

Aerobic Fitness Relation to Match Performance of Japanese Soccer Referees

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[Received February 17, 2015; Accepted November 11, 2015]

This study was conducted to investigate the relation between aerobic fitness parameters and match performance of Japanese soccer referees. This study examined 14 Japanese male referees (25.9 ± 3.1 yr) using a submaximal incremental treadmill test to ascertain the running speed at the onset of blood lactate accumulation (s-OBLA) and to estimate $\dot{V}O_{2max}$ from the heart rate. Match performances (total distance, high-intensity running (HIR: ≥ 15 km·h⁻¹) and distances from fouls) were calculated during competitive matches using data recorded from a GPS device and a video camera. The total distance covered during a match was 11.3 ± 0.6 km, of which 1.9 ± 0.4 km was covered by HIR. The mean distance from a foul was 14.4 ± 1.0 m. The s-OBLA was 14.5 ± 1.0 (12.6–16.3) km·h⁻¹, which was correlated positively with the distance covered at HIR ($r = 0.77$; $p < 0.05$) and negatively with the mean distance from a foul ($r = -0.62$; $p < 0.05$). The estimated $\dot{V}O_{2max}$ was not related to these variables ($p > 0.05$). Results suggest that OBLA assessment is a good index of fit referees who can cover longer distances at high speed and judge foul plays from short distances.

Keywords: Blood lactate, Onset of blood lactate accumulation (OBLA), Submaximal incremental exercise, High intensity running, Global positioning system

[Football Science Vol.12, 91-97, 2015]

1. Introduction

Soccer referees enforce the game rules. They are responsible for controlling player behaviour during match play (Castagna et al., 2007). Therefore, they are obliged to be in the best position to view a play by keeping up with players and making appropriate decisions (Weston et al., 2010, 2012). Recent reports have described that the risk of incorrect decisions was lowest when the distance from a foul was as short as 11–15 m (Mallo et al., 2012). The mean distance from a foul during a match (i.e., 15 m) coincides with this suggested distance (Krustrup & Bangsbo 2001; Krustrup et al., 2009; Weston et al., 2010, 2011a). To be within an appropriate distance from foul plays, referees must demonstrate and maintain a high level of aerobic fitness. For example, soccer referees cover 10–12 km during a match, with 10–20 % of it covered by high-intensity running (HIR ≥ 15 km·h⁻¹) (Krustrup & Bangsbo 2001; Krustrup et al., 2009; Weston et al., 2012). These match activity profiles are

similar to those required of players (Castagna et al., 2007; Weston et al., 2011b). Especially, the distance covered at HIR has been regarded as an important requisite for referees, given the intermittent nature of soccer (Krustrup & Bangsbo 2001; Krustrup et al., 2009).

Previous studies have demonstrated that, for experienced Italian elite-level referees, both the maximal oxygen uptake ($\dot{V}O_{2max}$) and running speed at blood lactate concentration of 4 mmol·L⁻¹ (onset of blood lactate accumulation; OBLA) are correlated with the total distance covered. Actually, $\dot{V}O_{2max}$ is regarded as a slightly better predictor of the total distance than OBLA is (Castagna et al., 2002; Castagna & D'Ottavio 2001). Neither $\dot{V}O_{2max}$ nor the speed at OBLA (s-OBLA) is correlated with the distance covered at HIR. For these studies, however, video images were used to calculate running speeds. Consequently, the accuracy might be limited. Therefore, further investigations of the correlation between the aerobic fitness parameters ($\dot{V}O_{2max}$

and s-OBLA) and the match activity profiles might be warranted. Such investigations are expected to help to identify the physiological parameters which enable referees to reach appropriate distances from fouls, thereby reducing the incidence of incorrect judgments. Ultimately, the results are expected to help to develop effective training schemes for referees.

