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BRIEF COMMUNICATION

Sustained high levels of physical activity lead to improved performance among "Race Across the USA" athletes

Cara Ocobock[1] | Aaron Overbeck[2] | Clare Carlson[2] | Chris Royer[2] | Alexander Mervenne[2] | Caitlin Thurber[3] | Lara R. Dugas[4] | Bryce Carlson[5] | Herman Pontzer[3,6]

[1]Anthropology, University at Albany, SUNY, Albany, New York
[2]Biomedical Sciences, Grand Valley State University, Allendale Charter Township, Michigan
[3]Anthropology, Hunter College, New York, New York
[4]Public Health Science, Loyola University Chicago, Stritch School of Medicine, Maywood, Illinois
[5]Anthropology, Purdue University, West Lafayette, Indiana
[6]Evolutionary Anthropology, Duke University, Durham, North Carolina

Correspondence
Cara Ocobock, 1400 Washington Ave. A&S 237 Albany, NY 12222
Email: cocobock@albany.edu

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Abstract

Objective: To investigate physiological and performance adaptations associated with extremely high daily sustained physical activity levels, we followed six runners participating in the 2015 Race Across the USA. Participants completed over 42.2 km a day for 140 days, covering nearly 5,000 km. This analysis examines the improvement in running speed and potential adaptation in mean submaximal heart rate (SHR) throughout the race.

Methods: Data were collected during three 1-week long periods corresponding to the race beginning, middle, and end and included heart rates (HRs), body mass, running distances and speeds. HR data were collected using ActiTrainer HR monitors. Running speeds and distances were also recorded throughout the entire race.

Results: Athletes ran significantly faster as the race progressed ($p < .001$), reducing their mean marathon time by over 63 min. Observed mean SHR during the middle of the race was significantly lower than at the beginning ($p = .003$); however, there was no significant difference between mean SHR at the middle and end of the race ($p = .998$).

Conclusion: These results indicate an early training effect in SHR during the first half of the race, which suggests that other physiological and biomechanical mechanisms were responsible for the continued improvement in running speed and adaptation to the high levels of sustained physical activity.

KEYWORDS
endurance exercise, submaximal heart rate, training adaptation

1 | INTRODUCTION

Adaptations to endurance running, which lead to greater running economy (the energetic demand at a given submaximal speed) typically occur within the first few weeks of a training program (Burgess & Lambert, 2010; Lake & Cavanagh, 1996). These adaptations improve through biomechanical and physiological mechanisms over time, and can include changes in cardiopulmonary function, lactate threshold, resource utilization (preferential fat oxidation), and structural changes within muscle such as increased mitochondrial density and fiber-type switching (Burgess & Lambert, 2010; Davies & Thompson, 1979; Hawley, 2002; Jones & Carter, 2000; Joyner & Coyle, 2008; Wang et al., 2004; Waters, Rotevatn, Li, Annex, & Yan, 2004). The work presented here focuses on changes in mean submaximal heart rate (SHR) and marathon speed among endurance athletes.

There is a positive and linear relationship between heart rate (HR) and metabolic rate over a narrow range of HRs (90–150 bpm) and, therefore, activities. Though this relationship is sensitive to psychological or emotional state (Hebestreit & Bar-Or, 1998; Keytel et al., 2005), sustained changes to the HR–metabolic rate relationship can occur during endurance training; such that SHR at a given exercise intensity is lower than it was previous to training, suggesting adaptations within the cardiopulmonary system and improved exercise economy (Patton & Vogel, 1977; Wilmore et al., 2001). Several lines of evidence suggest that cardiopulmonary changes can occur within 6–12 weeks; however, results have been equivocal (Conley, Krahenbuhl, Burkett, & Millar, 1984; Lake & Cavanagh, 1996; Overend, Paterson, & Cunningham, 1992; Wilcox & Bulbulian, 1984). Over the course of a 9-week endurance training program, a reduction in mean SHR and a 23% increase in VO_{2max}, the maximum amount of oxygen uptake during intense exercise, were observed (Hickson, Hagberg, Ehsani, & Holloszy, 1981) while others have found 5–10% improvements in VO_{2max} during far shorter programs (Billat, Flechet, Petit, Muriaux, & Koralsztein, 1999; Franch, Madsen, Djurhuus, & Pedersen, 1998; Gibbons, Jessup, Wells, & Werthmann, 1983; Mier, Turner, Ehsani, & Spina, 1997; Spina et al., 1996; Weston et al., 1996). However, the majority of experimental and observational studies examining physiological adaptations leading to improved exercise economy among endurance athletes do not exceed 12 weeks or are limited by low exercise intensity and small sample sizes.

