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Original article

Association between early-morning urinary 6-sulfatoxymelatonin changes and sports performance during tours to the UK and Germany

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Abstract

Elite athletes often travel across time zones, and overcoming jet lag is an unavoidable challenge for achieving peak performance in competitions. Current jet lag prevention methods include measures taken prior to departure, measures taken during travel, or measures taken after arrival. Unfortunately, the best method remains unresolved.

Melatonin, produced by the pineal gland, is secreted only at night in response to the circadian clock, making it virtually the only indicator that functions as a clock hand. Early-morning urinary 6-sulfatoxymelatonin (6SMEL) reflects the total amount of melatonin secreted during the night, and measuring this amount can serve as an indicator of the degree of adaptation to time zone differences. In this study, we measured early-morning urinary 6SMEL over time in youth athletes experiencing actual time zone differences during tours to the UK and Germany, while also measuring their physical performance. The purpose of this study was to clarify which factors are important in preventing jet lag in athletes' performance. Results showed that early-morning urine 6SMEL levels were significantly lower ($p < 0.05$) than pre-travel levels on the day after travel for both the UK and Germany tours, and gradually recovered on days 3 and 5. However, on the UK tour, early-morning urine 6SMEL levels did not return to pre-travel levels at any time after travel, whereas on the Germany tour, 6SMEL levels recovered to pre-travel levels by day 3 and were significantly higher than pre-travel levels by day 5. This suggests that one factor contributing to this difference between the two tours may be the length of time spent in sunlight (outdoor activities) after arrival. Next, on day 3 of the UK tour, when there was significant individual variation in the level of change of direction (COD15m), a significant correlation ($p < 0.05$) was found between urinary 6SMEL and COD15m, indicating that athletes with higher 6SMEL levels had better COD15m values. This suggests that athletes who adapt more quickly to the new environment perform better.

***KEY WORDS*:** overseas expedition, time difference, 6-sulfatoxymelatonin, performance

1. Introduction

Today, many elite soccer players struggle with jet lag as they repeatedly travel across time zones to prepare for matches.

The problem of jet lag is known as jet lag syndrome, or jet lag, which is defined in a joint statement by Janse van Rensburg et al. as "a temporary disruption of sleep, wakefulness, and other biological functions associated with rapid eastward or westward travel across three or more time zones" [1]. The most common symptoms of jet lag are gastrointestinal discomfort, daytime fatigue/sleeping, impaired mental or physical performance, and sleep deprivation [2,3]. The intensity and duration of symptoms are said to worsen as the number of time zones traveled increases [4,5].

Melatonin, produced by the pineal gland, is secreted only at night in response to the circadian clock. It is the sole indicator of the circadian clock, and can be detected in blood, saliva, and urine. 6-Sulfatoxymelatonin (6SMEL) in early morning urine reflects the total amount of melatonin

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secreted during the night [6], and measuring this amount can be used as an indicator of the degree to which an individual is entrained to a time zone change. Generally, an individual's circadian rhythm can be phase-shifted by external stimuli (entrainment factors) given at a certain time, such as light, to adjust to the cycle of a new environment. Phase shifts have also been observed in melatonin, and it has been reported that this is the exact opposite of the phase response curve to light; that is, administration of melatonin in the subjective night (from evening to a few hours before bedtime) causes a phase advance. It has been suggested that this phase-shifting effect as an entrainment factor is mediated by the melatonin receptor MT2 in the suprachiasmatic nucleus, where the circadian clock is located [7].

Regarding performance after traveling across time zones, some studies have shown a decline in basketball free throw success rate [8], an increase in 270-m sprint time for the first four days after an eastward flight across six time zones [9], and a decline in back strength, leg strength, and reaction time after a westward flight across five time zones [10]. These studies suggest that jet lag can have a negative impact on athletic ability and physical and mental performance. However, other studies have shown no change in 30-m sprint performance after long-distance travel [11], and that elite athletes experience jet lag and disruptions in various physiological indicators after long-distance travel, but the impact on performance is limited [12]. Thus, there is some debate as to whether jet lag negatively impacts performance in athletes.

Basic research and actual field studies targeting Japanese athletes are extremely limited. Hoshikawa et al. conducted a questionnaire survey of top Japanese athletes traveling overseas and found that 74 athletes (10.8%) "often suffered" from jet lag-related health problems, while 398 athletes (58.0%) "experienced symptoms but were not particularly bothered" [13]. However, this research was not based on objective indicators. Yamanaka et al. also conducted a study on jet lag using a time isolation laboratory to shift the subjects' daily rhythms and focus on the synchronization of melatonin rhythms [14]. However, this study did not involve actual athletes traveling overseas across time zones.

Given this situation, currently recommended strategies for dealing with jet lag are often difficult for top athletes to implement, making it extremely important to consider strategies for traveling across time zones. Therefore, the purpose of this study was to clarify which factors have a significant impact on physical performance by comparing the amount of 6SMEL in athletes' early morning urine and fluctuations in their physical performance during tours to the UK and Germany with a time difference.