Recent technological developments have facilitated new methods of assessing movement patterns in soccer referees, including multiple-camera method (Weston et al., 2010, 2011a, 2011b) and global positioning system (GPS) devices (Barbero-Álvarez et al., 2012). In comparison to traditional video-based time motion analysis (Castagna et al., 2002; Castagna & D'Ottavio 2001; Krstrup & Bangsbo 2001; Krstrup et al., 2009), these new automated match analysis methods provide a greater objectivity and a higher time-resolution, enabling more comprehensive and accurate examination of movement patterns in soccer (Randers et al., 2010, 2014). Specifically, advances in GPS method enable position data to be collected at 15 Hz during a match and training. Given the nature of movement patterns of soccer (frequent changes in direction at high speed over a short distance), this higher sampling rate might enhance the validity and reliability of data examinations. Investigations of relations between aerobic fitness parameters and match activity profiles will be strengthened using these techniques.

Therefore, this study was conducted using a GPS device and a video camera to investigate the relation between aerobic fitness parameters (s-OBLA and $\dot{V}O_{2max}$) and the match performance (total distance covered, distances at HIR and distances from fouls) of soccer referees. This report is the first of a study identifying potential aerobic fitness parameters that influence the distance from a foul.

2. Materials

2.1. Participants

Each of the 14 male Japanese soccer referees who participated in this study held a Japan Football Association (JFA) first-class or second-class license. Their mean age, referee experience, height, body mass and body mass index (BMI) were, 25.9 ± 3.1 yr, 7.3 ± 2.3 yr, 175.5 ± 5.4 cm, 66.5 ± 3.7 kg, and 21.6 ± 1.2 kg·m⁻², respectively. All participants were apprised of the study methods, procedures, and risks.

All signed an informed consent document before participating. This study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee for Human Experiments of Juntendo University.

2.2. Experimental design

Match data were collected by high-school and university top-level leagues in Japan (Kanto Prince League and the First Division of the Kanto University League) in September and October of 2011–2013 (2011, $n = 11$; 2013, $n = 4$). The match and half-time durations were 90 min (45 min \times 2) and 15 min, respectively. Environmental conditions during the matches were 28.7 ± 4.4 °C ambient temperature (T_a), 63.9 ± 16.9 % relative humidity (Rh) and Wet-Bulb Globe Temperature (WBGT) 26.7 ± 4.3 °C with no rainy day. Within 4 weeks after the match analysis, each participant visited the laboratory and performed an incremental treadmill test to determine the aerobic fitness parameters.

2.3. Data collection and analysis

2.3.1. Match physical demands

Match activity data were collected using a 15 Hz GPS device (Sports performance indicator, SPI-Pro X2; GPSports Systems Pty. Ltd., Canberra, Australia) from 14 matches (one match dataset per referee). The GPS device was placed on the referee's upper back inside a pocket sewn into the specific undershirt. After the GPS device was worn at the last minute before warm-up, this device operation was checked during warm-up. The validity and reliability of GPS methods were reported previously (Barbero-Alvarez et al., 2010).

After the match, the recorded data were exported (Team AMS software; GPSports Systems Pty. Ltd., Canberra, Australia) for motion analysis. Based on a previous report by Krstrup et al. (2009), the movement speeds of the referees were classified into the following categories: (1) walking, < 6 km·h⁻¹; (2) jogging, $6\text{--}8$ km·h⁻¹; (3) low-speed running, $8\text{--}12$ km·h⁻¹; (4) moderate-speed running, $12\text{--}15$ km·h⁻¹; (5) high-speed running, $15\text{--}18$ km·h⁻¹; and (6) sprinting, ≥ 18 km·h⁻¹, and high-intensity running (HIR) was defined as movement at a speed greater than 15 km·h⁻¹.

Each referee's heart rate (HR) was recorded

using short-range radio telemetry (polar T34; Polar Electro, Kempele, Finland). Each referees' individual maximum HR (HR_{max}) value was estimated using an age-predicted formula: $220 - \text{age}$. However, if the peak value of recorded HR during a match was higher than the age-predicted value, as it was for 4 of 14 referees, then the recorded value was adopted as HR_{max} . In addition, the rating of perceived exertion (RPE) was assessed immediately after a match using Borg's original (i.e., 6–20) scale (Borg 1982).