Several studies focus on long-term endurance running in particular. For example, one study followed an elite female distance runner for 5 years; and found a decrease in her submaximal oxygen consumption (Jones, 1998). A year-long study among middle and long distance runners of the Swedish national track and field team compared VO_{2max} and submaximal VO_2 at given speeds. Investigators found an increase in VO_{2max} and decrease in submaximal VO_2 during the competitive portion of the year compared to the noncompetitive portion (Svedenhag & Sjodin, 1985). The competitive season lasted 3 months during which they ran a mean weekly distance of 110 ± 15 km, which is fairly low weekly distance relative to the present study (Svedenhag & Sjodin, 1985).

The extent to which endurance runners, particularly well-trained ones, can develop and benefit from potential adaptations during a longer and more intense training period remains poorly understood. The study presented here examines physiological and performance changes that occurred among the 2015 Race Across the USA (RAUSA) competitors. RAUSA was developed by the 100 Mile Club® to spread awareness and combat childhood obesity in the United States. Twelve participants ran a mean of 42.73 km (similar to a marathon, 42.2 km) a day, 6 days a week for over 140 days, as they crossed the continental United States covering close to 5,000 km. HRs, body mass, race time, and race speeds were measured. These data were used to determine if runners experienced a decrease in mean SHR and improved performance, demonstrating endurance exercise adaptations, over a much longer and more intense exercise regimen than most previous studies.

2 | SUBJECTS AND METHODS

Subjects included six of the 12 RAUSA participants (five males and one female, ages 29–73, referred to as RAUSA 1–6, see Table 1). RAUSA began on January 16, 2015 in Huntington Beach, CA and ended on June 2, 2015 in Washington D.C. There were an additional three participants in RAUSA who agreed to take part in the study; however, were not included in this analysis. Two individuals decided to take a separate route, and one left the race due to injury. All of the runners had several years' endurance running experience. There were three data collection time points during this study: race-beginning (January 16–22), race-middle (March 5–10), and race-end (May 22–June 2). Running distance and time were recorded daily by RAUSA support crew members. Study protocols were submitted to, and approved by, the Grand Valley State University institutional review board for testing of human subjects (approved protocol reference number: 15-047-H).

2.1 | HR data

HR was collected using an ActiTrainer HR monitor (Actigraph, Pensacola, FL). Of the six participants in this study, four wore HR monitors during all three data collections; one (RAUSA 5) did not wear the HR monitor for the race-end data collection; and another (RAUSA 6) wore a HR monitor from a different research group—the data from which could not be obtained. Participants only wore the HR monitors while running. Missing HR data (less than 10% of data points) were estimated to be the mean of the first nonzero HR before and after the missing data point. To calculate mean SHR for a given day, the first 30 min of HR data were discarded, allowing the runner time to achieve a steady state; mean SHR was calculated from that point on for the following 30 min. This time frame was used as it was early enough in the race such that runners had not reverted to walking nor did it capture the end of the race sprint, providing a reasonable estimate for steady state, submaximal running HR. This was also verified by visual analysis of the HR data to ensure that a steady pace was maintained. Daily values were pooled to calculate each runner's mean SHR for each portion of the race.

2.2 | Race time and speed

As a result of race logistics and occasional inclement weather, each race was not an official marathon race distance, resulting in varying day-to-day distances. Over the three measurement periods, the mean daily running distance was 42.73 km, slightly greater than a typical marathon of 42.195 km. When RAUSA participants completed running across each state, they did not begin the new state on the same day, for example, the day they finished running across Arizona, they only ran 12.6 km that day and did not run in New Mexico until the following day. Weather also affected race distances. On February 27, 2015, participants only ran 30.5 km due to an ice storm along the race route in New Mexico. To make up for this, participants ran just over 48 km during each of the next two races. For this analysis, only distances between 41.84 and 43.45 km were included as they are close to official marathons distances, resulting in 103 marathons included in overall marathon speed and time analysis. Race speeds and times were also compared across each of the three HR measurement time points (Table 2).