2. Methods

2-1. Study Design

This study was an observational study using opt-out consent. It analyzed changes in sleep, fatigue, melatonin, and performance in male youth soccer players during a cross-time zone tour from Japan to either the UK or Germany. *Figure 1* shows the players' time schedule (including flight

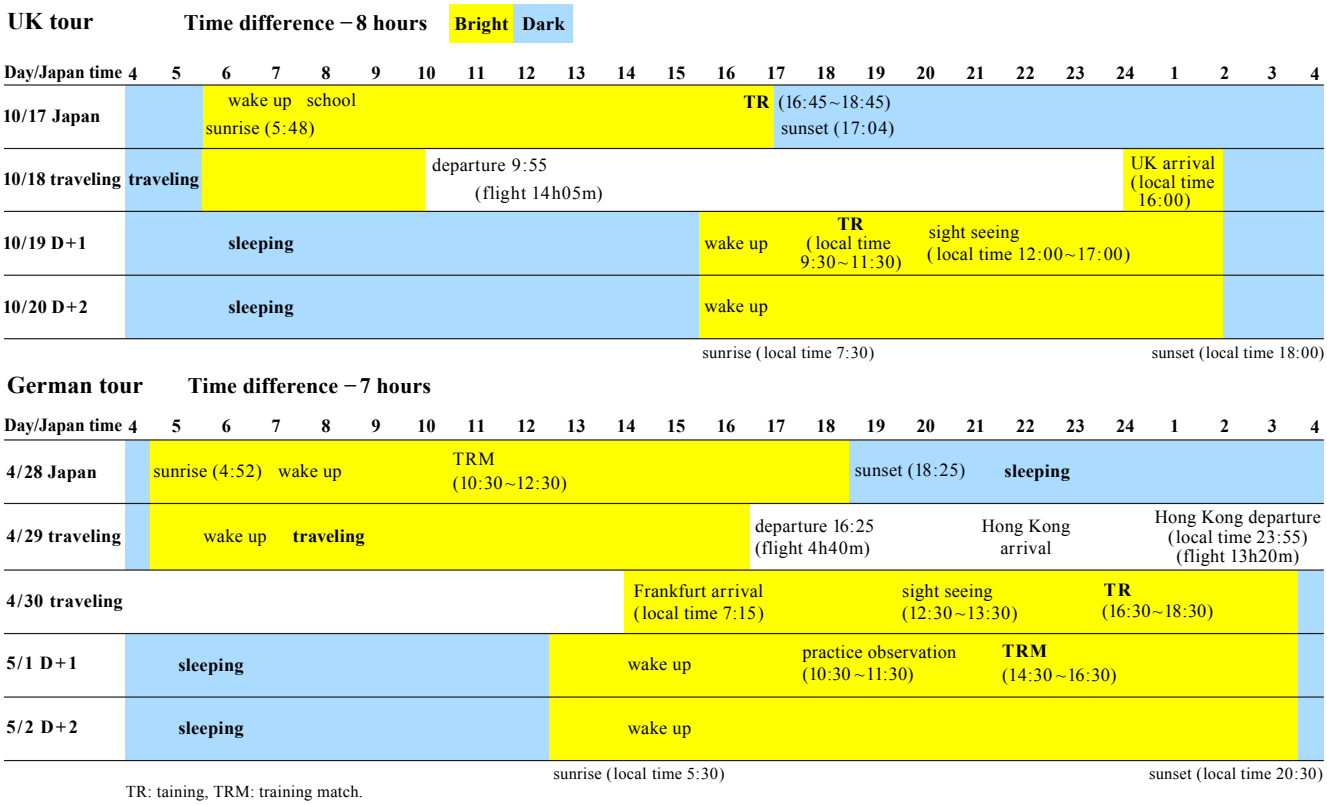


Fig. 1. **Time schedule for expedition to the United Kingdom and Germany.**

UK, United Kingdom; TR, training; TRM, training match.

schedule) from the day before travel (Japan) to the second day of travel (UK or Germany).

2-2. Subjects

For the UK tour, 18 of 19 third-year junior high school boys playing on an elite youth soccer team who were able to play and had no injuries or disabilities were selected as subjects (physical characteristics: height 171.4 ± 7.4 cm, weight 59.4 ± 9.6 kg, muscle mass 50.7 ± 6.4 kg, body fat 9.5 ± 4.0%, BMI 20.2 ± 2.5 kg/m^2).

For the Germany tour, 17 of 18 third-year junior high school boys playing on an elite youth soccer team who had no injuries or disabilities were selected as subjects (physical characteristics: height 168.8 ± 7.7 cm, weight 55.8 ± 7.0 kg, muscle mass 46.8 ± 5.1 kg, body fat 11.0 ± 2.5%, BMI 19.5 ± 1.1 kg/m^2).

