

Muscle Power Output Properties Using the Stretch-shortening Cycle of the Upper Limb and Their Relationships with a One-Repetition Maximum Bench Press

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Abstract The purpose of this study was to examine the output properties of muscle power by the dominant upper limb using SSC, and the relationships between the power output by SSC and a one-repetition maximum bench press (1 RM BP) used as a strength indicator of the upper body. Sixteen male athletes (21.4 ± 0.9 yr) participated in this study. They pulled a load of 40% of maximum voluntary contraction (MVC) at a stretch by elbow flexion of the dominant upper limb in the following three preliminary conditions: static relaxed muscle state (SR condition), isometric muscle contraction state (ISO condition), and using SSC (SSC condition). The velocity with a wire load via a pulley during elbow flexion was measured accurately using a power instrument with a rotary encoder, and the muscle power curve was drawn from the product of the velocity and load. Significant differences were found among all evaluation parameters of muscle power exerted from the above three conditions and the parameters regarding early power output during concentric contraction were larger in the SSC condition than the SR and ISO conditions. The parameters on initial muscle contraction velocity when only using SSC significantly correlated with 1 RM BP ($r=0.60-0.62$). The use of SSC before powerful elbow flexion may contribute largely to early explosive power output during concentric contraction. Bench press capacity relates to a development of the above early power output when using SSC. *J Physiol Anthropol* 25(3): 239-245, 2006 <http://www.jstage.jst.go.jp/browse/jpa2>
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Introduction

It is often experienced that countermovement (movement by which the muscle is expanded oppositely immediately before the beginning of agonist muscle shortening) can perform the

intended movement with greater strength and speed in daily movement and sports. A rapid eccentric muscle action stimulates the stretch reflex and builds up the elastic energy, which increases the force produced during the subsequent concentric action. Such a movement is called Stretch-Shortening Cycle movement (SSC) (Komi, 1992). The use of SSC produces greater muscle power output within a short time than that from a pure concentric contraction (Norman and Komi, 1979; Komi, 1984). SSC is, therefore, popularly used in competitive sports requiring explosive power output of the upper limb such as “throwing” and “hitting”.

Studies on SSC were started by Cavagna et al. (1965), and were conducted chiefly by Asmussen et al. (1974), Walshe et al. (1996) and Bosco and Komi (1979) using running or jumping. Although studies on SSC of the upper limbs have been conducted using elbow flexion (Takamatsu et al., 1991) or bench pressing (Wilson et al., 1991; Newton et al., 1996), there are very few such studies as compared with those for lower limbs. The potentiation (change in the force-velocity characteristics of the muscle's contractile elements caused by SSC) of the upper limbs has not been clarified compared with that of the lower limbs. As for the upper limbs, very dexterous movement is possible because they are liberated from any anti-gravity mechanisms. It is, therefore, considered that the mechanism of the power exertion using SSC is different from the upper limb and triceps surae (antigravity muscle) by which tension is continuously demonstrated for a standing posture. Moreover, elbow flexion is a single joint movement that does not move, although the jump is a moving multijoint movement. Therefore, SSC of the upper limbs should be evaluated from the viewpoint of differences from the past.

Power output properties using SSC differ considerably in each individual (Wilson et al., 1994; Walshe et al., 1996), and the elasticity property of the tendon and muscle-tendon complex (MTC) shows peculiar changes by training loads and muscle contraction types (Kubo et al., 2000a,b). The difference in training is, therefore, considered to influence the power output by SSC. The bench press is a typical training

program for the upper body, and one repetition maximum (1 RM) of a bench press is the index of muscular power development. Consequently, the bench press is much used by power athletes aiming at improving performance in spite of the difference with actual movement or difference in agonist muscle. However, owing to insufficient data, it is not clear whether the purpose of bench press training is for strength or for improvement of muscle contraction velocity.

The bench press is a very popular SSC movement (Elliott, 1989). The target value of the bench press is hoisted to the first step of plyometrics emphasizing the activity style of SSC which has often been used in training by athletes in recent years (Holcomb et al., 1998). The hypothesis "Bench press ability is related to power exertion using SSC (especially, for rate of force development)" was the basis for this study. As for clarifying this relation, useful information will be provided for future training regimes. Even if a countermovement is not used before the beginning of shortening the agonist muscle, a prestretch can be produced. Therefore, a comparison between a light isometric condition where the countermovement is not used and the condition for the muscle to loosen completely might be necessary to examine the relation between peculiar SSC potentiation (depending on neurophysiological and mechanical factors) and the bench press.