2.3 | Anthropometrics and environmental variables

Body mass, body fat percentage, and muscle mass were measured using a Tanita BC-558 Ironman Segmental Body Composition Monitor scale (Tanita Corporation, Arlington Heights, IL). Measurements were performed in the morning before the start of each race. Daily elevation changes were calculated using online course mapping, and environmental variables were retrieved from the National Oceanic and

TABLE 1 Sex, age, and height for each participating runner as well as body mass, body fat percentage, and muscle mass at the beginning, middle, and end of the race

Subject	Sex	Age (years)	Height (cm)	Race start Mass (kg)	Race start Body fat (%)	Race start Muscle mass (kg)	Mid-race Mass (kg)	Mid-race Body fat (%)	Mid-race Muscle mass (kg)	Race end Mass (kg)	Race end Body fat (%)	Race end Muscle mass (kg)
RAUSA 1	F	62	170	62.9	29.3	42.5	62.9	23.8	45.5	63.5	25.2	45.2
RAUSA 2	M	52	178	79.9	20.8	60.8	72.4	14.9	59.1	73.2	15.6	59.0
RAUSA 3	M	71	175	63.5	19.8	48.4	61.3	12.0	53.4	60.7	8.5	53.1
RAUSA 4	M	33	180	75.4	13.2	61.0	73.4	12.3	60.1	71.7	12.5	59.6
RAUSA 5	M	26	170	68.1	15.2	55.1	67.1	11.0	58.4	67.5	11.8	58.4
RAUSA 6	M	31	183	84.7	14.4	68.4	83.0	12.2	68.5	83.9	13.8	67.4

Atmospheric Administration National Centers for Environmental Information (Table 3).

2.4 | Statistical analysis

Data are presented as means ± SD. Paired samples *T* tests were performed to determine changes in participant body mass, body fat percentage, and muscle mass. A multiple regressions analysis was performed to determine if elevation, daily high temperature, and daily peak humidity significantly impacted mean speed and mean SHR for the three time points. Pearson correlations were performed for each individual and across individuals for every day that a race was run, not just during the three aforementioned time points, to determine if speeds changed throughout the entire race. Paired samples *T* tests were performed to determine if mean SHR changed between the three time points. One-way ANOVAs were performed to determine if there were significant differences in mean speed and mean SHR at the three time points for which HR data were collected. Results were considered significant at the $p < .05$ level.

3 | RESULTS

Prior to the start of the race, RAUSA males had a mean body mass of 75.7 ± 9.6 kg. The one female RAUSA subject had a body mass of 62.9 kg (Table 1). By the end of the race, males had a mean body mass of 72.3 ± 9.1 kg and the female subject had a body mass of 63.5 kg. Subjects significantly reduced their body fat percentage from the beginning of the race to the middle ($p < .01$); however, there was no significant change from the middle of the race to the end ($p = .81$). Subjects tended to gain muscle mass from the middle of the race to the end, this relationship approached but did not reach statistical significance ($p = .07$). There was no significant difference in overall body mass across the data collection time points ($p > .05$ in all cases).

Mean daily running time across the entire race was 320 ± 60 min; mean daily times were 348 ± 55 min, 298 ± 67 min, and 313 ± 57 min for the beginning, middle, and end of the race, respectively. Runners had a mean speed of 2.13 ± 0.40 m s^{-1} at the beginning of the race, 2.48 ± 0.59 m s^{-1} at the middle, and 2.38 ± 0.37 m s^{-1} by the end, for an overall mean of 2.3 ± 0.46 m s^{-1}. Speed significantly increased ($p < .001$) when comparing speeds of all runners throughout the entire race. On average, runners increased their mean speed from 2.15 to 2.37 m s^{-1} ($p < .01$) (Figure 1). Four of the six runners significantly increased speed across the three time points ($p < .01$). Notably, the two fastest runners (RAUSA 4 and RAUSA 6) were the only participants who did not significantly increase their speed throughout the race ($p = .135$) (Table 2).

