optimal Load for Maximal Power Output During Hang Power Cleans Submaximal?

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Purpose: The optimal load for maximal power output during hang power cleans (HPCs) from a mechanical perspective is the 1-repetition-maximum (1RM) load; however, previous research has reported otherwise. The present study thus aimed to investigate the underlying factors that determine optimal load during HPCs. **Methods:** Eight competitive Olympic weight lifters performed HPCs at 40%, 60%, 70%, 80%, 90%, 95%, and 100% of their 1RM while the ground-reaction force and bar/body kinematics were simultaneously recorded. The success criterion during HPC was set above parallel squat at the receiving position. **Results:** Both peak power and relative peak power were maximized at 80% 1RM (3975.7 [439.1] W, 50.4 [6.6] W/kg, respectively). Peak force, force at peak power, and relative values tended to increase with heavier loads ($P < .001$), while peak system velocity and system velocity at peak power decreased significantly above 80% 1RM ($P = .005$ and $.011$, respectively). There were also significant decreases in peak bar velocity ($P < .001$) and bar displacement ($P < .001$) toward heavier loads. There was a strong positive correlation between peak bar velocity and bar displacement in 7 of 8 subjects ($r > .90$, $P < .01$). The knee joint angle at the receiving position fell below the quarter-squat position above 70% 1RM. **Conclusions:** Submaximal loads were indeed optimal for maximal power output for HPC when the success criterion was set above the parallel-squat position. However, when the success criterion was defined as the quarter-squat position, the optimal load became the 1RM load.

Keywords: Olympic weight lifting, power training, squat position, 1-repetition maximum

Olympic weight-lifting exercises are among the most powerful movements in sport and are often used by athletes for power enhancement along with other primary power exercises like plyometrics and jump squats.¹ Among weight-lifting exercises, the hang power clean (HPC) is a widely used exercise in strength and conditioning settings.^{2,3} Many studies have shown the effectiveness of the use of optimal load to generate the highest power output.^{4,5} The reported optimal load for HPC varies among studies, ranging from 65% to 80% of 1-repetition maximum (1RM).⁶⁻¹⁰ This inconsistency may derive from factors such as differences in the training stage of the subjects' yearly schedule and their strength levels.^{9,11}

Olympic lifting is usually categorized as a ballistic exercise, along with bench press throws and jump squats.^{12,13} Ballistic exercise with an external load has little or no deceleration period, which results in the external load and/or the subject's body leaving the ground at the end of the concentric phase.¹² From a mechanical point of view, the resulting vertical height of the external load and/or subject's body lifting off the ground is determined by the maximum vertical velocity during takeoff. According to the National Strength and Conditioning Association guidelines, in HPC, one should receive the bar in a quarter-squat position.¹⁴ Because of this narrow range of success criteria, the bar height lifted during HPC should be consistent for each lifter and independent of external load. In the relationship between height and velocity, velocity is not affected by varying loads. Because

the vertical ground reaction force during HPC increases as loads increase,^{6,7,9,10,15} and power is calculated as force multiplied by velocity, the power output during HPC should be maximized at 1RM.

However, previous studies have reported that submaximal loads are optimal for peak power output during HPC.⁶⁻¹⁰ There are 2 possible explanations for these results. First, the movement might not be executed correctly at heavy loads. Because it is not easy to perform ballistic exercises like HPC with correct technique and consistency at near-maximum loads, subjects must be proficient in HPC for quantification of the pure power characteristics of the movement. In previous studies, the research subjects were not Olympic weight lifters. Another possible factor for an optimal load below 1RM is the wide range of success criteria, compared with the quarter squat mentioned before, for the receiving position during HPC. In previous studies, the success criterion was the lifter's upper thigh above parallel to the ground^{6,7,9} or was not clearly described.^{8,10} In either case, the wide range of criteria could allow for a significant decrease in the height of the bar, and thus a decreased velocity at heavier loads. With the success criterion set at the quarter-squat position as per the National Strength and Conditioning Association guidelines, the optimal load should be the 1RM.

Thus, the aim of the present study was to investigate the factors determining the optimum load for maximal power output during HPCs in Olympic weight lifters. We tested 2 hypotheses: (1) a decrease in velocity leads to a decrease in power output at loads above the optimal loads reported in previous studies (65%–80% 1RM), which is related to a significant decrease in lifted bar height and (2) 1RM is the optimal load when the success criterion is set at the quarter-squat position.