The purposes of this study were to compare the output properties of muscle power exerted by explosive elbow flexion using SSC and non-SSC (static relaxed muscle and isometric muscle contraction states), and to examine the relationship between their output properties and a one-repetition maximum bench press.

Method

1. Subjects

The subjects were sixteen trained male athletes (mean age 21.4 ± 0.9 yr, mean height 1.74 ± 0.05 m, mean weight 71.0 ± 7.9 kg, mean 1 RM BP 85.5 ± 15.9 kg). They were selected from the following events: baseball (5), basketball (2), swimming (3), track and field (5), and soccer (1). Their mean training age was 12.1 ± 1.5 yr. Informed consent was obtained from them after a full explanation of the experimental project and its procedures. The power test was performed with the dominant arm determined by Oldfield's (1971) handedness inventory (all subjects were right-handed). The bench press capacity was evaluated by the maximum lifts (maximum one-repetition of bench press: 1 RM) within one month.

2. Experimental exercise

From connection with agonist muscle of bench press, experimental exercise should originally adopt elbow extension. However, it was judged that reproducible measurement would not be possible because the elbow extension by countermovement in this device was difficult. Moreover, from the result of preliminary experiments a heavy burden to the elbow joint of a subject was a matter of concern in this

measurement device. Although, therefore, agonist muscle was different from bench press, we adopted the elbow flexion that could use SSC with ease.

To clarify the output properties of muscle power by elbow flexion using SSC (SSC condition), the following two static preliminary states before explosive elbow flexion without using SSC were selected as comparison conditions: a static relaxed arm muscle state (SR condition) and an isometric muscle contraction state (ISO condition).

The subjects sat in an adjustable ergometric chair sideways, and put their right-arm on the table. They then put the axilla on the edge of the table with supination of the forearm. A bowling protector was worn to restrict the movement of the wrist. Subjects touched their palm to the handle, and explosively pulled the handle by elbow flexion as quickly as possible in the opposite direction to a wire rope that was connected to a constant load mass (Fig. 1). The motion-range of the elbow flexion was from 80° to 120° (the full-extension angle being 0° degrees), and the starting position angle was 80° .

The three preliminary conditions were as follows.

1) SR condition: Each subject pulled the handle from a static relaxed arm muscle state keeping an 80° elbow joint by concentric contraction.

2) ISO condition: Referring to the isometric condition introduced by Takamatsu et al. (1991) to examine the effect of a prestretch before concentric contraction, each subject pulled the handle from a state of pulling the load (40% MVC) with an 80° elbow joint for about 3 s by isometric contraction.

In the SR and ISO conditions, a tester confirmed a geostationary state and gave the starting signal. After the signal, the subject pulled the handle according to his own timing.

3) SSC condition: Each subject pulled the handle with the same load using a voluntary countermovement according to the subject's original rhythm and timing within the range of 80° – 120° . Because an original effect of SSC could not be demonstrated when the restriction of the countermovement was severe, frequencies of countermovement were assumed to be arbitrary. The position of the measurement device was adjusted in advance, so that the elbow joint angle at the beginning of concentric contraction was 80° . Several rehearsals were undertaken by the subject.

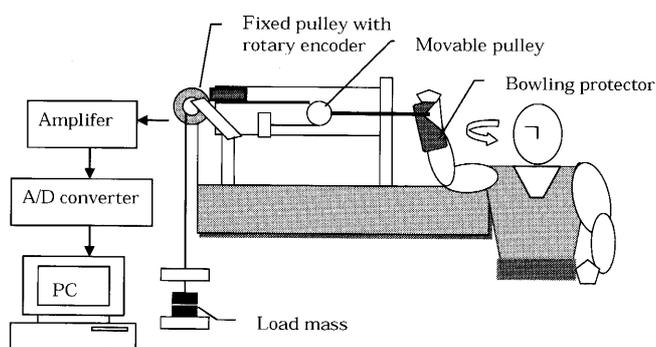


Fig. 1 Schematic representation of experimental setup.