Mean SHR for each runner decreased significantly from the race-beginning (128 ± 7 bpm) to the race-middle (116 ± 6 bpm) ($p = .003$). There was a significant difference between mean SHR from the race-beginning and the race-end (114 ± 8 bpm) ($p = .022$). Differences between the race-middle and race-end were not statistically significant ($p = .998$) (Figure 2). There was no correlation between the magnitude of mean SHR change and magnitude of speed change nor with body mass. Peak daily humidity, elevation climbed, mean daily temperature, daily high temperature, and total ascent did not have a significant impact on speed or mean SHR ($p > .08$ in all instances).

4 | DISCUSSION

This study analyzed mean SHR and running speed changes among individuals running over 40 km a day for 140 days as they ran across the continental United States.

TABLE 2 Mean submaximal heart rate, speed, and race time for each participating RAUSA runner for the race start, mid-race, and the race end

Subject	Race start SHR (bpm)	Race start Speed (m s^{-1})	Race start Time (min)	Mid-race SHR (bpm)	Mid-race Speed (m s^{-1})	Mid-race Time (min)	Race end SHR (bpm)	Race end Speed (m s^{-1})	Race end Time (min)
RAUSA 1	126 ± 13	1.89 ± 0.16	389 ± 32	114 ± 7	2.01 ± 0.25	327 ± 38	122 ± 6	2.10 ± 0.12	352 ± 23
RAUSA 2	131 ± 8	1.85 ± 0.12	386 ± 25	120 ± 16	2.18 ± 0.20	326 ± 31	120 ± 3	2.20 ± 0.10	357 ± 16
RAUSA 3	123 ± 10	1.82 ± 0.03	380 ± 7	107 ± 6	1.82 ± 0.12	397 ± 27	107 ± 4	1.90 ± 0.13	383 ± 29
RAUSA 4	121 ± 11	2.53 ± 0.21	292 ± 25	116 ± 4	3.02 ± 0.15	239 ± 12	107 ± 3	2.70 ± 0.14	254 ± 20
RAUSA 5	137 ± 9	1.97 ± 0.19	362 ± 32	121 ± 7	2.52 ± 0.10	291 ± 20	X	2.62 ± 0.03	275 ± 4
RAUSA 6	X	2.74 ± 0.19	265 ± 19	X	3.33 ± 0.14	214 ± 9	X	2.80 ± 0.13	259 ± 12

TABLE 3 Mean temperature, high temperature, peak humidity, maximum elevation, and total ascent for the three time points of race across the USA data collection. None of these elements had a significant impact on runner speed or mean submaximal heart rate

Time period	Mean temp (°F)	High temp (°F)	Peak humidity (%)	Maximum elevation (m)	Total ascent (m)
Beginning	61.8	76.6	69.4	1866.6	1425.9
Middle	48.4	60.4	92.8	2617.4	308.6
End	75.4	85.7	94.3	424.0	981.8

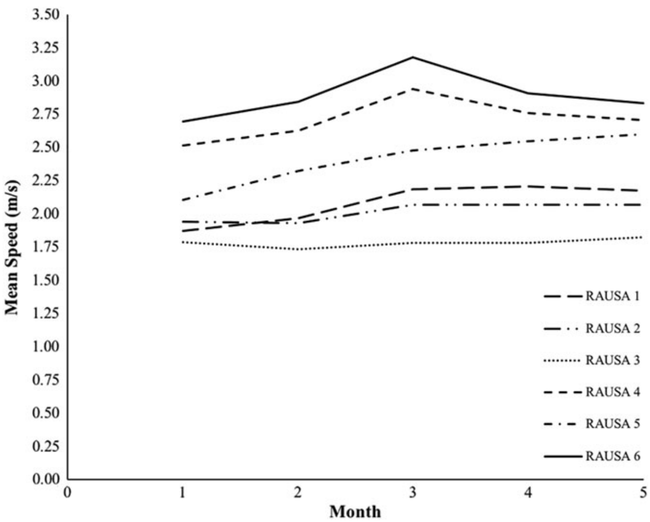

FIGURE 1 Mean monthly speed for each participating runner. Overall, subjects increased running speed throughout the race. RAUSA 4 and 6 decreased running speeds from the middle to the end of the race