2.3.2. Distance from a foul

All matches were recorded using a broad-view video camera (HDR-CX560 V; Sony Corp., Tokyo, Japan) to evaluate the distances from fouls. The camera was positioned in the stands as an extension of the halfway line. The distance between the camera and the field was about 20–30 m. The camera filmed a referee and players near the ball at a wide angle to evaluate the referee's distance from a foul. The distance from a foul was calculated based on a method used for a previous study (Aoba et al., 2011). In brief, the video was stopped temporarily each time a foul occurred. Then the spot where the referee signalled a foul and the spot at which a foul had occurred were transcribed to a 1/400 scale paper of a soccer-field. The distance between the spots was ascertained by drawing a straight line. To obtain the most accurate positions possible, we made marks representing the lines on the grass on the pitch, advertisements, and field lines. The same experienced observer analyzed all 14 matches.

2.3.3. Submaximal exercise test

To determine OBLA, defined as blood lactate concentration of $4 \text{ mmol}\cdot\text{L}^{-1}$, participants completed a submaximal test using an incremental treadmill protocol. The treadmill inclination was set at 1 % throughout the test. Following 3 min of stretching exercises and 5 min of a warm-up on a treadmill (Nishikawa Iron Works, Kyoto, Japan), the test commenced at a speed of $8 \text{ km}\cdot\text{h}^{-1}$. Then the speed was increased by $1 \text{ km}\cdot\text{h}^{-1}$ every 3 min until the blood lactate concentration was higher than $4 \text{ mmol}\cdot\text{L}^{-1}$. The rest between each stage was 30 s. Blood samples were taken from an earlobe during the rest period immediately after each stage. The blood lactate level was measured using a lactate analyzer (Lactate Pro; Arkray Inc., Kyoto, Japan). For each, HR was monitored throughout the test using a watch (Polar

RS800; Polar Electro, Kempele, Finland). Running speeds at lactate concentrations of 2 (LT2) (Faude et al., 2009; Kindermann et al., 1979; Yoshida et al., 1987) and 4 (OBLA) (Sjodin & Jacobs 1981) $\text{mmol}\cdot\text{L}^{-1}$ were calculated using a quadratic equation calculated from the values of blood lactate at each speed. Then the relation between the running intensity and the speed at LT2 (s-LT2) and OBLA (s-OBLA) was determined.

The oxygen uptake ($\dot{V}O_2$) was also measured throughout the test using a metabolic measurement system (AE-300S; Minato Medical Science Co. Ltd., Osaka, Japan). This system was calibrated using two gases of known concentrations: oxygen and carbon dioxide. Before testing, the flow sensor was calibrated using a 3-litre syringe. $\dot{V}O_{2max}$ was estimated by fitting the value of HR_{max} into the linear regression equation calculated from the individual $\dot{V}O_2$ and HR value during a sub-maximal exercise test. Similarly, the running speed at estimated $\dot{V}O_{2max}$ (s- $\dot{V}O_{2max}$) was calculated using $\dot{V}O_2$ and running speed. Actually, 5 of the 14 participants underwent an actual $\dot{V}O_{2max}$ test using an incremental treadmill protocol to confirm the validity of the estimated $\dot{V}O_{2max}$ within 6 weeks, with the difference to the actual value being $-2.3 - 2.5 \%$.

2.4. Statistical analyses

All calculations were performed using pc software Statistical Package for Social Sciences ver. 17.0 (SPSS Inc., Chicago, IL, USA). Differences in the measured variables between the first and second half of the match were assessed using Student's paired *t*-test. Pearson's correlation analysis was used to assess the relation between measured variables. Statistical significance was inferred for $p < 0.05$. Data were presented as the mean \pm S.D.

3. Results

3.1. Aerobic fitness parameters

The s-LT2 and s-OBLA were 12.2 ± 1.4 and $14.5 \pm 1.0 \text{ km}\cdot\text{h}^{-1}$, respectively. Also, $\dot{V}O_2$ at LT2 and OBLA were 42.6 ± 3.7 and $49.4 \pm 2.9 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, respectively. HR at LT2 and OBLA were $157 \pm 13 \text{ beats}\cdot\text{min}^{-1}$ ($80.9 \pm 6.8 \%$ of HR_{max}) and $175 \pm 11 \text{ beats}\cdot\text{min}^{-1}$ ($90.8 \pm 5.4 \%$ of HR_{max}), respectively. In addition, estimated $\dot{V}O_{2max}$ and s- $\dot{V}O_{2max}$ were $56.8 \pm 6.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $17.0 \pm 1.8 \text{ km}\cdot\text{h}^{-1}$, respectively.

