Introduction

Travelers, workers and athletes can easily and rapidly reach high-altitude sites by air and road. The Dakar Rally is a 10-day endurance rally in a desert climate. The stages in the rally differ among Europe, Africa and South America and a high-altitude stage was added that has increased over the years from two, to six days. Dakar Rally teams usually include drivers, and a crew with technical and other types of expertise. Originally, drivers were the only persons in teams that went to high altitudes when the duration was only two days, but did not change in the control team (1 [4%] of 25 and 0 [0%] of 25, respectively vs. 3 [18.8%] of 16; \( P = 0.0128 \) Fisher exact test).

Conclusions: An HCM with knowledge of AHAI was effective in preventing the development of AHAI among endurance rally crews.

Key words: acute high-altitude illness, health care manager, measurement, wearable device, smartphone

Prevention of Acute High-Altitude Illness by Health Care Management during Endurance Motor Rallies

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Aims: The crew members of an endurance motor sports rally team developed acute high-altitude illness (AHAI) during the first year of a route that included driving at high altitude for three days. Therefore, a health care manager (HCM) was assigned to the team to help prevent AHAI during the second and third years. We evaluated the effect of the HCM on the prevalence of AHAI.

Methods: The numbers of individuals who presented at the official medical tent of the rally were recorded. Reports from another team without an HCM served as the control.

Results: The rates of visits were essentially the same between the two teams (5 [20.8%] of 24 vs. 3 [20.0%] of 15) respectively during 2016. These values were reduced in the team with the HCM during 2017 and 2018, but did not change in the control team (1 [4%] of 25 and 0 [0%] of 25, respectively vs. 3 [18.8%] of 16; \( P = 0.0128 \) Fisher exact test).

Conclusions: An HCM with knowledge of AHAI was effective in preventing the development of AHAI among endurance rally crews.

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treks, but we were unable to uncover any published information regarding tour guides and AHAI prevention. Doctors or nurses are assumed to help prevent AHAI during mountain expeditions, but we could not find any validated publication about this either. Therefore, we analyzed the ability of an HCM to prevent health problems arising at high altitudes.

**Materials and Methods**

**Environment**

The Dakar Rally is a 10-day endurance race that usually attracts > 300 vehicles, drivers, support crews, media and organizers. Therefore, over 2,500 people accompany racers in non-racing vehicles, and organizers arrange a bivouac for all participants that harbors a medical tent to address medical issues that arise during the event. A high-altitude bivouac was not available during the first South American rally in 2009, and was available for only one night until the 2015 rally. Thereafter, the high-altitude stages of the rally were extended to three days in 2016 and to six days in 2017 and 2018. Thus, accompanying crews and drivers were required to function and sleep at high altitudes during these stages (Table 1).

**Participants**

The target and control teams were the HRC team and HINO TEAM SUGAWARA, respectively. The HRC has continuously participated in the Dakar Rally. Their crews included 24, 25 and 25 mechanical assistants and managers during years 2016, 2017 and 2018, respectively. None of them were aware of the physiological changes that can occur at high altitudes and AHAI, and five developed AMS during 2016. The HRC then decided to assign an HCM to prevent health issues associated with high altitudes. The control HINO TEAM SUGAWARA team from Japan has also continuously participated in the Dakar Rally and their crew comprised 15, 16 and 16 members during 2016, 2017 and 2018, respectively.

| Table 1 | Bivouac locations for high-altitude stages of Dakar Rally |
|---------|-------------------------------|
|          | 2016          | 2017          | 2018          |
|          | Overnight location | Altitude (m) | Overnight location | Altitude (m) | Overnight location | Altitude (m) |
| Before HA | San Salvador de Jujuy | 1238         | San Salvador de Jujuy | 1345         | San Juan de Marcona | 105          |
| HA night 1 | Uyuni          | 3700         | Tupiza          | 3465         | Arequipa          | 2514         |
| 2         | Uyuni          | 3700         | Oruro           | 3938         | La Paz            | 3424         |
| 3         | –              | –            | La Paz          | 3424         | La Paz            | 3424         |
| 4         | –              | –            | La Paz          | 3424         | Tupiza            | 3465         |
| 5         | –              | –            | Uyuni           | 3669         | Tupiza            | 3465         |
| After HA  | Salta          | 1187         | Salta           | 1187         | Salta             | 1187         |

High-altitude stages exceeded three days during 2016 then increased to six days during 2017 and 2018. Altitude of bivouac location depended on Dakar Rally office. Locations at > 2,500 m were defined as high-altitude. HA, high altitude.
HCM, smart phones and devices