Methods

Subjects

Eight male weight lifters with at least 5 years of experience in Olympic lifting participated in this study. All of them participated

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in the national and/or international level competitions. Subject characteristics (mean [SD]) are as follows: age 21 (3) years, height 169.0 (4.2) cm, body mass 80.3 (14.9) kg, 1RM HPC 125.6 (14.5) kg, and 1RM HPC 1.59 (0.17) kg/body mass. They often perform various power cleans in the catch position above the quarter squat besides cleans with a deeper catch position, especially during the preparatory phase of their yearly schedule. All testing sessions were conducted shortly after the preparatory phase. This study was approved by the ethical review board of Waseda University, and each subject provided informed consent. Because of our study design, the hypotheses were not disclosed until data collection was complete.

Procedures

Data collection took place over 2 days with the 1RM test of HPC and power test conducted on day 1 and day 2, respectively. HPC was performed as previously described.^{6–10,15} Briefly, (1) the subjects stood still on a force platform while holding the bar at their upper thigh, (2) moved the bar down to the upper part of their knees, (3) pulled the bar drastically upward with countermovement, and (4) then lowered themselves into a quarter-squat position to receive the bar on their shoulders. For 1RM HPC testing on day 1, the subjects initiated the session with a warm-up of 2 sets of 5 repetitions of HPC with a 20-kg Olympic lifting bar. After finishing the warm-up sets, the subjects performed HPCs at 50%, 70%, 80%, and 90% of their self-reported 1RM. The subjects then progressively increased the weight by 2 to 5 kg depending on their performance of the previous lift. The test was terminated when the subjects failed the lifts 2 times in a row. The success criterion was set at the subjects' upper thigh above parallel to the ground at the receiving position.^{6,7,9} The power test (day 2 of testing) was conducted from 2 to 10 days after the 1RM test. The loads used in the power test were determined based on the subjects' 1RM obtained on day 1 of testing. As with the 1RM test, the session started after warm-up sets with a 20-kg Olympic lifting bar. HPCs were then performed at 40%, 60%, 70%, and 80% 1RM with 2 attempts per load and 90%, 95%, and 100% 1RM with 1 attempt per load on a force platform (0625, ACP, AccuPower; AMTI, Watertown, MA). The subjects were instructed to attempt each lift with their maximum effort. A rest period of 2 minutes was given between attempts at loads of 40%, 60%, 70%, and 80% and 3 minutes at loads of 90%, 95%, and 100% 1RM. As with the 1RM test, loads were gradually increased from 40% to 100% 1RM for injury prevention. Subjects were allowed to use tape, hook grips, knee sleeves, and weight belts during the 1RM and power tests.

Measurement

During the power test, all attempts were recorded from a sagittal plane at 120 Hz with a digital camera (15373667; FLIR Integrated Imaging Solutions Inc, British Columbia, Canada). Analog data obtained from the force platform were digitally converted at a sampling rate of 1000 Hz using an analog-to-digital converter (EIRBZ22002369; CONTEC Co Ltd, Osaka, Japan) and then recorded in a personal computer. Force platform and video data were synchronized using Kinema Tracer analysis software (KISSEI COMTEC Co Ltd, Nagano, Japan). The vertical ground reaction force obtained from the force platform was used to determine the vertical acceleration and vertical velocity of the system (lifter's body mass plus external load) using forward dynamics. System power was calculated as the force value multiplied by the

system velocity at each time interval (power = force $\times$ velocity). Because the present study investigated power output during the second pull phase of HPC, only the propulsion phase was analyzed, that is, the phase from the instance when the system velocity changed from negative to positive, to the instance when the force fell 10 N below the system mass. The peak force, peak velocity, and peak power values were the highest during the propulsion phase of the force–time, velocity–time, and power–time data, respectively. The force at peak power and velocity at peak power were the values when peak power was expressed. To obtain those relative values, we divided the peak power, peak force, and force at peak power by each subject's body mass. The test–retest reliability of the current measuring protocol was previously validated by Suchomel et al⁶ with intraclass correlation coefficients ranging from .84 to .99. Two-dimensional video analysis was performed to determine the bar kinematics data and knee joint angle during the receiving phase of HPC. Bar displacement data were filtered with a fourth Butterworth filter with a cutoff frequency of 6 Hz. The displacement data were then converted to the vertical acceleration and velocity of the bar using inverse dynamics. The peak bar velocity was the highest value of the vertical velocity data, and the bar displacement was the vertical displacement from the bar height at peak bar velocity to the greatest bar height. The knee joint angle at the receiving position was the smallest angle formed by 2-dimensional position data of the greater trochanter, knee joint, and lateral malleolus. The position data for each joint were manually plotted.