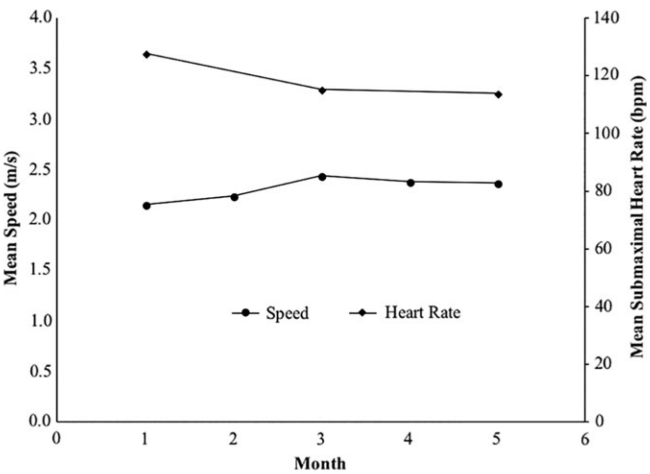

FIGURE 2 Mean monthly speed and mean SHR rates for each participating runner. Overall, subjects increased running speed throughout the race while mean SHR significantly decreased from the beginning to the middle of the race. Mean SHR did not significantly change from the middle of the race to the end

4.1 | Body mass, submaximal heart rate, and Marathon running speed

There were no significant changes in body mass across the three measurement time points of RAUSA. Though subjects lost a significant amount of body fat, and tended to gain muscle mass, there was minimal change in overall body mass. This suggests that though performance and speed were improving, potentially increasing energy demands, participants were meeting those energetic demands. This parallels work among Tour de France cyclists who maintained an adequately high energy intake to avoid body mass changes while undergoing over 22 days of high intensity endurance cycling (Saris, van Erp-Baart, Brouns, Westertep, & ten Hoor, 1989; Westerterp, Saris, van Es, & ten Hoor, 1986). As RAUSA runners had support crews to aid them throughout this process as well as regular access to food during the race, this result is unsurprising.

Overall, RAUSA subjects decreased mean SHR from race-beginning to race-middle, and maintained a similar mean SHR for the remainder of the race. However, speeds continued to improve with time, particularly for four of the six runners. The reduced mean SHR suggests a training effect resulted from the high level of repeated daily endurance exercise, and potentially reduced the cost associated with improved speeds during the initial part of the race. However, the stasis of mean SHR after the mid-point of the race suggests that the physiological training effects on SHR plateaued, and that other endurance adaptations were responsible for the improved performance during the latter half of the race. It should be noted that environmental factors such as temperature and humidity did not have a significant impact on SHR. However, this was in part intentionally planned by the RAUSA organizers; they scheduled the start of the race in California in January in hopes that the weather would be similar to Washington D.C. by late May–early June at the end of the race while avoiding drastic elevation changes as much as possible.

Most work on endurance training does not explore adaptations past 20 weeks, leaving a dearth of information about adaptations and adaptational timing that may occur during longer duration endurance exercise regimens such as RAUSA. The few studies that do assess longer term endurance exercise are limited in other ways. For example, previous work has examined physiological changes associated with extreme endurance events in arctic conditions (Frykman et al., 2003; Helge et al., 2003). One study followed four men as they took part in a 42-day cross-country skiing expedition, an activity that heavily relies on both the upper and lower body, across Greenland. Investigators found that participating individuals increased fat oxidation in their triceps muscles, but not the vastus lateralis, suggesting differential adaptation between upper and lower body muscles to cross-country skiing endurance exercise (Helge et al., 2003). Similarly, Frykman et al. (2003) followed two men over the course of a three-month Arctic expedition that covered just under 3,000 km. Investigators performed a battery of pre-expedition and post-expedition tests expecting the rigorous wear and tear of the expedition to result in reduced exercise abilities. Yet, they found no changes in aerobic capacity as measured by VO_{2max} and maximal HR suggesting that they were able to properly fuel and recover from their activities. SHR was not reported (Frykman et al., 2003). The arctic conditions, though fascinating, make these studies limited for comparative purposes.