The assigned HCM was a telecommunication professional who had supported a surgical operator using devices that he developed. He studied high-altitude physiology as noted above, but did not have a medical license. His purpose was to prevent the crews from AHAI (Fig. 1). His roles were sharing the information mechanism of AMS at group meetings, observation of the crews on finding health problems, to propose smoking cessation and banning alcohol consumption, to encourage water consumption, further respiration and monitoring \( \text{SpO}_2 \), pulse rate, blood pressure, body temperature and LLS using smart phone applications, to check data and advise when deconditioning is found, and to maintain and manage devices including battery charging. He developed a new smart phone application to monitor and record LLS and record oxygen saturation, blood pressure and body temperature using MP-1000 pulse oximeters, DS-S10 sphygmomanometers and MT-500BT thermometers (all from Nihon Seimitsu Sokki Co. Ltd., Gunma, Japan) that communicated via Bluetooth. Only two smart phones and measurement devices were available, so the entire crew of the target team had to present themselves to the HCM while at high altitudes during 2017. This limited availability was inconvenient for the crew, who only consulted the HCM when they became symptomatic. Therefore, fewer measurements were taken and deconditioning could not be quickly detected.

The HCM improved the system in 2018 to include sets of wearable for mixed pulse oximeters and TG-283 thermometers (Kyocera Corporation, Kyoto, Japan), and smart phones with the intent to increase the numbers of individuals who measured (Fig. 2). The measurement with this new wearable system was approved by research ethics committee of Nihon University School of Medicine, approval number of 29-14-0, and all the crews of target team in 2018 provided written informed consent.

**Numbers of measurements**

The smart phone data were innominate, but specific IDs were assigned when physiological data were analyzed. Each measurement by each device made one file in the smartphone. The number of measurements were determined with the number of the files. The number of crews who measured was determined with the number of specific IDs of measured files. Only one measurement among all devices in one ID was not counted to omit testing measurement.

**Determination of AHAI**

High-altitude health issues were determined at the official medical tent provided by the rally organizers. The numbers of control and target team crew members who presented at the tent during the years before and after intervention by the HCM were counted and confirmed by the team managers. High-altitude experience was also confirmed in the target team and new participants in the rally each year were counted.

**Ethical approval**

This retrospective analysis was approved by research ethics committee of Nihon University School of Medicine, approval number of 31-16-0. We focused on the preventive effect of HCM without a medical license from AHAI at Dakar Rally which held at South America including high altitude stage in 2016, 2017 and 2018. Main outcome was the numbers of individuals who presented...
and diagnosed AHAI at the official medical tent of the rally. Data concerning the main outcome were provided from the target team with or without HCM and the control team without HCM. The written informed consents were provided from both team. The data are not including personally identifiable information. Analyses were conducted from January 2018 to December 2019.

### Statistical analysis

Attendance at the medical tent before and after HCM intervention within the target team and between the target and control teams each year were compared using Fisher exact tests. The numbers of measurements taken by each device between 2017 and 2018 were analyzed using Welch t-tests. Data were statistically analyzed using “R” version 3.5.2, which is a language and environment for statistical computing (R Foundation for Statistical Computing, Vienna, Austria). Values with $p < 0.05$ were considered as being statistically significant.

### Results

The crew of the target team spent two nights and three days during the 2016 rally in Uyuni (3,700 m) (Table 1). That was the first time any of the crew of 24 had spent time at high altitudes. All five of those who presented at the medical tent (Table 2) were diagnosed with AMS. The crew of 25 for the target team spent six days in Tupiza (3,465 m), Oruro (3,938 m), La Paz (3,424 m) and Uyuni (3,700 m) during the 2017 rally. The HCM advised one person to go to the medical tent and this person required evacuation due to HAPE. The 2018 crew of 25 also spent six days at high altitudes, staying in Arequipa (2,514 m), and two nights each in La Paz (3,424 m) and Tupiza (3,465 m). No-one went to the medical tent.

Visits to the medical tent by the control crews during 2016, 2017 and 2018 numbered 3 of 15, 3 of 16 and 3 of 32, respectively, with no change in prevalence.

Having the HCM decreased medical demands by the target team during 2017 and reduced them to zero in 2018. The outcomes of the target team with and without the HCM between 2016 and 2018 significantly differed. However, the annual outcomes did not significantly differ between the target and control teams. Nonetheless, outcomes significantly differed when the years 2017 and 2018 were combined and compared between the two teams (Table 2).

On the other hand, the crew experience of high altitude was considered as a positive factor in these results. The number of new participants in the target team each year were 24, 13 and 8 in 2016, 2017 and 2018, respectively (Table 3), and all visitors to the medical tent were exposed to high altitudes for the first time. We could not find a significant correlation between new crew members and the prevalence of AHAI, and we had no control data. Therefore, we could not compare our findings of new participants and medical issues with control data.