A unique feature of the teams on both tours was that they were all boarding schools, so all participants followed the same schedule for training and matches before and after the tours.

2-3. Measurement Method and Items

2-3-1. Measurement Method

This study analyzed measurement data collected by the target team during their tours to the UK and Germany. The target team had been conducting measurements for the purpose of condition checks even before this analysis intervention.

2-3-2. Measurement Items

Subjective Questionnaire

Condition information was collected every morning using the application ONE TAP SPORTS (Euphoria, Tokyo, Japan). Each player completed a questionnaire via the application via the internet every morning. Questionnaire items included subjective fatigue, subjective sleep quality, number of nighttime awakenings, and number of daily bowel movements.

Urine

We targeted melatonin, which is believed to regulate circadian rhythms such as sleep and wakefulness. Melatonin is secreted into the bloodstream from the pineal gland, hydroxylated in the liver, and excreted in urine as 6-sulfatoxy melatonin (6SMEL). Melatonin is secreted minimally during the day and abundantly at night [6,15-17]. Therefore, early morning urine can be used to noninvasively assess post-trip environmental entrainment. Therefore, in this study, we used early morning urine to measure urinary 6SMEL levels.

Urine Collection Method

Each athlete collected urine in a paper cup upon awakening (early morning) and transferred it to a tube using a 1 mL dropper. The tubes were collected by the team's trainer, refrigerated for up to 7 days, and analyzed upon return home. It was previously confirmed that 6SMEL levels remained unchanged after 7 days of refrigeration.

Urine Sample Preparation Procedure for LCMS Measurement: 100 µL of urine sample was diluted 5-fold with 400 µL of methanol, vortexed, and centrifuged at 14,000 rpm for 20 min at 4 °C using a Centrifuge 5417R (Eppendorf, Hamburg, Germany). 100 µL of the supernatant was transferred to a 0.22 µm Ultrafree-MC-GV filter tube (Merck Millpore, Burlington, Massachusetts, USA) and centrifuged again at 10,000 rpm for 2 min at 4 °C. The filtrate was subjected to LCMS analysis.

Quantification of 6SMEL by LCMS: The resulting samples were analyzed using an LCMS-8050 mass spectrometer (Shimadzu, Kyoto, Japan) and a NexeraX2 high-performance liquid chromatograph (Shimadzu). Measurement of urinary 6SMEL by LCMS is considered a simple, highly reproducible, and sensitive method [17].

MS Conditions for 6SMEL: A calibration curve was created using 6-Sulfatoxymelatonin sodium salt (Toronto Research Chemicals, Inc., North York, Canada), and urinary 6SMEL was quantified using m/z 327.0 as the precursor ion and m/z 161.0 as the product ion.

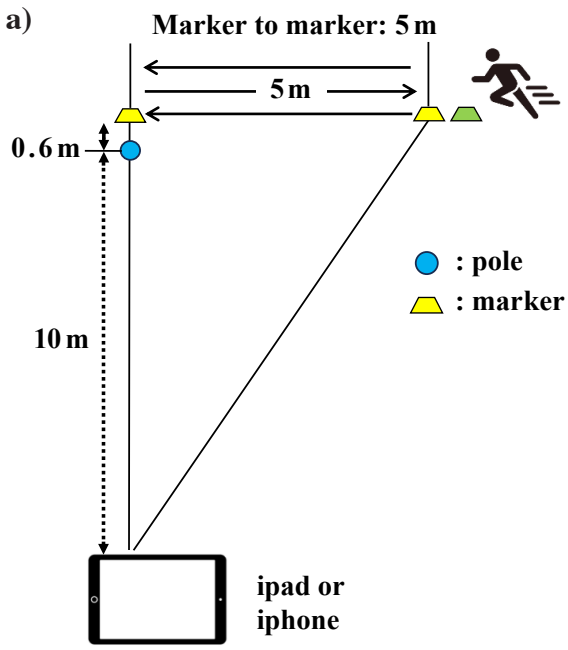
Creatinine Correction

Creatinine concentration was measured to correct for excretion. Creatinine concentrations in urine samples were measured using the LabAssay Creatinine creatinine measurement kit (Fujifilm Wako Pure Chemical Corporation, Osaka, Japan). 6SMEL concentrations were then corrected as excretion per mg of creatinine (Cre).

Performance Test (5m × 3 Change of Direction Run: COD15m)

The performance test consisted of a 5 m × 3 Change of Direction Run (COD15m). The measurement methodology was based on the physical measurements of the Japan Football Association (JFA) Physical Fitness Project [18].

Two markers were placed 5 m apart, and a goal pole was placed 0.6 m away from them. An iPad or iPhone 12 (Apple, Cupertino, California) was placed 10 m from the poles, and the trial was filmed in slow motion (1080p/240fps) (*Fig. 2-a*).



