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Kinematics of unmounted and mounted horses at walk before and after treadmill exercise

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Summary

To determine the influence of strenuous exercise on kinematic variables at the walk, eight horses underwent an exercise test on a treadmill unmounted and mounted.

The workload, represented by heart rate and plasma lactate concentration, was significantly higher in the mounted horses. The evaluation of walk kinematics before and after strenuous exercise, showed that each horse had a characteristic pattern of head movement and joint motions, that were not changed by a rider's weight or strenuous exercise. Comparing kinematic variables at the walk before and after strenuous exercise, the mounted horses showed significant increases of stride duration, stride length, absolute stance duration, maximal fetlock extension in fore and hind limbs and range of pro-/retraction of the forelimb, and a decrease in vertical height of the head.

It is concluded that a strenuous workload significantly influences kinematics, even at the walk, although each horse kept its characteristic pattern.

Keywords: horse, treadmill exercise, fatigue, locomotion, walk kinematics

Bewegungsmuster von Pferden mit und ohne Reiter im Schritt vor und nach Belastung auf dem Laufband

Um den Einfluß einer anstrengenden Belastung auf kinematische Variablen im Schritt festzustellen, wurden acht Pferde in randomisierter Reihenfolge sowohl mit als auch ohne Reiter je einem Belastungstest auf dem Laufband unterzogen.

Die Belastungsintensität, gemessen an Herzfrequenz und Laktatkonzentration im Plasma, war bei den Pferden mit Reiter signifikant höher als bei denen ohne Reiter. Die Untersuchung der Bewegungsmuster im Schritt vor und nach der Belastung zeigte, daß jedes Pferd ein charakteristisches Schema der Bewegung von Kopf und Gelenken aufwies, das weder durch das Reitergewicht noch durch anstrengende Belastung beeinflußt wurde. Der Vergleich kinematischer Variablen vor und nach Belastung machte deutlich, daß bei den gerittenen Pferden die Schrittdauer, Schrittlänge, Dauer der Stützphase, maximale Extension der Vorder- und Hinterfesseln sowie der Bereich der Vor- und Rückführung der Vordergliedmaßen signifikant anstiegen, wohingegen die vertikale Höhe der Kopfhaltung abnahm.

Daraus wird geschlossen, daß eine intensive Belastung die Bewegungsmuster bereits im Schritt signifikant beeinflußt, obwohl jedes Pferd sein eigenes Schema beibehielt.

Schlüsselwörter: Pferd, Laufbandbelastung, Ermüdung, Fortbewegung, Bewegungsmuster im Schritt

Introduction

It is well known that strenuous exercise influences heart rate and plasma lactate concentration, but the influence of strenuous exercise, and thus fatigue, on equine locomotion has not been well documented. *Leach* and *Sprigings* (1977) evaluated the kinematics of the gallop stride of Thoroughbreds shortly after the start and just before the finish of a race. However, their horses had reductions in running speed and stride frequency at the end of the race, so it is not possible to separate the effects of fatigue from speed dependent changes in stride kinematics.

A review by *Siler* and *Martin* (1991) of field studies in human runners revealed that as a runner fatigues, velocity decreases, stride length shortens, and the range of motion at the joints of the lower extremity is reduced. These authors postulated that the running speed has to be controlled (e.g. on a treadmill) to allow differentiation between behavioral changes occurring with the development of fatigue and those associated with a reduced running speed.

Although slight differences between overground and treadmill locomotion have been found in the horse *(Buchner* et al. 1994), the biggest advantage of using a treadmill is that the horse moves at an exactly defined speed, which is repeatable on different occasions. In treadmill studies horses usually exercise unmounted, although riding is the normal manner of use for most sport horses. As previous studies have shown that riding a horse influences both locomotion and energetics *(Sloet* et al. 1995a and 1995b), in the present study the horses were exercised both unmounted and mounted.

The aim of the present study was to determine the influence of strenuous exercise, and thus fatigue, on kinematic variables at the walk. This was done on a treadmill both unmounted and mounted to evaluate whether riding a horse induced greater differences in walk kinematics before and after exercise.