Another factor that was considered to affect the prevalence of AHAI between 2017 and 2018 was the number of devices. Two sphygmomanometers were available during the 2017 and 2018 rallies, but the numbers of pulse oximeters and thermometers were increased from 2 to 25 to supply the entire crew and those were also combined with headsets (Fig. 2). Therefore, an increase in the number of measurements was expected. However, only 3 (32.0%) and 13 (52.0%) crew members measured each parameter more than once using more than two devices in 2017 and 2018, respectively (Table 4). The effects of measurements on the prevalence of AHAI were considered limited, and the wearable devices were not particularly popular regardless of the ease of accessibility. Oxygen saturation was measured more frequently, and this was considered to be due to ease of using a wearable

### Table 2  Prevalence of AHAI in crews of control and target teams

| Team          | 2016      | 2017      | 2018      | 2017 and 2018 |
|---------------|-----------|-----------|-----------|---------------|
|               | Target    | Control   | Target    | Control       | Target    | Control   | Target    | Control       |
| HCM           | No        | No        | Yes       | No            | Yes       | No        | Yes       | No            |
| Crew members (n) | 24        | 15        | 25        | 16            | 25        | 16        | 50        | 32            |
| AHAI, n, prevalence (%) | 5 (20.8%) | 3 (20.0%) | 1 (4.0%)  | 3 (18.8%)     | 0 (0.0%)  | 3 (18.8%) | 1 (2.0%)  | 6 (18.8%)     |
| Target team   |           |           |           |               |           |           |           |               |
| 2017, 2018 vs. 2016 |           |           |           |               |           |           |           |               |
| $p$ = 0.09828  | $p = 0.02229^*$ | $p = 0.0122^*$ |
| Target vs. control team | $p = 1.00$ | $p = 0.2811$ | $p = 0.05253^*$ | $p = 0.0128^*$ |

The prevalence of AHAI in the target team with or without HCM and in the target versus control teams was analyzed using Fisher exact tests. $P$ values tended to decrease in the target crew after the HCM was assigned compared with the control team, but it did not reach significance. Differences became significant when values from 2017 and 2018 were combined.

* Significant at $p < 0.05$ (Fisher exact tests).
† Decreasing tendency with HCM did not reach significance.

AHAI, acute high-altitude illness; HCM, health care manager.
pulse oximeter, but the increase did not reach significance. Responses to the LLS questionnaire were even more scant than device data and we considered that this was due to the lack of symptoms because the HCM instructed the crew to check their LLS when they became aware of symptoms.

**Discussion**

This retrospective study found that an HCM prevented AHAI arising in a motor rally crew. The outcome effect was significant compared within the target team before having an HCM and between the target and control teams. We could not determine significance among new crew members, which is important in terms of separating the effects of experience and knowledge of high-altitude effects. However, the number of new crew members was insufficient to determine differences. More data are needed from a larger sample, but information from other teams and the office of the Dakar Rally was unavailable.

Having an HCM is more cost-effective than having a medical doctor. The Dakar Rally is a large event and the medical tent is prepared for all participants. Therefore, one doctor for one team is excessive when all that is needed is sufficient knowledge to monitor health status at high altitude, educate participants of the symptoms of AHAI and advise them to seek medical help should any of these symptoms arise. We believe that this is the first report about how to prevent AHAI without the need for a medically qualified doctor.

The ascent profile was beyond the “gold standard” for the first and/or second night during the rally each year. The gold standard states that, “above an altitude of 3,000 m, individuals should not increase the elevation at which they sleep by more than 500 m per day and should include one rest day every 3 to 4 days”. In addition, the altitude during the first night was over 2,800 m, which is a risk factor for AMS. Acetazolamide prophylaxis for AMS was considered when ascent profiles were not within the gold standard and rapid ascents, but this agent was not administered to the target team at any time because it is a prescription drug in Japan. The HCM therefore provided preventive advice that lay people can deliver, for example, to be mindful of their respiration, move slowly and consume more water.