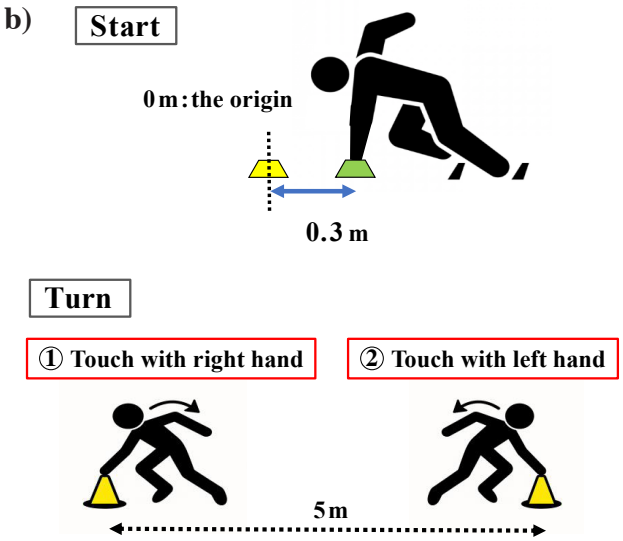


Fig. 2. **Arrangement of equipment for COD15m measurement (a) and specific measurement methods (b).**
COD15m, 5 m × 3 Change of Direction Run (Performance Test).

The subject performed a three-point start from a stationary position, with their hands touching a marker placed 30 cm behind the starting point. Measurements were conducted by running one and a half round trips between the 5-m markers. Important points during the trial included touching the marker with the right hand for the first turn and with the left hand for the second turn (***Fig. 2-b***).

Triple trials were limited to one per day. The COD15m time was calculated by counting the number of frames from the start to the finish line in slow motion footage taken on an iPad or iPhone 12.

2-3-3. Protocol

Subjective questionnaires for the UK tour were completed every morning, with the average of data collected up to departure being used as PreD data. Urine samples were collected before departure (PreD), the day after travel (D+1), three days after travel (D+3), and five days after travel (D+5). Performance tests (COD15m) were also conducted on PreD, D+3, and D+5.

Subjective questionnaires for the Germany tour were completed every morning, with the average of data collected up to departure being used as PreD data. Urine samples were collected before departure (PreD), the day after travel (D+1), three days after travel (D+3), and five days after travel (D+5). Performance tests (COD15m) were also conducted on PreD, D+1, and D+3.

2-3-4. Statistical Processing

To address individual variability in the 6SMEL and COD15m times, a nonparametric Wilcoxon signed-rank test was performed using the Statistical Package for the Social Science (SPSS) (IBM, Armonk, New York) on the PreD, D+1, D+3, and D+5 data, with the PreD value set as 100%. Bonferroni correction was then performed.

Due to the large variability in the COD15m data from the UK tour, the data were divided into two groups for analysis: a "deteriorating group" and a "no change/improvement" group for D+3 times compared to PreD. We also examined whether there was a correlation between the 6SMEL values and the COD15m scores.

2-3-5. Ethical Standards

This study was approved by the Ethics Committee of the College of Sport and Wellness at Rikkyo University.

3. Results

3-1. Changes in 6SMEL

The PreD value during the UK tour was 57.8 ± 37.3 ng/mg Cre. Therefore, this value was set as 100%, and the values on D+1, D+3, and D+5 were calculated as percentages. The 6SMEL values in early morning urine taken at each time point were 29.8 ± 15.2% of the Pre value on D+1, 51.0 ± 25.0% on D+3, and 70.0 ± 28.1% on D+5. Compared to PreD, 6SMEL levels were significantly lower on D+1, D+3, and D+5 ($p < 0.05$, ***Fig. 3-a***).

The PreD value during the German tour was 31.6 ± 16.6 ng/mg Cre. Taking this value as 100%, the 6SMEL values in early morning urine taken at each time point were significantly ($p < 0.05$) reduced to 40.2 ± 26.1% on D+1, recovered to nearly PreD levels at 105.6 ± 39.6% on D+3, and significantly increased to 137.7 ± 36.2% on D+5 ($p < 0.05$, ***Fig. 3-b***).