Materials and methods

Horses

Eight well trained Dutch Warmblood horses were used, five mares and three geldings, age 7–14 years and weight 550–714 kg. The horses were fully accustomed to all experimental procedures as the present study was carried out immediately after earlier experiments with less demanding exercise tests *(Sloet* et al. 1995a). In the present study, the horses underwent a near maximal standardized treadmill exercise test, unmounted and mounted by an experienced 90 kg rider. The rider tried to keep the horse balanced and followed the movements of the horse as closely as possible. Before and after the tests, a routine clinical examination and blood screening proved that all horses were healthy and sound.

Standardized exercise test

Before both tests each horse was fitted with locomotion analysis equipment and a heart rate meter (Horse Tester, Polar Electro, Finland) as described earlier (*Sloet* et al. 1988). Each horse was always tested at the same time of day and at similar environmental temperatures. The sequence of unmounted and mounted exercise tests was chosen at random. The period between two tests was at least 48 h but no more than 92 h.

The protocol of the standardized exercise test was:

- blood sampling
- 4 minutes walk and trot to warm up
- 3 minutes walk (1.7 m/s) on a horizontal treadmill - kinematic measurements were made after 1 minute when a consistent stride pattern was observed
- 6 minutes trot (4.0 m/s) consisting of horizontal 2 minutes, 2% incline (1 minute), 4% incline (1 minute) 6% incline (1 minute) and 6→0% incline (1 minute)
- 7p minutes canter (7.0 m/s) consisting of horizontal (1 minute), 2% incline (1 minute), 4% incline (1 minute) 6% incline (1 minute), 4% incline (1 minute), 2% incline (1 minute) and horizontal (1 minute), and canter→walk (p minute)
- halt for one minute for blood sampling
- 8 minutes walk (1.7 m/s) on a horizontal treadmill - kinematic measurements were made after 1 minute when a consistent stride pattern was observed
- halt and final blood sampling (end of the test)

This test protocol, which took 28p minutes in total, had proven in earlier studies to be near maximal for horses carrying a rider.

The exercise tests were performed on a modified high speed treadmill (MUSTANG®, KAGRA, SWITZERLAND) (*Sloet* et al. 1995a).

Blood sampling procedure and analysis

Immediately before exercise, 30 seconds after the canter, and 30 seconds after the end of the exercise test, jugular venous blood samples were taken with a vacuum system and tubes with potassium oxalate (VENOJECT§, TERUMO, BELGIUM) to determine plasma lactate concentration (LA), using the Beckman method (LAC, SYNCHRON CXu SYSTEMS, BECKMAN INSTRUMENTS INC., BREA, CA, USA).

Kinematic measurements

Kinematic data were recorded using a modified CODA-3 apparatus (CHARNWOOD DYNAMICS, LOUGHBOROUGH, UK) as described earlier (*Schamhardt* et al. 1993). CODA-markers were glued to the skin of the horse covering easily palpable skeletal landmarks.

In the forelimb:

- no's 1 and 2 were fixed at the distal and proximal lateral hoof wall parallel with the foot axis
- no 3 at the metacarpal attachment of the lateral collateral ligament of the fetlock joint, close to the centre of rotation
- no 4 at the ulnar carpal bone, close to the effective centre of rotation of the carpal joint complex
- no 5 at the attachment of the lateral collateral ligament of the elbow joint on the radius and
- no 6 on the wing of the atlas.

In the hind limb:

- no's 7 and 8 were fixed at the distal and proximal lateral hoof wall parallel with the foot axis
- no 9 at the metatarsal attachment of the lateral collateral ligament of the fetlock joint, close to the centre of rotation
- no 10 at the lateral malleolus of the tibia
- no 11 at the attachment of the lateral collateral ligament of the stifle joint on the head of the fibula and
- no 12 at the coxal tuberosity.

Unidirectional (custom made) accelerometers were fixed to the lateral wall of the left fore and hind hooves to indicate the accelerations associated with ground contact and lift off.

Data analyzed in this study, were collected before and after the strenuous part of the exercise test for 10 seconds at the walk (1.7 m/s) on a horizontal treadmill.

Definitions of variables used, data processing and statistical evaluation

The resting heart rate is the average heart rate of the horses at rest. The maximal heart rate is the heart rate of the last half minute of the maximal exercise step at the canter (7.0 m/s on a 6% inclined treadmill). The recovery heart rate is the heart rate of each horse immediately after the test, standing still on the treadmill.