Statistical Analyses

All results are expressed as the mean (SD). Normality of data was analyzed using the Shapiro–Wilk test. One-way repeated-measures analysis of variance (ANOVA) was used to compare each load's peak power, relative peak power, peak force, relative peak force, force at peak power, relative force at peak power, peak system velocity, system velocity at peak power, peak bar velocity, bar displacement, and knee joint angle at the receiving position. When significant differences were found, post hoc tests with Bonferroni correction were used for paired comparisons. Partial eta squared (η_p^2) was also calculated to indicate the effect size in ANOVA tests. Cohen *d* effect sizes between the optimal load and other loads were calculated to display practical significance. Effect sizes of 0.00 to 0.19, 0.20 to 0.59, 0.60 to 1.19, 1.20 to 1.99, 2.00 to 3.99, and ≥ 4.00 were interpreted as trivial, small, moderate, large, very large, and nearly perfect, respectively.¹⁶ For loads with data for 2 attempts, the one that generated the higher peak power was used for analysis. Pearson correlation coefficient (*r*) was used to assess relationships between bar displacement and peak bar velocity for each subject. The significance level was set at $P < .05$. All statistical analyses were performed using SPSS version 23 (IBM Corp, New York, NY).

Results

System Power, Force, and Velocity

The ANOVA results indicated that relative intensity had significant effects on peak power ($P = .006$, $\eta_p^2 = .595$), relative peak power ($P = .002$, $\eta_p^2 = .644$), peak force ($P < .001$, $\eta_p^2 = .774$), relative peak force ($P < .001$, $\eta_p^2 = .838$), force at peak power ($P < .001$, $\eta_p^2 = .808$), relative force at peak power ($P < .001$, $\eta_p^2 = .859$), peak system velocity ($P = .005$, $\eta_p^2 = .572$), and system velocity at peak power ($P = .011$, $\eta_p^2 = .473$). The post hoc test results and Cohen *d* values are presented in Table 1.

Table 1 Effect of Different Relative Loads on Kinetic Variables During HPC

Load (%1RM)	40%	60%	70%	80%	90%	95%	100%
PP, W	3152.1 (479.7)	3781.7 (387.1)	3878.3 (396.4)	3975.7 (439.1)	3885.4 (503.1)	3889.1 (508.5)	3832.6 (591.4)
<i>P</i>		.025*	.025*	.033*			
<i>d</i> (vs 80%)	1.79	0.47	0.23	—	0.19	0.18	0.28
Relative PP, W/kg	40.3 (8.7)	48.0 (7.5)	49.1 (6.2)	50.4 (6.6)	49.1 (6.6)	49.1 (6.0)	48.2 (5.5)
<i>P</i>		.012*	.010*	.013*			
<i>d</i> (vs 80%)	1.38	0.35	0.21	—	0.20	0.21	0.38
PF, N	2384 (223)	2739 (260)	2873 (296)	2960 (309)	3015 (340)	3071 (375)	3200 (477)
<i>P</i>		<.001*	.001, *.017**	.002, *.036**	.003, *.031**	.004, *.030**	.020*
<i>d</i> (vs 80%)	2.14	0.77	0.29	—	0.17	0.33	0.60
Relative PF, N/kg	30.4 (4.9)	34.7 (4.9)	36.3 (4.1)	37.4 (4.2)	38.1 (4.3)	38.8 (4.1)	40.2 (3.7)
<i>P</i>		<.001*	<.001, *.003**	<.001, *.020**	<.001, *.009**	<.001, *.009, **.015***	.004*
<i>d</i> (vs 80%)	1.66	0.67	0.28	—	0.17	0.34	0.75
<i>F</i> _{PP} , N	2338 (266)	2655 (272)	2739 (296)	2837 (311)	2878 (335)	2929 (381)	2910 (367)
<i>P</i>		.001*	.004*	.003, *.034***	.005*	.014*	.008*
<i>d</i> (vs 80%)	1.73	0.62	0.32	—	0.13	0.26	0.22
Relative <i>F</i> _{PP} , N	29.6 (3.68)	33.6 (3.38)	34.5 (2.83)	35.8 (2.93)	36.3 (3.18)	36.9 (3.05)	36.6 (2.71)
<i>P</i>		<.001*	.001*	.001, *.027, **.025***	.001, *.018**	.003*	.001, *.048**
PV, m/s	1.86	0.70	0.43	—	0.17	0.36	0.30
<i>P</i>							
<i>d</i> (vs 80%)	1.51 (0.13)	1.6 (0.08)	1.57 (0.07)	1.56 (0.07)	1.48 (0.07)	1.46 (0.06)	1.42 (0.08)
<i>P</i>					.022, ***.001†	.015, **.011, ***.004†	.030, **.020, ***.007†
<i>d</i> (vs 80%)	0.48	0.52	0.20	—	1.11	1.48	1.94
<i>V</i> _{PP} , m/s	1.35 (0.11)	1.43 (0.08)	1.42 (0.07)	1.41 (0.08)	1.35 (0.07)	1.33 (0.05)	1.31 (0.07)†
<i>P</i>					.036, ***.017†	.036, **.007, ***.011†	.027†
<i>d</i> (vs 80%)	0.60	0.27	0.18	—	0.82	1.16	1.28