According to the recommendations of the UIAA Medical Commission for work under hypoxic conditions, effective measures to prevent AHAI are the following:

Table 3: New crew members in target team

|                     | 2016 | 2017 | 2018 | 2017 and 2018 |
|---------------------|------|------|------|---------------|
| HCM                 | No   | Yes  | Yes  | Yes           |
| Crew members (n)    | 24   | 25   | 25   | 50            |
| New crew members (n)| 24   | 13   | 8    | 21            |
| AHAI among new crew members (n %) | 5 (20.8%) | 1 (7.7%) | 0 (0.0%) | 1 (4.8%) |
| Prevalence of AHAI 2017 and 2018 vs. 2016 | – | p = 0.3945 | p = 0.2964 | p = 0.1927 |

All individuals who developed AHAI were new to the Dakar Rally. Fisher exact tests did not uncover significant changes in new crew members and AHAI prevalence. The numbers of control crew members who repeatedly participated could not be clarified.

HCM, health care manager; AHAI, acute high-altitude illness.

Table 4: Number of measurements

|                     | 2016 | 2017 | 2018 | t-test |
|---------------------|------|------|------|--------|
| Days at high altitude (n) | 3    | 6    | 6    |        |
| Crew members (n)      | 24   | 25   | 25   |        |
| Data collection using smart phone | –   | Yes  | Yes  |        |
| Wearable device and smart phone for all crew members | No   | Yes  |      |        |
| Crew members who collected measurements (n %) | –   | 8 (32.0%) | 13 (52.0%) |        |
| Average (SD) number of values obtained |         |       |       |        |
| Sphygmomanometry      | 4.0 (1.2) | 3.0 (2.2) |        | p = 0.1937 |
| Thermometer           | 4.4 (1.3) | 1.5 (1.6) |        | p = 0.000357* |
| Response to LLS questionnaire | 2.5 (1.4) | 0.6 (1.2) |        | p = 0.00776* |
| Pulse oximetry        | 4.3 (1.0) | 6.0 (4.6) |        | p = 0.2071 |

The number of crew members who measured parameters using the provided equipment was determined from data collected by smart phones. Pulse oximeters and thermometers were wearable in 2018, but the applications were divided. Questionnaires regarding LLS were answered with an original application.

* Significant (p < 0.05).
the Dakar Rally 2016, 2017 and 2018 corresponded to “Limited Exposure”, which “has to focus on AMS”. The crews of the target team were not instructed about AHAI in 2016, despite the recommendations and about 20% of them developed AMS and were unable to continue to function. The HCM educated the crews and suggested preventive behaviors during 2017 and 2018, and this might have been a factor in the decreasing incidence of AHAI. Reports indicate that overall knowledge and awareness of AHAI is better among trekkers than Dakar Rally teams and crews. However, these studies did not compare the incidence of AHAI with or without education. Nonetheless, the importance of greater awareness and education is not in doubt.

Another factor implemented by the HCM was collecting of physiological data, especially SpO2, the amount of which increased with the personal use of convenient devices. The focus of pulse oximetry discussions was on the prediction of AMS. We considered that measuring SpO2 could help to prevent AMS because pulse oximetry reflects personal respiratory status at high altitude and thus encourages load reduction and more respiration. However, we could not find any studies in the literature that described AMS prevention involving pulse oximetry. About half of the crew of the target team did not measure their SpO2 values. Therefore, the effect of measurements was considered to be less powerful in the present study.

The present study is unique as we included a smart phone application for LLS and wearable devices for measurements. We found only one report of a smart phone application helpful to collect data about heart rate variability at high altitude. We could not find a study that included wearable devices at high altitude, but such devices were reviewed at the XII International Society for Mountain Medicine World Congress 2018. Most people who go to high altitudes are now equipped with smart phones, so the likelihood of using them to measure physiological parameters along with wearable devices is likely to increase in the future.

Having an HCM relieved anxiety among the crew. This is notable because anxiety is associated with AMS according to the State-Trait-Anxiety-Inventory (STAI). Anxiety comprises current and sustained types, the latter of which is a predictor of severe AMS, and it is associated with AMS severity. We did not use the STAI and could not evaluate the effect of the HCM on the psychological status of the crew, but we considered anxiety release as a hidden, but important role of an HCM.

The limitations of this study were the small sample, compliance with personal measurements, and the retrospective design with a control. We did not determine the age, gender and ethnicity to avoid unpredictable interference and we could not show any differences in both teams. A medical history of the crew members taken by a doctor was not available. Determination of AHAI might depend on the capacity of individual crew members to endure symptoms or complaints, leading them to avoid visiting the medical tent. The HCM did cause behavioral changes in the target team. The results might be influenced by unknown factors associated with the HCM. We could not exclude the effects that experience of high-altitude effects during previous Dakar Rallies might have had on all crew members.

Conclusion

An HCM without a medical license prevented the development of AHAI in an endurance rally team at high altitude. Education about AHAI, the accumulation of physiological data and anxiety release were considered as factors involved in prevention.

Disclosure statement

The authors have no conflicts of interest to declare.

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