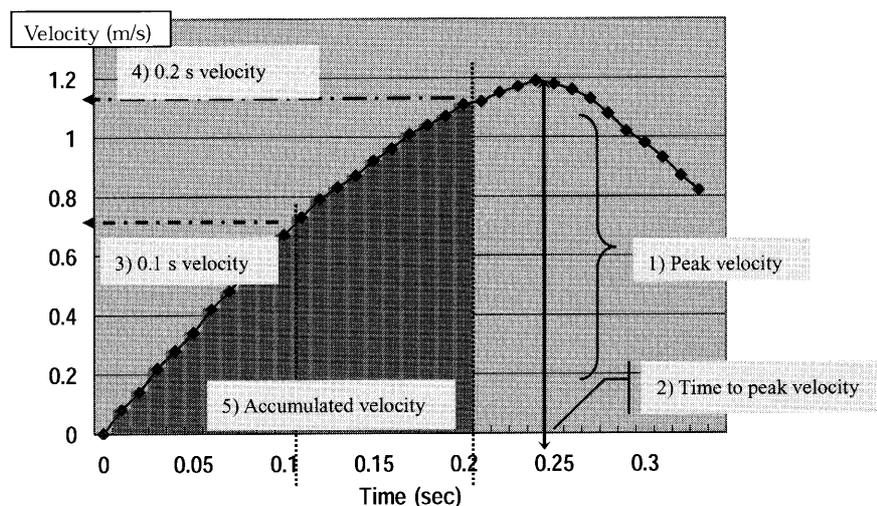


Fig. 2 Velocity-Time curve and parameters.

- 1) Peak velocity (m/s)
- 2) Time to peak velocity (s)
- 3) 0.1 s velocity during concentric contraction (m/s)
- 4) 0.2 s velocity during concentric contraction (m/s)
- 5) Accumulated velocity to 0.2s (m/s)
- 6) Peak power (peak power was calculated from the relative value based on MVC) (W)

3. Experimental device and muscle power measurement

Muscle power was measured using a muscle power measurement instrument developed by Ikemoto et al. (in press) (Yagami, Japan) (Fig. 1). This measurement device consists of a rotary encoder attached to a fixed pulley and a recording device. The rotary encoder measures the rotational angle with a sampling frequency of 100 Hz via an analog-to-digital interface. The rotational angle was converted to the pulling velocity of the wire rope with the load in the recording device. Funato et al. (1992) produced the isotonic load device (power processor) using a rotary encoder, and attempted to measure the power in the multijoint movement.

To determine the submaximal load for the power test, the subjects performed the maximal voluntary contraction (MVC) test with elbow flexion at 80°. The load was selected to be 40% MVC by referring to previous studies (Berger, 1963; Kaneko et al., 1983; Moritani et al., 1987). The power test was performed twice for the above-stated three conditions, and the higher value was used as the analysis data. The subjects conducted a number of practical trials to get accustomed to the device and explosive contraction. The experimental design was a crossover design where the subjects were arranged at random in each condition. The interval between trials and conditions was set for 3 min in consideration of the influence of muscle fatigue.

4. Evaluation parameters

The following muscle power parameters were selected by referring to previous studies (Demura et al., 2003): 1) peak velocity (m/s), 2) time to peak velocity (s), 3) 0.1 s velocity and 4) 0.2 s velocity during concentric contraction (m/s), 5)

accumulated velocity from starting to 0.2 s (m/s), and 6) peak power (W). Peak power was calculated from the relative value based on MVC (Fig. 2). The 0.1 s and 0.2 s velocities and accumulated velocity are initial muscle contraction velocity (IMCV) parameters to evaluate the rate of force development during concentric contraction.

5. Data analysis

To examine the reproducibility of the output properties of muscle power exerted from the three conditions, the cross-correlation coefficients were calculated. Repeated-Measures Analysis of Variance (ANOVA) was used to reveal mean differences among the three conditions for the parameters. When showing a significant difference, Tukey's HSD was used for post hoc comparisons. The criterion level for significance was set at $p < 0.05$.

Results

The cross-correlation coefficients between trials for time-series power parameters exerted from each preliminary condition were high ($r = 0.75\text{--}0.99$, $p < 0.05$). Figure 3 shows their typical time-series velocity curves. Table 1 shows the test results of ANOVA for power parameters, and Table 2 shows the correlations between power parameters and MVC and 1 RM BP.