The kinematic variables used were (*Back* et al. 1993, *Buchner* et al. 1994 and *Sloet* et al. 1995a):

* stride duration = the time in seconds between onset of successive ground contacts of the left forelimb
* stride length = the distance in meters covered during each stride, calculated from the stride duration and the treadmill speed
* absolute stance duration = the time in seconds between onset of ground contact, determined by the impact accelerometer peak, and the end of the stance phase, determined by the vertical movement of the distal hoof marker in combination with the accelerometer signal
* relative stance duration = the absolute stance duration expressed as a percentage of the stride duration
* fetlock joint angle = for the forelimb the angle between lines connecting markers 2, 3 and 4, and for the hind limb the angle between lines connecting markers 8, 9 and 10
* carpal joint angle = the angle between lines connecting markers 3, 4 and 5
* tarsal joint angle = the angle between lines connecting markers 9, 10 and 11
* pro- and retraction angles = in the hind limb, the angle between a vertical line through marker 12 on the coxal tuberosity and a line connecting markers 12 and 9; in the forelimb, the angle between a vertical line through an imaginary point on the shoulder (that was related for each horse individually to marker 12 on the coxal tuberosity) and a line through that point and marker 3: rotation of the limb cranial to the vertical is negative, and rotation caudal to the vertical is positive
* maximal and minimal vertical height of the head = the highest (respectively lowest) point in the trajectory of the wing of the atlas, which represents the head height.

The accelerometer impact peak was used to detect the beginning of each stride both in fore and hind limbs. In this way the joint angles for each stride could be calculated and standardized to the total stride duration (*Back* et al. 1993). Within the angle definitions as described above, positive values indicate flexion and negative values extension of the joint (figure 1).

All data are given as mean ± standard deviation (SD). Data were subjected to an analysis of variance using a repeated measures model (STAT-VIEW, ABACUS CONCEPTS, BERKELEY 1987 ON

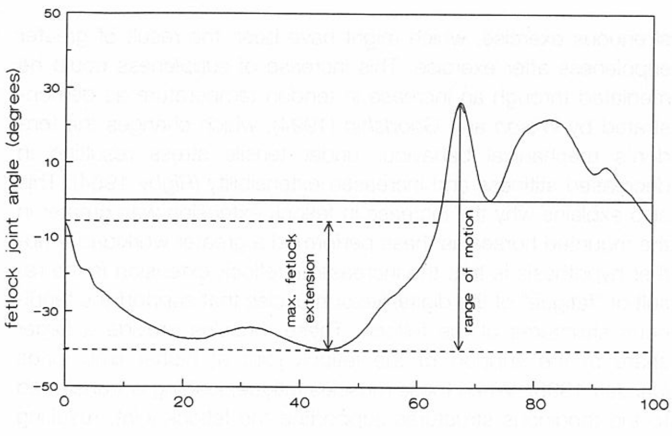

Fig.1: Definition of some kinematic variables in an angle-time diagram of the forelimb fetlock joint at the walk (1.7 m/s).

AN APPLE MACINTOSH TM LCII W); $p < 0.05$ was considered statistically significant.

Result2

Heart rate and plasma lactate

The mean heart rate (HR) and the mean plasma lactate concentration (LA) before exercise were not significantly different between the unmounted and the mounted horses (HR 36±7 and 39±6 beats/min respectively; LA 1.0±0.3 and 0.9±0.3 mmol/l respectively).

Comparing the unmounted to the mounted horses, mean peak HR (189±14 and 200±12 beats/min respectively), mean peak plasma LA (3.3±1.2 and 7.3±3.4 mmol/l respectively), mean recovery HR (63±9 and 70±8 beats/min respectively), and mean recovery LA (1.3±0.3 and 3.3±1.9 mmol/l respectively) differed significantly. These results indicate that the workload in the mounted test was significantly higher.

Kinematic variables

Each horse had a characteristic pattern of joint motion and head motion ("kinematic fingerprint") that was not changed by the addition of a riders weight or the effects of strenuous exercise (figure 2 and 3).