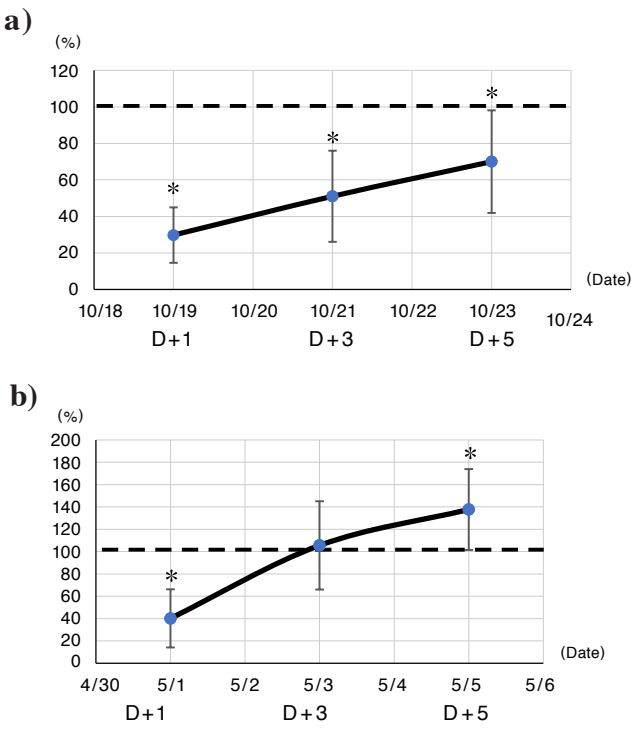


Fig. 3. **Changes in 6SMEL in early morning urine during the UK (a) and German (b) tours.**
% values are expressed as 100% of the values before the expedition (Pre), means ± SD, n = 18. * $p < 0.05$ vs PreD by Wilcoxon signed-rank test. 6SMEL 6-sulfatoxymelatonin. UK, United Kingdom; SD, standard deviation.

3-2. Performance Change (COD 15m)

During the UK tour, the PreD value of 4.3 ± 0.1 sec was set as 100% and used as a corrected value. Values below 100% indicate faster times than PreD, while values above 100% indicate slower times. During the UK tour, D+3 was 101.4 ± 6.1% and D+5 was 103.5 ± 2.7%, resulting in worse times compared to PreD. Meanwhile, during the German tour, the PreD value was 4.4 ± 0.2 sec, and assuming this value to be 100%, D+1 was 97.6 ± 2.5% and D+3 was 99.8 ± 2.3%. These were faster times than PreD. However, neither value was significantly different from the PreD value.

3-3. Comparison of 6SMEL Amounts When Divided into Two Groups by COD15m Times in the UK Tour

Next, while COD15m times in the German tour did not worsen from the first day of travel (D+1) compared to PreD, times in the UK tour were slower even on the third day of travel (D+3). Furthermore, there was significant inter-individual variability. Therefore, we divided the subjects into two groups (***Fig. 4-a***): a group whose COD15m times worsened compared to PreD (Worse; Group W) and a group whose COD15m times remained unchanged or improved (Better; Group B). There were no significant differences between the physical characteristics of Group W and Group B.

The 6SMEL values when divided into Group W and Group B are shown in ***Fig. 4-b***. In Group W, the 6SMEL values were 27.8 ± 13.6% on D+1, 39.1 ± 23.5% on D+3, and 58.6 ± 18.3% on D+5. In Group B, the values were 32.2 ± 18.5% on D+1, 64.5 ± 22.1% on D+3, and 84.3 ± 34.3% on D+5. On D+1, both groups showed a decrease, with no significant difference between the two groups. However, on D+3, Group W showed lower 6SMEL values than Group B ($p = 0.054$), and on D+5, Group W showed significantly lower 6SMEL values than Group B ($p < 0.05$) (***Fig. 4-b***). A

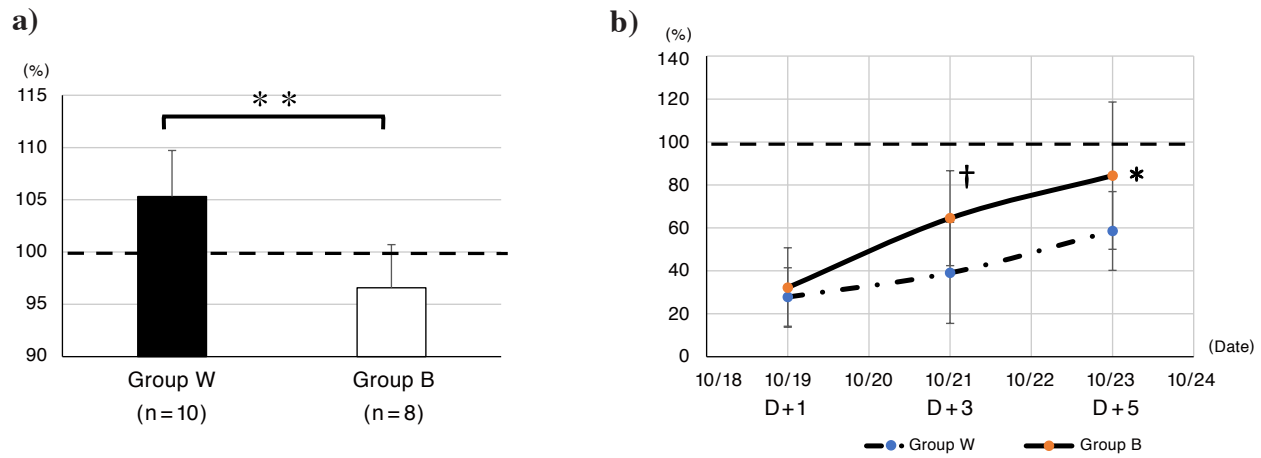


Fig. 4. **COD15m values for D+3 in the worse (Group W) and better (Group B) groups (a) and daily changes in 6SMEL in the two groups after the tour (b).**

* $p < 0.05$, ** $p < 0.01$ compared Group W to Group B, † $p = 0.054$ compared Group W to Group B by Wilcoxon signed-rank test. 6SMEL 6-sulfatoxymelatonin; COD15m, 5m × 3 Change of Direction Run (Performance Test).