There were significant differences among the three preliminary conditions in all power parameters. Peak velocity and peak power from the SR and SSC conditions were significantly higher than those of the ISO condition, and time to peak velocity from the SSC condition was significantly

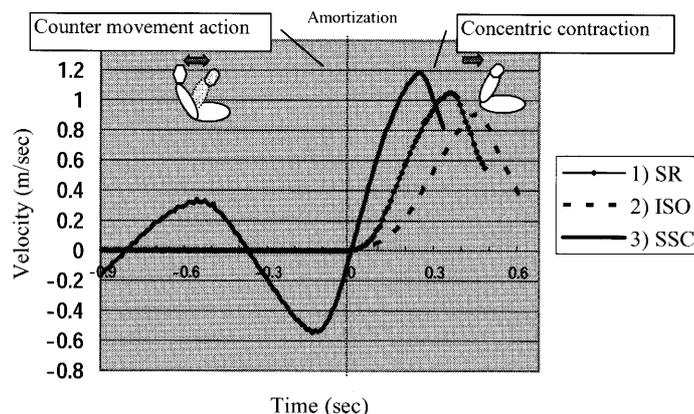


Fig. 3 Typical time-series velocity curve of SR, ISO, and SSC conditions.

Table 1 One-way ANOVA between three conditions for power parameters

	1) SR Mean±SD	2) ISO Mean±SD	3) SSC Mean±SD	F-value	post-hoc, HSD
0.1 s velocity (m/sec)	0.19±0.04	0.17±0.09	0.45±0.11	66.51**	3)>1), 2)
0.2 s velocity (m/sec)	0.60±0.07	0.51±0.18	0.86±0.13	39.69**	3)>1), 2)
Accumulated velocity (m/sec)	4.95±0.79	4.25±1.80	9.26±1.87	58.00**	3)>1), 2)
Peak velocity (m/sec)	1.17±0.13	1.05±0.11	1.17±0.12	18.71**	1), 3)>2)
Time to peak velocity (sec)	0.40±0.04	0.40±0.06	0.32±0.05	22.46**	1), 2)>3)
Peak power (W)	90.76±17.30	81.99±14.83	91.94±20.48	16.73**	1), 2)>3)

** : $p < 0.01$.

Table 2 Correlations between power parameters and MVC and 1 RM BP

	1) SR Correlation with		2) ISO Correlation with		3) SSC Correlation with	
	MVC	1 RM BP	MVC	1 RM BP	MVC	1 RM BP
0.1 s velocity	-0.02	-0.18	-0.25	-0.20	0.43	0.62
0.2 s velocity	-0.29	-0.15	-0.27	-0.18	0.27	0.60
Accumulated velocity	-0.14	-0.16	-0.26	-0.19	0.40	0.60
Peak velocity	-0.47	-0.28	-0.55	-0.36	-0.13	0.13
Time to peak velocity	0.13	-0.05	0.14	0.03	-0.23	-0.41
Peak power	0.83	0.71	0.87	0.72	0.91	0.82

MVC: maximal voluntary contraction, 1 RM BP: maximum one-repetition of bench press.

Shadow portions are significant ($p < 0.05$).

shorter than that of the SR and ISO conditions. IMCV parameters of 0.1 s and 0.2 s velocities and accumulated velocity were significantly higher in the SSC condition than the SR and ISO conditions.

Figure 4 shows the ratio of the 0.1 s and 0.2 s velocities occupying the peak velocity in the three preliminary conditions. The SSC condition (38.4%) was twice or higher at the 0.1 s velocity than the SR (16.4%) and ISO (15.9%) conditions (SSC>SR, ISO $p < 0.01$), but a difference between the peak and 0.2 s velocities was higher for the SR (48.2%) and ISO (51.3%) conditions than the SSC (26.6%) condition ($p < 0.01$).

MVC showed significant and high correlations ($r = 0.83$ – 0.91 , $p < 0.05$) with peak power exerted from the SR, ISO, and SSC conditions. Peak power exerted from the three conditions and 1 RM BP showed significant and high correlations ($r = 0.71$ – 0.82 , $p < 0.05$). 1 RM BP showed significant and moderate correlations ($r = 0.60$ – 0.62 , $p < 0.05$) with initial muscle contraction velocity in the SSC condition, but not in the other conditions.