HR_{max} was 194 ± 3 beats·min⁻¹.

3.2. Match performance

The total distance covered during a match was 11.3 ± 0.6 km, of which 1.9 ± 0.4 km were covered by HIR (17.1 ± 3.1 % of total distance covered) (**Table 1**). The mean movement speed during a match was 7.11 ± 0.42 km·h⁻¹. Mean HR during a match was 166 ± 9 beats·min⁻¹, which corresponded to 85.3 ± 4.4 % of HR_{max} . The RPE after a match was 15 ± 2 . The mean distance from a foul during a match was 14.4 ± 1.0 m. These measured variables did not differ significantly between the two halves.

3.3. Relations between measured variables

The relations between aerobic fitness parameters and the distance covered at each movement speed during a match are presented in **Table 2**. Pearson correlation analysis revealed that the total distance covered did not correlate with all parameters of aerobic fitness, although correlation with s-OBLA was almost significant ($r = 0.53$; $p = 0.051$). The values of s-LT2 and s-OBLA were correlated significantly with the distance covered at HIR during a match ($r = 0.73$; $p = 0.003$ and $r = 0.77$; $p = 0.001$, respectively, **Table 2**). The estimated $\dot{V}O_{2max}$ and s- $\dot{V}O_{2max}$ were not correlated significantly with it ($r = 0.49$; $p = 0.073$ and $r = 0.52$; $p = 0.055$, respectively, **Table 2**).

The relations between aerobic fitness parameters

Table 1 Match activity profiles of soccer referees (mean \pm S.D.) in Japanese youth top-level league matches

Match activity variables	first half	second half	total
Distance covered (m)			
walking (< 6 km·h ⁻¹)	1490 \pm 163	1514 \pm 143	3003 \pm 286
jogging (6–8 km·h ⁻¹)	653 \pm 109	676 \pm 106	1329 \pm 203
low-speed running (8–12 km·h ⁻¹)	1512 \pm 257	1547 \pm 213	3059 \pm 455
moderate-speed running (12–15 km·h ⁻¹)	962 \pm 160	984 \pm 116	1945 \pm 231
high-speed running (15–18 km·h ⁻¹)	563 \pm 101	573 \pm 85	1125 \pm 174
sprint (\geq 18 km·h ⁻¹)	400 \pm 149	413 \pm 162	813 \pm 242
HIR	957 \pm 229	981 \pm 232	1938 \pm 390
Total	5574 \pm 398	5730 \pm 274	11304 \pm 588
Mean speed (km·h ⁻¹)	7.18 \pm 0.53	7.04 \pm 0.39	7.11 \pm 0.42
Mean HR (beats·min ⁻¹)	166 \pm 9	165 \pm 9	166 \pm 9
Mean distance from a foul (m)	14.3 \pm 1.3	14.4 \pm 2.4	14.4 \pm 1.0
RPE	14 \pm 2	15 \pm 2	

Notes: High-intensity running (HIR) was defined as movement at a speed greater than 15 km·h⁻¹ (high-speed running+ sprinting).

Table 2 Relations between aerobic fitness parameters and distance covered at each speed category during a match

	Match mean HR (beats·min ⁻¹)	s-LT2	s-OBLA	VO_{2max} (estimated)	s- VO_{2max} (estimated)
Distance covered					
walking (< 6 km·h ⁻¹)	-0.03	0.09	-0.05	0.53	-0.04
jogging (6–8 km·h ⁻¹)	-0.46	-0.12	-0.00	-0.22	-0.02
low-speed (8–12 km·h ⁻¹)	0.07	-0.12	-0.14	-0.48	-0.33
moderate-speed (12–15 km·h ⁻¹)	-0.49	0.39	0.52	0.37	0.63 *
high-speed (15–18 km·h ⁻¹)	0.66 *	0.65 *	0.76 **	0.44	0.60 *
sprinting (\geq 18 km·h ⁻¹)	0.70 **	0.71 **	0.70 **	0.48	0.41
HIR	-0.73 **	0.73 **	0.77 **	0.49	0.52
Total	-0.50	0.45	0.53	0.06	0.30