Similar to RAUSA, subjects taking part in a 20-week training program on a cycle ergometer experienced a significant decrease in mean SHR as well as a significant increase in both stroke volume and cardiac output (Wilmore et al., 2001). Furthermore, Patton and Vogel (1977) compared VO_{2max}, SHR, and maximal HR among 60 military personnel taking part in a 2–4 mile daily run for 6 or 11 months. The group that had been training for 11 months had a higher VO_{2max} but lower SHR and maximal HR compared to the group that had been training for 6 months. Though this study included a large sample size and a long training period, the distance covered is far less than that seen among the RAUSA subjects. Furthermore, this study was a pre-post design, such that the timing and limits of these adaptations remain uncertain. The present study among RAUSA participants is the first to examine potential physiological adaptations associated with consistent, repetitive, long duration runs with a mid-point measurement in addition to pre–post measurements.

4.2 | Potential for endurance adaptation

RAUSA subjects mirrored the mean SHR decrease seen in both long- and short-duration endurance studies. This decrease in mean SHR appeared in the first ~70 days of RAUSA, and remained constant to the race-end, without any further decrements. These results demonstrate that mean SHR adaptation plateaus when training stimulus, daily marathons, remains constant. Though mean SHR adaptation did not continue, most RAUSA participants improved their running speeds through to the race end. In order to do so, other adaptations must have transpired during and beyond the first half of the race. These results suggest that adaptations to endurance training may occur in a piece-meal fashion and exhibit different limitations on the extent to which they manifest during a constant training stimulus.

Potential avenues for continued endurance adaptations are through:

1. The cardiopulmonary system by decreases in submaximal VO_2, increased cardiac output, increased heart mass and volume, and increased capillarization, (Jones, 1998; Patton & Vogel, 1977; Svedenhag & Sjodin, 1985);
2. Neuromuscular system adaptations such as increased mitochondrial content, slower use of muscle glycogen stores, muscle fiber-type switching, and differential motor unit recruitment (Bailey & Messier, 1991; Hawley, 2002; Holloszy & Coyle, 1984; Jones & Carter, 2000; Wang et al., 2004; Waters et al., 2004);
3. Lactate threshold increase such that a greater exercise intensity can be achieved and sustained before lactate begins to accumulate (Davies & Thompson, 1979; Dennis, Noakes, & Bosch, 1992; Tanaka & Matsuura, 1984);
4. Preferential fat oxidation over carbohydrate oxidation and increased glycogen storage as well as improved fat mobilization for eventual oxidation (Helge et al., 2003; Hurley et al., 1986; Kiens, Essen-Gustavsson, Christensen, & Saltin, 1993; Martin et al., 1993);
5. Biomechanical changes in running such as adjusting stride length and stride frequency, though results demonstrating biomechanical adaptation have proven elusive (Bailey & Messier, 1991; Lake & Cavanagh, 1996).

It should be noted that the increased speed throughout the race did not apply to the two fastest RAUSA runners. Through personal communications; RAUSA 4 revealed that when he knew he would not win the race against RAUSA 6, he slowed his pace. With reduced competitive pressure, RAUSA 6 similarly slowed pace. This slowed pace increased the race time and reduced speed from race middle to end when looking at the group of participants as a whole; however, RAUSA 1, 2, 3, and 5 all improved their times and speeds. This highlights the more difficult to measure avenues for performance and endurance adaptation: motivational and psychological factors.

4.3 | Limitations

Measurements of other physiological and biomechanical characteristics were not included in this study making unequivocal evidence for other potential changes that improve running economy impossible. The limited measurements were the result of a desire to reduce the burden on the participants, so as to minimally impact their race experience and performance. Additionally, the number of subjects was extremely low with six total subjects, only one of whom was female. Finally, all participants were avid, seasoned runners before taking part in RAUSA, making this a self-selected subject pool. As such, caution should be used when broadly applying these results.

5 | CONCLUSION

RAUSA participants demonstrated physiological adaptations as a result of running back-to-back near marathon distances for a total of 140 days. By race-middle, there was a significant decrease in mean SHR, which was sustained until the race-end, while running speeds significantly increased for the duration of the race. The results of this study suggest that long-term adaptation to extended endurance training does occur; however, these adaptations occur and plateau at different times when training stimulus remains constant. This work demonstrates the need to further explore potential physiological and biomechanical adaptations to long-term endurance exercise in order to tease apart adaptational timing and limitations.

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ORCID

Cara Ocobock https://orcid.org/0000-0002-6949-2029

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