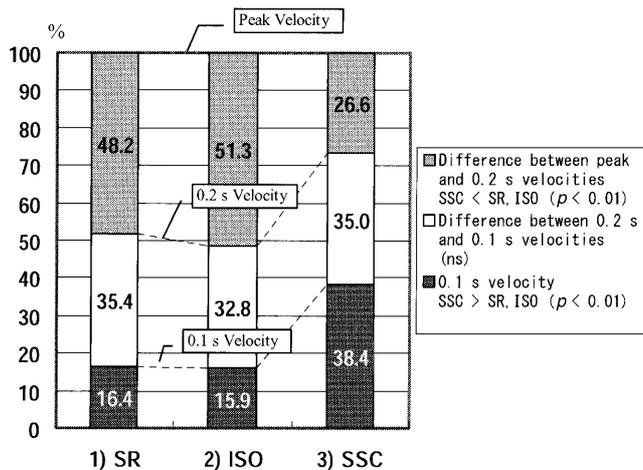


Fig. 4 Ratio of the 0.1 s and 0.2 s velocities occupying peak velocity.

Discussion

1. Muscle power output properties using the SSC of the upper limb

Reproducibility of power output

All cross-correlation coefficients of time-series power parameters exerted from the three preliminary conditions were above 0.70, which Fleiss proposed as a high criterion for ICC. The reproducibility of power output is, therefore, considered to be high. These results agreed with those reported by Ikemoto et al. (in press) who measured explosive grip strength using the same muscle power measurement instrument.

Significant differences were found among all power parameters exerted from the three preliminary conditions. It was suggested that there were differences of prestretch at the beginning of concentric contraction between the three preliminary conditions. A difference in the effect of a preliminary tension by the difference of the load style and the neurophysiological and mechanical background that brought it about were considered in this study based on this assumption.

Comparison of muscle power parameters in the three preliminary conditions

IMCV parameters evaluating early power output during concentric contraction were significantly higher in the SSC condition than in the SR condition, but peak velocity and peak power showed insignificant differences between the above conditions. This suggests that we must pay more attention to measuring IMCV parameters to evaluate output properties in detail and that muscle power properties cannot be properly evaluated with only peak power. It will be desirable to evaluate the rate of force development in a range of 0.1–0.2 s rather than evaluate peak velocity or peak power that demands times of 0.32 ± 0.05 s on ballistic movement (throwing, hitting etc.) achieved in an extremely short time, if assuming actual movement in sports.

When the accumulated velocity until 0.2 s is considered to be an amount of work, SSC (9.26 ± 1.87 m/s) achieves twice the work of the SR (4.95 ± 0.79 m/s) and ISO (4.25 ± 1.80 m/s) condition. Therefore, an enough augmentation effect by SSC is suggested.

The peak velocity and peak power were inferior in the ISO condition compared to the SR and SSC conditions. In a human movement that requires great force and power, it may be useful to enhance the preliminary force activity level before entering the main movement phase (Ae et al., 1978). Although 40% MVC in this study was selected considering the maximum strength difference, in an ISO condition it might have been an excessive stretching load producing nerve and muscular tension that acts negatively on the main movement phase.

The time to peak velocity, 0.1 s and 0.2 s velocities, and accumulated velocity to 0.2 s were superior in the SSC condition compared to the SR and ISO conditions. These results support the potentiation by SSC in previous studies that examined the movements of lower limbs (Asmussen and Bonde-Petersen, 1974; Bosco and Komi, 1979; Zushi and Takamatsu, 1995; Walshe et al., 1996) and upper limbs (Takamatsu et al., 1991; Wilson et al., 1992, 1994; Elliott et al., 1999).

Asmussen and Bonde-Petersen (1974) reported that mechanical energy is conserved in a muscular elastic element during countermovement and it is reused in active work, and energy is hardly conserved in the muscle in a movement by which power is exerted from the state of the rest. In addition, Thys et al. (1975) indicated that the elastic energy is reused in the first stage of active work, and contraction energy contributes to exerting power after that. These reports might prove that a part of the additional energy seen in the first half of active work of the SSC condition is reuse of the elastic energy conserved while countermoving.