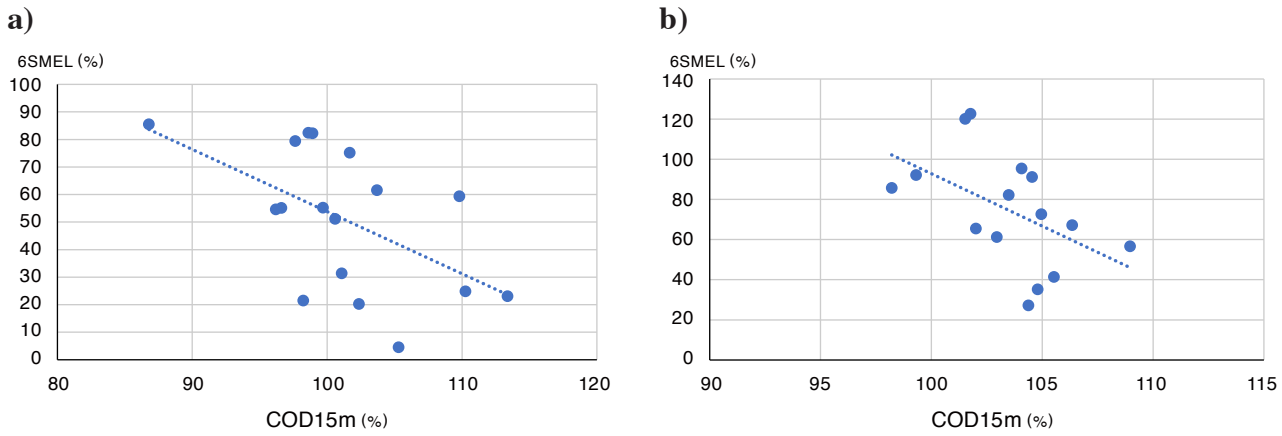


Fig. 5. **Correlation between 6SMEL and COD15m for each individual at D+3 (a) and D+5 (b).**

a: $y = -2.2578x + 279.58$, $r = -0.546$. $p < 0.014$, $n = 18$. **b:** $y = -5.2199x + 614.81$, $r = -0.502$, $p < 0.034$, $n = 18$. 6SMEL 6-sulfatoxymelatonin; COD15m, 5m × 3 Change of Direction Run (Performance Test).

similar analysis was performed on the German tour, and no significant difference in 6SMEL values was found between the two groups. During the UK tour, the times of Group W were significantly ($p < 0.05$) slower not only on D+3 but also on the subsequent D+5 (data are not shown).

3-4. Correlation between Urinary 6SMEL and Performance (COD15m) During the UK Tour

We therefore investigated whether there was a correlation between early morning urine 6SMEL values and performance (COD15m) on Days 3 and 5 of the UK tour. Results showed a correlation between 6SMEL and performance, with $r = -0.546$ ($p < 0.014$, ***Fig. 5-a***) on Day 3 and $r = -0.502$ ($p < 0.034$, ***Fig. 5-b***) on Day 5. On both days, players with higher 6SMEL values performed better.

3-5. Comparison of Other Questionnaire Data

The results are shown in ***Table 1***. There were no significant changes in questionnaire items (subjective fatigue, subjective sleep quality, number of nighttime awakenings, and daily bowel movements) from the day before travel (PreD) to the fifth day of travel (D+5) for both the UK and Germany tours.