The mean data for the kinematic variables are shown in table 1. Comparing the results before and after strenuous exercise in the mounted horses, noticeable features are the significant increase of stride duration, stride length and absolute stance duration of fore and hind limbs. Furthermore, the maximal fetlock extension in fore and hind limbs increased both in the unmounted and the mounted horses after exercise, but this was only significant in the mounted horses. Mounted horses showed more protraction and less retraction in the forelimb compared to the unmounted horses. After strenuous exercise, the mounted horses showed an increased maximal range of motion of the forelimb, based on an increased retraction.

Compared with the unmounted horses, the mounted horses showed significant increases of relative stance duration, maximal fetlock extension and range of fetlock joint motion of the forelimb, range of fetlock joint motion in the hind limb, and range of the carpal joint motion.

Mounted horses held their heads significantly higher before exertion than unmounted horses. After exertion, most horses tended to carry their heads lower, but this decrease in maximal and minimal head height was only significant in the mounted horses.

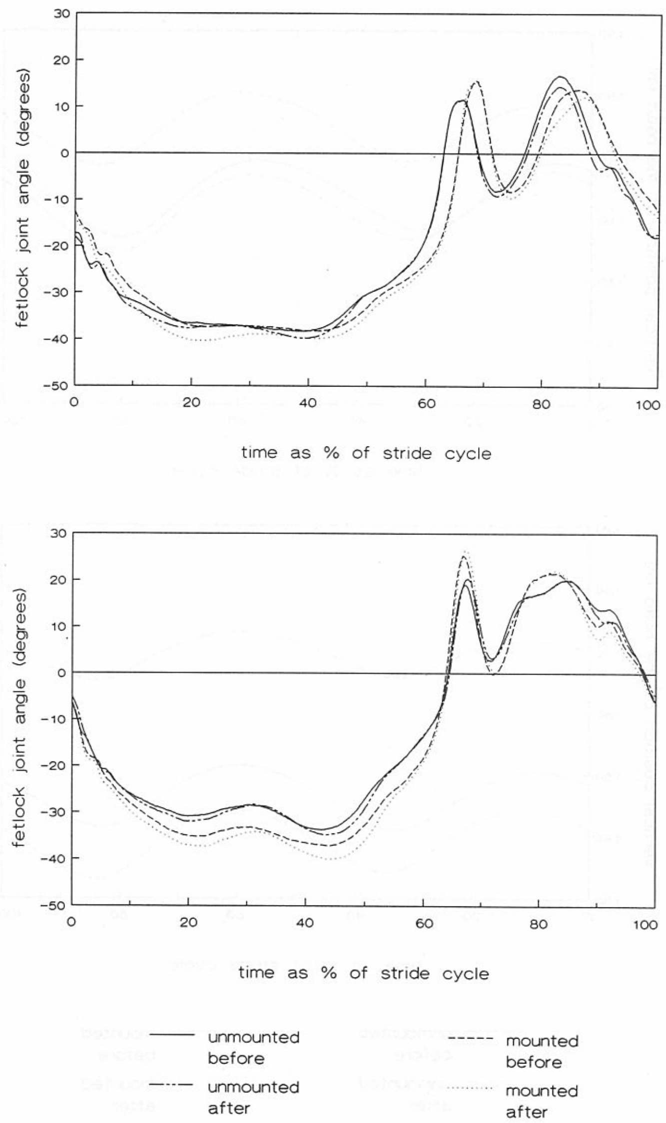

Fig. 2: Angle-time diagram of the forelimb fetlock joint angle of horse A (upper diagram) and horse B (lower diagram) at the walk (1.7 m/s) before and after strenuous exercise in both unmounted and mounted situations.

Discussion

The workload of the exercise test, represented by heart rate and plasma lactate concentration, was significantly higher in the mounted horses compared to the unmounted situaton, as has been shown earlier (*Sloet* et al. 1995a). The results of heart rate and plasma lactate concentration also indicate that the mounted horses were working at or near their maximal capacity (*Sloet* et al. 1987). Strenuous exercise resulted in similar kinematic changes with and without a rider, but these tendencies reached the level of statistical significance only in the mounted horses, which had performed a higher workload. This supported the hypothesis that the influence of fatigue on kinematics is proportional to workload.

Considering all kinematic data (the individual time variables, the angle-time diagrams and the movements of the head), it is clear that each horse has an inherant locomotion pattern as described by *Back* et al. (1994). This pattern or "kinematic fingerprint" is maintained when working with a rider and when fatigued.