* $p < 0.05$, ** $p < 0.01$

Notes: High-intensity running (HIR) was defined as movement at a speed greater than 15 km·h⁻¹ (high-speed running + sprinting).

and the mean distance from a foul during a match are also presented in **Table 3**. Actually, s-OBLA was correlated negatively with the distance from a foul ($r = -0.62$; $p = 0.019$, **Table 3**), whereas s-LT2, $\dot{V}O_{2\max}$ and s- $\dot{V}O_{2\max}$ were not correlated with it ($r = -0.38$; $p = 0.183$, $r = -0.31$; $p = 0.274$ and $r = -0.51$; $p = 0.068$, respectively, **Table 3**). Results show that the distance covered at HIR was not correlated with the distance from a foul ($r = -0.27$; $p = 0.351$).

For this study, some matches were played in hot and humid conditions. The total distance covered was correlated negatively with WBGT ($r = -0.56$; $p = 0.036$), whereas the HIR distance, mean HR and distance from a foul were not correlated with WBGT ($r = -0.25$; $p = 0.933$, $r = 0.38$; $p = 0.186$ and $r = 0.01$; $p = 0.978$, respectively).

4. Discussion

The total distance covered by referees during Japanese youth top-level league matches examined in this study was 11.3 ± 0.6 km, of which 1.9 ± 0.4 km was covered by HIR. The mean HR and speed during a match were 166 ± 9 beats·min⁻¹ (85.3 ± 4.4 % of HR_{max}) and 7.11 ± 0.42 km·h⁻¹, respectively. The mean distance from a foul was 14.4 ± 1.0 m. These values were similar to those of FIFA or domestic experienced referees assigned to the European top leagues and international competition matches (Castagna et al., 2007; Weston et al., 2012). Regarding effects of heat and humidity on match performance, although the total distance covered was correlated with WBGT, no other performance variable was correlated with WBGT. Therefore, it is likely that heat stress had no strong influence on the match performance of well-trained referees. The primary findings of this study were the following: 1) s-LT2 and s-OBLA demonstrated a significant correlation with the distance covered at HIR of referees for Japanese youth top-level league matches; and 2) significant correlation was found between s-OBLA and the distance from a foul.

The distance covered at HIR has been regarded

as a superior physical performance index for soccer referees, given the intermittent nature of soccer (Krustrup & Bangsbo 2001; Krustrup et al., 2009; Mallo et al., 2009; Weston et al., 2011a). Again, s-OBLA, rather than estimated $\dot{V}O_{2\max}$, had a significant correlation with the distance covered by HIR (**Table 2**). Notably, s-LT2 was also correlated with the distance covered at HIR. The findings presented above agreed well with previous studies of soccer players, which showed significant correlation of s-LT2 and s-OBLA with HIR distances during a match (Krustrup et al., 2005; Sirotic & Coutts 2007). Moreover, results show that s-OBLA has a stronger relation with repeated sprint ability in soccer players than $\dot{V}O_{2\max}$ has (Da Silva et al., 2010). This result is not surprising because the match activity profiles and physiological demands during a match are reportedly similar between the referees and players (Castagna et al., 2007; Krustrup & Bangsbo 2001; Weston et al., 2006). The lack of a significant correlation between the estimated $\dot{V}O_{2\max}$ and the distance covered at HIR is explainable by the number of HIR in a match, which exceeded 100 times for the matches examined in this study. Results of previous studies also showed that the HIR might take place 60–100 times in a match (Krustrup & Bangsbo 2001; Krustrup et al., 2009). Such a highly frequent occurrence of HIR may necessitate the ability to counter fatigue development. The submaximal aerobic parameters such as s-LT2 and s-OBLA may better reflect this type of ability, compared to estimated $\dot{V}O_{2\max}$; an index of maximal aerobic power at fast speed but for a limited duration. In intense intermittent exercise, the reduced deterioration of performance might be affected by the abilities of resynthesis of phosphocreatine and buffering H⁺ in skeletal muscles (Bishop et al., 2004; Bogdanis et al., 1996). Therefore, LT2 or OBLA, which reflects muscle oxidative capacity during exercise, can be expected to be a better index of match activity in high-intensity intermittent sports such as soccer.