The ratio of the 0.1 s velocity occupying the peak velocity in the SSC condition was about twice that of the SR and ISO conditions. Thus, SSC may be very useful to increase the initial muscle contraction velocity during concentric contraction (see Fig. 4). However, after 0.2 s, the SR and ISO conditions had larger acceleration. This suggests that there is a negative counterbalancing effect mitigating the positive effect acquired in the first half of the main movement phase. It was reported also in previous studies (Cavagna et al., 1968; Takamatsu et al., 1991; Walshe et al., 1998) that the effect of SSC is markedly in the first half of concentric contraction.

Load setting in the measurement

In previous studies (Berger, 1963; Kaneko et al., 1983; Moritani et al., 1987), it was reported that the maximum power was exerted at 30–45% MVC. Although this study used 40% MVC, a lighter load should be used to evaluate the stretch shortening potentiation. For example, although smashing in racquet sports and pitching in baseball require explosive power output, the tools (racquet, ball, etc.) actually used in the games are very light. Because the lower limbs, which always support

the weight of one's body, are fairly different from the upper limbs in anatomical structure and functional properties (forms and amounts of muscles and tendons, and the attachment of muscles), the mechanism of the power output is considered to differ in both limbs. Thus, it is valid to examine the power output properties of the upper limbs using a different technique or viewpoint from lower limbs (Glasheen and McMahon, 1995). In fact, it was recently reported that strength of stretch reflex response regarding SSC is different in an upper limb and a lower limb (Yamamoto, 2000). It will be necessary to examine power output properties exerted using SSC with various loads in future. Furthermore, in consideration of the relation with SSC performance (smashing, pitching, etc.), we would like to go on to devise a new measurement method in order to examine SSC in elbow extension.

2. Relationships between the muscle power parameters and a one-repetition maximum bench press

The IMCV parameters exerted using the SSC condition showed significant and moderate correlations with 1 RM BP, but not with MVC. This means that the IMCV parameters evaluating the rate of force development are more closely involved in the 1 RM BP than MVC (maximal elbow flexion strength).

In the SSC condition, it is estimated that a functional adjustment of the nerve system relating a peculiar power exertion on 1 RM BP movement affects the muscle contraction velocity rather than the influence of strength. It is, therefore, considered that 1 RM BP showed significant correlations with initial muscle contraction velocity in the SSC condition but not in the other conditions, although both agonist muscles are different. This suggests that the bench press is only effective in improving the performance of a movement that is accompanied by a countermovement.

The bench press is a very popular SSC movement that lends itself to the storage and release of strain energy (Elliott et al., 1989), and both styles of power output are very similar. Actually, it is known that well-trained athletes can lift heavier barbells skillfully using a countermovement called "cheating".

In addition, traditional heavy strength training, including the bench press, has frequently been used as a method to lift heavy loads (80–90% of the maximum) with few repetitions (4–8 RM). This produces an optimal strength increase (Berger, 1962) and enhances power and movement speed more than training with light loads (Schmidtbleicher and Haralambie, 1981; Schmidtbleicher and Buehrle, 1987). Consequently, it is possible that the neuromuscular function reacting to SSC movement in addition to myopachynsis is improved by bench press training, and the effect contributes to increasing the initial muscle contraction velocity during concentric contraction when using SSC. Although a quick lift (power clean and snatch) has been recommended to enhance explosive power output up to now, the present results suggest that the traditional bench press training also contributes to increasing the early power output when using SSC.

From the above, it is suggested that the initial phase is important for evaluation of SSC in the upper limbs, and we cannot sufficiently understand the properties by evaluating only the maximum value. Moreover, it is suggested that 1 RM BP contributes to the rate of force development of the power exertion using SSC. Training not only athletes but also reinforcing muscle power as part of a senior citizen's health measures is attracting attention, and research on the muscle power evaluation of the senior citizen has advanced in recent years (Symons et al., 2004; Haykowsky et al., 2005). The finding concerning muscle power that uses SSC will contribute to the training regime of senior citizens in the future.

Conclusions

In conclusion, the use of SSC before powerful elbow flexion may contribute significantly to early explosive power output during concentric contraction. Bench press capacity relates to the development of the above early power output when using SSC.

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