Abbreviations: 1RM, 1-repetition maximum; *d* (vs 80%), Cohen *d* effect size between 80% 1RM and other loads; *F*_{PP}, force at peak power; HPC, hang power clean; PF, peak force; PP, peak power; PV, peak system velocity; *V*_{PP}, system velocity at peak power.

*Significantly different from the value at 40% 1RM. **Significantly different from the value at 60% 1RM. ***Significantly different from the value at 70% 1RM. †Significantly different from the value at 80% 1RM.

Both peak power and relative peak power at 60%, 70%, and 80% 1RM were significantly higher than peak power at 40% 1RM, and both were maximized at 80% 1RM. Peak force and relative peak force at 60%, 70%, 80%, 90%, 95%, and 100% 1RM were significantly higher than 40% 1RM, and peak force and relative peak force at 70%, 80%, 90%, and 95% 1RM were significantly higher than 60% 1RM. Relative peak force at 95% 1RM was significantly higher than 70% 1RM. In addition, both force at peak power and relative force at peak power at 60%, 70%, 80%, 90%, 95%, and 100% 1RM were significantly higher than at 40% 1RM, and force at peak power and relative force at peak power at 80% 1RM were significantly higher than at 70% 1RM. Relative force at peak power at 80%, 90%, and 100% 1RM was significantly higher than at 60% 1RM. Post hoc tests also revealed that peak system velocity at 95% and 100% 1RM was significantly lower than that at 60% 1RM. In addition, peak system velocity at 90%, 95%, and 100% 1RM was significantly lower than that at 70% and 80% 1RM. Similarly, system velocity at peak power at 95% 1RM was significantly lower than that at 60% 1RM; system velocity at peak power at 90% and 95% 1RM was significantly lower than that at 70% 1RM; and system velocity at peak power at 90%, 95%, and 100% 1RM was significantly lower than that at 80% 1RM.

Bar Velocity and Displacement

Analysis of variance confirmed the significant effect of relative load on peak bar velocity ($P < .001$, $\eta_p^2 = .870$) as well as bar displacement ($P < .001$, $\eta_p^2 = .750$; Figure 1). Peak bar velocity significantly decreased as load increased, with the exceptions of 60% versus 70% 1RM, 90% versus 95% 1RM, and 95% versus 100% 1RM (all $P < .05$). The peak bar velocity effect sizes of each load against 80% 1RM were 2.59, 1.42, 0.98, 1.01, 1.26, and 1.49 for 40%, 60%, 70%, 90%, 95%, and 100% 1RM, respectively. Regarding bar displacement, the values at 90% and 100% 1RM were significantly lower than the value at 40% 1RM ($P = .042$ and $.028$, respectively),