The finding that the stride duration before strenuous exercise was shorter in the mounted horse than in the unmounted horses might

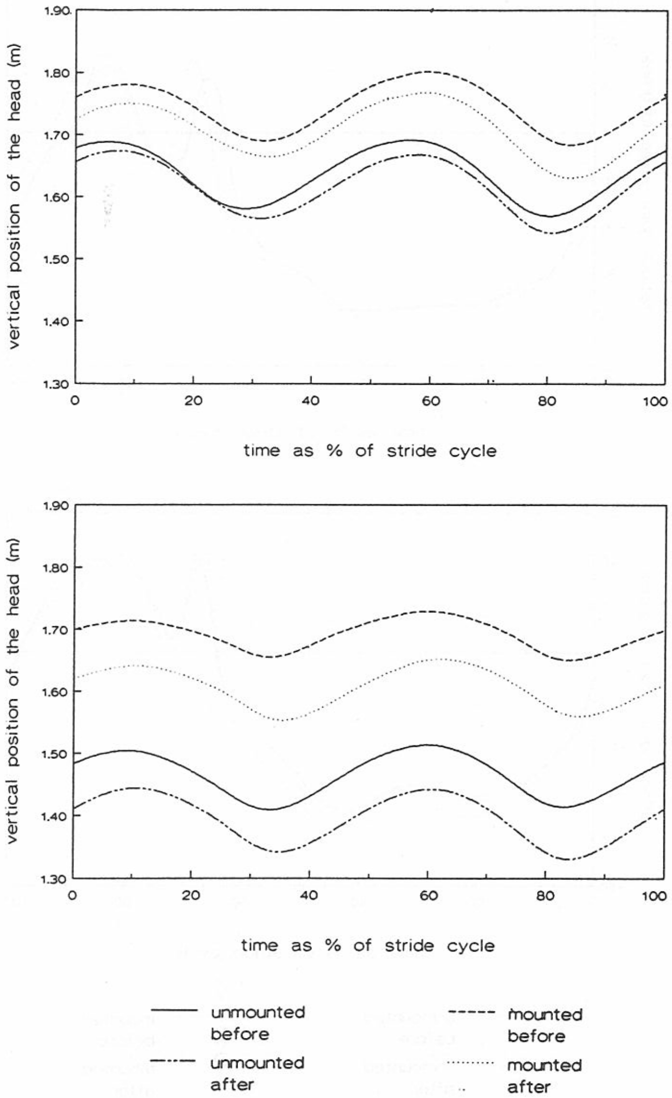

Fig. 3: The vertical height of the head during one stride of horse A (upper diagram) and horse B (lower diagram) at the walk (1.7 m/s) before and after strenuous exercise in both unmounted and mounted situations.

be related to the fact that most horses seemed slightly more excited at the beginning of the test in the mounted situation. It is not possible from these results to determine whether the increase in stride duration, and thus stride length, after strenuous exercise was a result of a more relaxed gait, or was an effect of fatigue. The finding that the stride length after exercise was also significantly longer in the mounted horses than in the unmounted horses, suggests that it may be at least partly a consequence of fatigue. *Siler* and *Martin* (1991) reported also an increase in stride length in human athletes running on a treadmill, and they considered this to be a response to fatigue.

The fetlock joint is supported by tendinous elastic structures, which makes it easy to understand that additional loading is reflected by an increased fetlock extension *(Jansen* et al. 1993, *Sloet* et al. 1995a). This finding was confirmed in the present study: the mean fetlock extensions and ranges of motion of fore and hind limbs were greater in the mounted horses compared to the unmounted horses. Within each test situation (unmounted or mounted) the maximal fetlock extension increased as a result of strenuous exercise, which might have been the result of greater suppleness after exercise. This increase of suppleness could be mediated through an increase in tendon temperature as demonstrated by *Wilson* and *Goodship* (1994), which changes the tendon's mechanical behaviour under tensile stress resulting in decreased stiffness and increased extensibility *(Rigby* 1964). This also explains why the increase in fetlock extension was greater in the mounted horses as these performed a greater workload. Another hypothesis is that the increase of fetlock extension is the result of "fatigue" of the digital flexor muscles that support the tendinous structures of the fetlock. These muscles provide a larger share of the support of the fetlock joint at higher limb loads *(Jansen* 1995). When these muscles fatigue, loading is transferred to the tendinous structures supporting the fetlock joint, resulting in greater fetlock extension.