4. Discussion

4-1. Changes in 6SMEL during the UK and Germany Expeditions

In this study, urinary 6-sulfatoxymelatonin (6SMEL), a metabolite of melatonin, was used as an indicator of circadian synchronization during cross-time zone tours. During the UK tour, early morning 6SMEL levels were significantly decreased on D+1, D+3, and D+5 compared to PreD. During the Germany tour, early morning 6SMEL levels were significantly decreased on D+1 compared to PreD, whereas early morning urinary 6SMEL levels were significantly increased on D+5. Overall, the German tour demonstrated better COD15m performance than the UK tour. Furthermore, on the third day of travel during the UK tour, a significant correlation was observed between urinary 6SMEL and COD15m, indicating that athletes with higher 6SMEL levels had better COD15m values. This suggests that athletes who adapt more quickly to the new environment perform better. In this study, the time difference between Japan and the UK was -8 hours and -7 hours between Japan and Germany. Bedtime in the UK and Germany corresponds to morning hours in Japan time, while waking time corresponds to the afternoon in Japan time. The 6SMEL results suggest that travel across time zones caused a misalignment between the internal clock and external environmental rhythms during the initial period of travel, resulting in jet lag. Härmä et al. reported that melatonin rhythms (circadian cycle peak phase) were delayed compared to pre-flight after a long-distance westward flight from Helsinki to Los Angeles [19]. The changes in 6SMEL observed in this study are consistent with those of Härmä et al., as well as with a previous study that examined melatonin rhythms on days 1 and 5 of flights from Japan to Los Angeles in six Japanese men aged 29 to 45 [20]. This suggests that travel across time zones can also cause jet lag symptoms, as measured by 6SMEL.

Comparing the changes in 6SMEL between the UK and German expeditions revealed significant differences. While caution is required when making comparisons due to the different subjects involved in both tours, the overall trend was that 6SMEL recovery was slower in the UK tour and faster in the German tour. Yamanaka et al. reported that jet lag occurs when traveling across several time zones. This is due to external desynchronization between the central clock (oscillator I), which was synchronized to the light-dark cycle

Table 1. Results of fatigue, sleep and defecation (UK and German tours).

UK	PreD	Moving day	D+1	D+2	D+3	D+4	D+5
Fatigue (Subjective) (0-100)	48.5 ± 12.0	49.3 ± 12.3	53.7 ± 10.6	49.6 ± 11.2	52.9 ± 11.4	54.5 ± 6.6	51.0 ± 9.4
Quality of Sleep (Subjective) (0-100)	58.8 ± 14.6	47.2 ± 15.1	53.6 ± 11.5	51.9 ± 11.2	54.9 ± 11.2	55.3 ± 12.0	52.4 ± 14.4
No. of wake up during night	0.1 ± 0.2	0.3 ± 0.7	0.6 ± 0.9	1.2 ± 0.9	0.9 ± 0.8	1.1 ± 1.1	0.6 ± 0.8
No. of defecation	2.7 ± 1.1	2.4 ± 0.9	2.0 ± 1.3	1.9 ± 0.8	1.9 ± 1.3	1.4 ± 1.2	1.9 ± 1.3
Germany	**PreD**	**Moving day**	**D+1**	**D+2**	**D+3**	**D+4**	**D+5**
Fatigue (Subjective) (0-100)	45.6 ± 21.9	63.4 ± 26.0	46.9 ± 20.3	47.6 ± 22.7	47.4 ± 21.2	45.7 ± 23.4	48.6 ± 24.2
Quality of Sleep (Subjective) (1-5)	3.8 ± 0.7	2.6 ± 0.6	3.3 ± 1.0	4.1 ± 0.8	3.5 ± 0.5	3.6 ± 0.8	3.6 ± 0.9
No. of wake up during night	0.2 ± 0.4	1.2 ± 1.4	0.7 ± 1.1	0.2 ± 0.4	0.3 ± 0.5	0.1 ± 0.2	0.1 ± 0.3
No. of defecation	2.4 ± 1.2	1.7 ± 1.4	2.3 ± 1.4	2.4 ± 1.3	2.4 ± 1.3	2.2 ± 1.4	2.3 ± 1.4

Values are expressed as means ± SD, n = 18. UK, United Kingdom; SD, standard deviation.

at the departure site, and the light-dark cycle at the destination site. Yamanaka et al. also reported that jet lag occurs when traveling across several time zones[21]. This desynchronization occurs between the sleep-wake rhythm (oscillator II), which quickly resynchronizes with the circadian rhythm at the destination, and the biological rhythm, which takes time to resynchronize. They also suggested that bright light is the synchronizing factor for oscillator I, while social factors such as strict daily schedules and exercise are the synchronizing factors for oscillator II[21]. In this study, both the UK and Germany tours had fixed daily team schedules, all participants followed a regular schedule, and all participated in similar daily exercise. Therefore, it is unlikely that there would be any differences in the entrainment factors for oscillator II between the UK and Germany tours. However, when we examined bright light and sunlight, which are known to be entrainment factors for oscillator I, we found a significant difference in daylight duration: approximately 10.5 hours (sunrise around 7:30 AM, sunset around 6:00 PM) during the UK tour and approximately 15 hours (sunrise around 5:30 AM, sunset around 8:30 PM) during the German tour (***Fig. 1***). Since oscillator I, which is entrained by bright light, is thought to control core body temperature and melatonin rhythms, it is likely that re-entrainment from external de-entrainment occurred during the German tour, where daylight hours were longer, resulting in a faster recovery of the 6SMEL compared with the UK tour.