Figure 1 — Peak bar velocity and bar displacement at different relative loads during HPC. All values for peak bar velocity differ significantly from each other except for 60% versus 70% 1RM, 90% versus 95% 1RM, and 95% versus 100% 1RM. HPC indicates hang power clean; 1RM, 1-repetition maximum. *Significantly different from the value at 40% 1RM. **Significantly different from the value at 60% 1RM. ***Significantly different from the value at 70% 1RM. †Significantly different from the value at 80% 1RM.

and the values at 90%, 95%, and 100% 1RM were significantly lower than the value at 60% 1RM ($P = .031$, $.042$, and $.023$, respectively). Furthermore, the values at 90% and 100% 1RM were significantly lower than the value at 70% 1RM ($P = .015$ and $.009$, respectively), and the values at 90%, 95%, and 100% 1RM were all significantly lower than the value at 80% 1RM ($P = .017$, $.029$, and $.004$, respectively). The bar displacement effect sizes of each load against 80% 1RM were 0.81, 0.50, 0.28, 1.07, 1.06, and 1.39 for 40%, 60%, 70%, 90%, 95%, and 100% 1RM, respectively. Figure 2A shows the strong correlations between peak bar velocity and bar displacement in all subjects ($r > .90$) except subject h. Figure 2B depicts the peak power at different relative intensities for subject h, who showed no such correlation and yielded the maximum peak power value at 100% 1RM.

Knee Joint Angle

Analysis of variance revealed significant effects of external load on knee joint angle at the receiving position ($P < .001$, $\eta_p^2 = .893$; Figure 3). In the post hoc test, the values at 70%, 80%, 90%, 95%, and 100% 1RM were significantly lower than the value at 40% 1RM ($P = .032$, $.002$, $<.001$, $<.001$, and $.001$, respectively), and the values at 80%, 90%, 95%, and 100% 1RM were significantly lower than the value at 60% 1RM ($P = .001$, $.002$, $<.001$, and $.003$, respectively). In addition, the values at 90%, 95%, and 100% 1RM were significantly lower than the value at 70% 1RM ($P = .004$, $.001$, and $.003$, respectively), and the values at 90%, 95%, and 100% 1RM were significantly lower than the value at 80% 1RM ($P = .028$, $<.001$, and $.029$, respectively). The knee joint angle effect sizes of each load against 80% 1RM were 5.78, 3.48, 1.73, 1.54, 2.12, and 2.03 for 40%, 60%, 70%, 90%, 95%, and 100% 1RM, respectively. The bar was received at a position considered to be a quarter squat at 40%, 60%, and 70% 1RM and at a half-squat position at 80%, 90%, 95%, and 100% 1RM.

Discussion

The present study examined the effects of relative load on peak power output during HPCs by Olympic weight lifters to elucidate the underlying factors that make submaximal loads optimal for peak power output. Peak power was maximized at 80% 1RM when the success criterion was set above the parallel-squat position, which resulted from the significant decrease in velocity and bar displacement at loads $\geq 90\%$ 1RM. Conversely, peak power was maximized at the 1RM load when the success criterion was set at the quarter-squat position. These results support our hypotheses, indicating that the success criterion is likely to determine the optimal load for HPC.

Both peak power and relative peak power were maximized at 80% 1RM during HPC, consistent with reports by Suchomel et al.⁶ and Kilduff et al.¹⁰ However, because of the small sample size, the value at the optimal load was not statistically significant compared with most of the other loads, as previously reported.^{6,9,10} Cohen d effect size revealed that the farther the compared load from 80% 1RM, the larger its practical significance (Table 1). Power was calculated as force multiplied by velocity. Because peak force and force at peak power tended to increase with heavier loads, it can be concluded that the decrease in peak power at loads 90% 1RM or heavier was caused by the significant decrease in peak system velocity and system velocity at peak power (Table 1). Bar displacement also decreased significantly for loads equal to 90% 1RM or heavier. These results supported our first hypothesis that

Figure 2 — (A) Scatterplots showing the correlation between peak bar velocity and bar displacement. Subpanels (a) to (h) present the correlation for each subject; r is the correlation coefficient; n.s. means not significant. (B) Peak power at different relative intensities for subject h, who showed no correlation between peak bar velocity and bar displacement.