A similar implication can be made for the mean distance from a foul, regarded as a better match

Table 3 Relations between aerobic fitness parameters and the mean distance from fouls during a match

	s-LT2	s-OBLA	$\dot{V}O_{2\max}$ (estimated)	s- $\dot{V}O_{2\max}$ (estimated)
Mean distance from a foul	-0.38	-0.62*	-0.31	-0.51

* $p < 0.05$

performance index for soccer referees. Many reports of the literature have described that shorter distances from fouls might be beneficial for referees to take a close view of the match play (Krustrup & Bangsbo 2001; Krustrup et al., 2009; Mallo et al., 2007, 2012; Weston et al., 2010, 2011a). In this study, the mean distance from a foul during a match was 14.4 ± 1.0 m, which was similar to that of top class referees, and within the suggested distance range (11–15 m) to minimize the chance of incorrect decisions (Mallo et al., 2012). Based on our findings, s-OBLA, rather than estimated $\dot{V}O_{2\max}$, might be regarded as a determining factor for the ability of referees to keep up with play, possibly enabling their judgments to be more accurate and more convincing.

In this study, greater HIR distances were not necessarily associated with shorter distances from fouls ($r = -0.27$; $p = 0.351$). Although our results gave no proof, it is regarded as follows. The relations between OBLA and match performances are regulated by individual fitness. On the other hand, both HIR and distance from fouls during a match are controlled sufficiently by the referee. Consequently, the referee can jog and cover the game action based on the referee's own level of fitness. Moreover, experienced referees might better predict future events and use clever positioning (Weston et al., 2010), minimizing unnecessary movements in order to make judgments. Additionally, previous reports describe that a referees' match performance is influenced by the existence of assistant referees (Mallo et al., 2012). Therefore, it is possible that the referee has made a decision by incorporating foul support from assistant referees when a foul occurs near an assistant referee or out of the view of the referee. These confounding factors might explain the lack of significant correlation between the HIR distances and the distances from fouls.

Although $\dot{V}O_{2\max}$ of this study was estimated, with the total distance covered, this study found no correlation either with s-OBLA or the estimated $\dot{V}O_{2\max}$ (Table 2). The total distance covered has been regarded as a worse measure to evaluate soccer referees than the HIR distance (Krustrup & Bangsbo 2001; Mallo et al., 2009; Weston et al., 2011a). Results of present (65.4 %) and previous studies (69.1–74.7 %) (Krustrup & Bangsbo 2001; Krustrup et al., 2009) have revealed that most of the total distance was covered by low-intensity activity such as walking, jogging and low-speed

running, which would impose few or no aerobic challenges. Consequently, the total distance covered might measure the physical performance of referees inappropriately. This notion may further emphasize that the measurement of HIR distances during a match, rather than the total distance, is expected to be an important consideration for evaluating the match performance of soccer referees.

The results of this study imply that the soccer referee might strive to improve the running speed at OBLA in their fitness training. To assess the fitness levels of referees, the OBLA test, rather than the $\dot{V}O_{2\max}$ test, might be recommended because it does not impose exhaustive physical stresses on the examinees. Moreover, the OBLA test is more closely related to match performance. Further studies must be done to investigate the availability of OBLA assessment for older and elite standard or female referees, and to measure $\dot{V}O_{2\max}$ directly for greater accuracy.

5. Conclusion

Results of this study demonstrated that referees who had greater s-OBLA used greater distances covered at HIR and shorter distances from fouls to officiate matches, although the estimated $\dot{V}O_{2\max}$ was not correlated with any match activity profile. Submaximal aerobic capacity with delayed rate of fatigue development might be necessary for Japanese soccer referees to be able to cover longer distances at high speeds repeatedly and make judgments closer to the site of a foul.

Acknowledgments

This study was supported by the Juntendo University Institute of Health and Sports Science & Medicine. We thank all participants for their participation and effort. We also thank Mr. Ko Oishi, Chairman of the Refereeing Department of the Chiba Football Association and the Refereeing Department of the Kanto Region Football Association for their assistance in data collection.

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Main Works:

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Membership in Learned Societies:

- Japanese Society of Science and Football
- Japanese Society of Physical Fitness and Sports Medicine
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