Probably both factors, alterations in tendon properties and muscle fatigue, contribute to the increased fetlock extensions found after strenuous exercise and thus make the tendinous structures of the lower limb more prone to injuries.

The significant alterations in maximal pro- and retraction of the forelimb in the mounted horses compared to the unmounted horses, might be the result of riding, while the increase in range of motion after strenuous exercise resulted perhaps both from increased suppleness of the whole body and from muscle fatigue.

The fact that mounted horses carried their heads significantly higher than the unloaded horses might be caused by the rider, although the rider tried to influence the horses as little as possible. Since the head position was lower after exertion in both the unmounted and mounted conditions, this decrease in height of the head was probably due to fatigue.

From the present study it is concluded that a strenuous workload significantly influences kinematics, even at the walk, but each horse keeps its individual "kinematic fingerprint". Consistent effects of fatigue were: longer stride and stance durations, increased maximal fetlock extension and a lower head position. These differences were more pronounced in the mounted horses that performed a higher workload.

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Tab1: Mean values ± SD of kinematic variables collected at the walk (1.7 m/s) before and after strenuous exercise in eight Dutch Warmbloods exercising on a treadmill unmounted and mounted. For explanation of the variables see materials and methods.

variable (unit)	unmounted before	unmounted after	mounted before	mounted after
stride duration (s)	1.13±0.03	1.13±0.04	1.10±0.06	1.15±0.05 *
stride length (m)	1.92±0.06	1.93±0.07	1.87±0.10	1.96±0.08 *
absolute stance duration forelimb (s)	0.56±0.02	0.57±0.02	0.57±0.03	0.60±0.03 *
absolute stance duration hind limb (s)	0.59±0.01	0.60±0.02	0.59±0.02	0.62±0.02 *
relative stance duration forelimb (%)	49.8±1.4	50.1±1.4	51.8±1.4 #	52.4±1.4
relative stance duration hind limb (%)	52.1±1.6	52.6±1.8	53.5±1.4 #	53.4±1.5
max. fetlock extension forelimb (degrees)	-22.0±3.0	-23.0±3.5	-24.7±3.2 #	-26.2±3.7 *
range fetlock joint angle forelimb (degrees)	58.3±3.6	59.3±3.7	63.7±5.9 #	64.8±5.2
max. fetlock extension hind limb (degrees)	-22.8±3.6	-24.0±4.0 *	-24.3±3.0	-25.6±3.8 *
range fetlock joint angle hind limb (degrees)	66.1±7.0	68.5±6.9	71.4±8.4 #	71.8±8.0
range carpal joint angle (degrees)	60.7±5.3	61.8±4.8	65.9±2.9 #	65.5±3.1
range tarsal joint angle (degrees)	36.9±2.8	39.0±6.0	37.6±2.7	36.8±2.3
range pro/retraction forelimb (degrees)	46.4 ±2.5	47.1±2.8	46.2±2.9	48.2±2.3 *
max. protraction forelimb (degrees)	-25.3±2.0	-25.5±2.3	-26.0±2.0 #	-26.7±2.6
max. retraction forelimb (degrees)	21.2±2.3	21.5±2.0	20.2±2.9 #	21.6±2.2 *
range pro/retraction hind limb (degrees)	44.8±2.0	45.2±2.3	44.6±2.3	45.8±2.6
max. protraction hind limb (degrees)	-10.1±1.1	-10.1±1.1	-9.5±0.9	-10.1±1.5
max. retraction hind limb (degrees)	34.7±1.5	35.1±1.5	35.1±1.8	35.7±1.5
max. height of head (m)	1.69±0.10	1.66±0.12	1.79±0.07 #	1.71±0.09 *
min. height of head (m)	1.59±0.10	1.55±0.12	1.69±0.06 #	1.61±0.09 *

* values before and after strenuous exercise are significantly different ($p < 0.05$)
\# values between unmounted and mounted situations before strenuous exercise are significantly different ($p < 0.05$)

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