Another factor may be the schedule after arrival (***Fig. 1***). For the UK tour, the team departed Japan at 9:55 am, arrived at 16:00 local time in the UK, and then proceeded to the hotel by 18:00 when the sun set. For the Germany tour, the team departed Japan at 16:25, transited in Hong Kong, and then arrived in Germany at 7:15 am local time. After arriving, the team proceeded to the hotel and had lunch, then continued their activities, including training, in the afternoon while basking in the sunshine until 18:30. This suggests that there were differences in the amount of activity or exposure to bright light on the day of arrival. Light exposure is considered the most powerful regulator of biological rhythms[22-24]. It is possible that differences in the post-arrival schedule contributed to the differences in 6SMEL recovery between the UK and Germany tours.

In this study, the team did not implement any specific measures to address the time difference, so the differences between the UK and Germany tours were likely due to bright light. Rather than adjusting your sleep schedule before traveling across time zones or adjusting your daily rhythm to match the local time while you're traveling, it's probably much more important to schedule your life so that you're exposed to as much bright light as possible, such as sunlight, once you arrive at your destination. If that's not possible, it's important to take other measures, such as exercising, after you arrive.

4-2. Performance Changes Between the UK and Germany Expeditions

Only on Day 3 of both tours was the performance test, COD15m, conducted on the same day. Therefore, examining the data on Day 3 revealed a tendency for data variability to be greater in the UK tour and smaller in the Germany tour.

Forbes-Robertson et al. reported that using bright light at specific times before, during, and after travel, or taking melatonin, can accelerate the adaptation of circadian rhythms to a new time zone and mitigate performance decline[25]. As mentioned above, during the UK tour in this study, due to local daylight hours, flight schedules, and team schedules, exposure to bright light was short, resulting in slower recovery of 6SMEL. However, during the Germany tour, exposure to bright light was longer, resulting in faster recovery of 6SMEL. Therefore, it is thought that during the UK tour, where many athletes had not adapted their circadian rhythms to the local time, there was a deterioration in performance and a large variance in times between athletes, while during the Germany tour, where many athletes had adapted to the local time, there was a small deterioration in performance and a small variance in times between athletes.

4-3. Relationship between Performance and Urinary 6SMEL

To examine performance in more detail, we divided the athletes into two groups for both the UK and Germany tours: those whose COD15m times worsened (Worse; Group W) on Day +3 compared to PreD and those whose COD15m times maintained or improved (Better; Group B).

Comparing COD15m times between the groups, Group W had significantly slower times than Group B on Days +3 and +5 during the UK tour. Furthermore, the number of participants in the groups was similar (10 for Group W and 8 for Group B). It is clear that there are athletes who can maintain their performance and those who cannot after traveling across time zones. So, where does this difference come from? During the UK tour, we investigated whether there was a correlation between early morning urine 6SMEL values and COD15m performance (i.e., time taken to change direction) on D+3 and D+5. The results were $r = -0.546$ ($p < 0.014$, ***Fig. 5-a***) on D+3 and $r = -0.502$ ($p < 0.034$, ***Fig. 5-b***) on D+5, demonstrating a correlation between 6SMEL values and performance. In other words, the higher the 6SMEL values, the better the performance of athletes, which may indicate that athletes who adapt to the local environment quickly perform better.

4-4. Jet Lag Countermeasures

Current jet lag countermeasures include those implemented before departure, those during travel, and those after arrival. Previous research has recommended measures to combat jet lag, such as gradually adapting sleep schedules to those expected upon arrival approximately one week before departure[26,27], adjusting meal timing and sleep duration during transit[3,28-30], and adjusting light exposure times after arrival[31,32]. Adjusting sleep duration one week before departure is often difficult when working in a team. Furthermore, adjusting meal timing and sleep duration during transit can often result in shorter total sleep time. In such cases, participants may arrive at their destination before adequate recovery from travel-related fatigue, potentially resulting in poor performance. The results of this study suggest the importance of light exposure and time of day upon arrival. Future research should further examine the amount and timing of light exposure after arrival, as well as sleep during and after travel, using more objective data.

5. Research limitations

The factors that generally synchronize the circadian clock include light (sunlight), meals, and social factors (environment). In this study, all participants consumed meals including breakfast, but it was not possible to make the meal menus (e.g., protein intake) identical (or comparable) between the two tours. While none of the participants took naps, environmental factors such as accommodation facilities were different between the two tours. This limitation is inherent in studies conducted during actual tours involving athletes, and further detailed investigations using experimental facilities are likely to be necessary in the future.

6. Conclusion

This study demonstrated that jet lag occurs in Japanese youth athletes when traveling across time zones, consistent with previous reports. Furthermore, a correlation was found between early morning urinary 6SMEL values and performance recovery after travel, revealing that athletes with faster 6SMEL recovery exhibit better performance. Furthermore, the importance of increasing sunlight exposure time and the timing of exposure after arrival at the destination to promote 6SMEL recovery is suggested, and this point requires further clarification.

Conflict of interest declaration

None in particular.

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None in particular.

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