Figure 3 — Knee joint angle at the receiving position. The highlighted gray area shows the knee joint angle range of 110° to 140°, which is considered a quarter-squat position.^{17,18} *Significantly different from the value at 40% 1RM. **Significantly different from the value at 60% 1RM. ***Significantly different from the value at 70% 1RM. †Significantly different from the value at 80% 1RM. 1RM indicates 1-repetition maximum.

at loads heavier than the optimal loads reported in previous studies (65%–80% 1RM), peak power would decrease significantly due to decreases in velocity relative to decreases in bar displacement.

When the criterion for a quarter squat was set at a knee joint angle of 110° to 140°, consistent with the criterion used by Hartmann et al¹⁷ and Schoenfeld,¹⁸ loads where the subjects received the bar at the quarter-squat position or higher were 40% to 70% 1RM (Figure 3). In the present study, peak power increased with increment in relative load from 40% to 80% 1RM. If the success criterion was set exactly to the quarter-squat position, 1RM became the optimal load for HPC, which is consistent with our second hypothesis.

We adopted the same success criterion used in previous studies^{6,7,9} such that HPC attempts were considered unsuccessful if the subject's upper thigh went below parallel to the ground at the receiving position. The results showed that the highest peak power was generated at a submaximal load of 80% 1RM, which is consistent with optimal loads of 65% to 80% 1RM reported in the previous studies.^{6–10} The highest peak power was generated at a submaximal load due to the significant decrease in system velocity

and bar velocity relative to the decrease in bar displacement (Table 1; Figure 1). During ballistic exercises like Olympic weight lifting, the velocity at the takeoff phase determines the resulting heights of the barbell and/or lifter (ignoring the trivial contribution of the upper extremities). Indeed, Figure 2A indicates strong positive correlations between peak bar velocity and bar displacement in 7 of 8 subjects. The success criterion used in the previous studies allowed the bar height to decrease significantly at heavier loads. This coincided with a decrease in system velocity and bar velocity, resulting in a decrease in peak power at 90% 1RM or greater (Table 1; Figure 1). Taking this into consideration, the reason for the optimal load during HPC being submaximal may be because the success criterion was set above a parallel squat, which is relatively wide. The only subject who did not show any salient change in bar velocity or displacement across the different relative loads (subject h) generated the highest peak power at 100% 1RM, which supports our point that the optimal load is 1RM when a narrower range of criterion is adopted, namely the quarter-squat position.

The optimal load differed on the basis of whether the success criterion adopted was narrow as a quarter-squat position or wide as a parallel-squat position as in the previous studies. The results in Figure 3 suggest that with a narrow criterion, even though the load that maximizes peak power output does not change, the optimal load becomes 100% 1RM. This implies that if the receiving position was consistent regardless of relative load, then the optimal load would always be the maximal load; in this regard, there should not be any differences among individuals or studies. In previous works, it was suggested that inconsistencies in optimal load were due to differences in the subjects' strength, fatigue, and training stage.^{9,11} However, based on our findings (Figure 3), the lifters' receiving positions might not have been strictly controlled, which could be the primary factor for such inconsistency. It has been stated in a journal article,¹⁹ a review article,¹ and original research articles^{6–10} that the optimal load for Olympic weight-lifting exercises that include the motion of receiving the bar after the second pull phase is a submaximal load. However, because it is possible that the success criterion (quarter squat vs parallel squat) is a determinant of the optimal load for HPC, the results of the previous studies and their interpretations should be applied with caution in strength and conditioning settings.

Practical Application

Consistent with previous studies, peak power during HPCs was seemingly maximized at 80% 1RM in the present study. However, this finding was limited to cases where the success criterion for the receiving position was set above the parallel-squat position. By contrast, in the standard quarter-squat position, the optimal load was the maximal load. Thus, when using HPCs for power training, coaches and athletes should select the appropriate %1RM load based on the desired receiving position.

Conclusions

When the success criterion is set above the parallel-squat position, a submaximal load is indeed the optimal load for maximal power output in HPCs. The decreased peak power at loads $\geq 90\%$ derives from the significant decrease in velocity and bar displacement. However, when the success criterion is set exactly to the quarter-squat position, 1RM becomes the optimal load.

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