Exercises and Skin Physiology During International Space Station Expeditions

Nicole Braun; Berit Hunsdieck; Carmen Theek; Katja Ickstadt; Ulrike Heinrich

BACKGROUND: The first skin physiological pilot experiment (SkinA) on a single astronaut showed a deterioration of the skin. In a follow-up experiment (SkinB) we showed that skin physiological parameters improved on average. However, it is well known that sports have positive effects on the skin, that astronauts prefer special sports devices, and do sports with different intensity. The aim of this study was to analyze the different sports activities of SkinB astronauts and to find out whether they have an influence on the skin physiological parameters.

METHODS: The cumulative distance covered on the treadmill and on the cycle ergometer as well as the repetition of arm-related exercises have been calculated and possible correlation between sports activities and skin physiological parameters have been analyzed.

RESULTS: The average distance covered for all six astronauts per day is 1364 AU on the treadmill T2, and 11,077 AU on the cycle ergometer CEVIS. In addition, the astronauts performed an average of about 73 repetitions of all arm-related exercises daily. Here, we were able to show very well how differently the astronauts on the ISS train. In addition, a decreasing trend in skin volume can be observed in astronauts with increasing activity on the bicycle and more repetitions on arm-related exercises.

CONCLUSION: Increased activity on the cycle ergometer and increased arm-related exercises have a medium negative impact on the parameter skin volume and thus reflects more fluid content in the skin. No correlations between sports activities and skin moisture/skin barrier function could be found.

KEYWORDS: sports, astronauts, skin physiology, long duration stay, International Space Station.

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The first skin physiological pilot experiment was performed on a single astronaut (SkinA) previously. The study indicated that long-duration spaceflight has negative effects on skin health and function, similar to aging. In particular, the results from the SkinA experiment showed a thinner, more structured epidermis and a decrease in collagen and elastic fibers.[15] In the follow-up SkinB experiment, skin physiological data of six astronauts during a long-term stay on the International Space Station (ISS) were also examined.[1] During the stay on the ISS, the skin physiological parameters skin moisture, skin barrier, and skin volume were investigated. It was shown that both skin moisture and skin barrier significantly improved on average. Nevertheless, the astronauts reacted differently. In detail, two astronauts demonstrated generally higher skin hydration values throughout the mission, two astronauts showed increasing values after half of the ISS stay, one astronaut showed unchanged values, and one astronaut showed lower skin hydration values after half of the stay compared to preflight. Furthermore, in five out of six cases, the skin barrier was improved over the entire in-flight period compared to preflight.

In addition, due to the fluid shift the parameter skin volume significantly decreased by about 50%.[1] Here, the parameter volume describes the number and depth of the wrinkles. Figuratively described, the skin volume parameter describes the virtual amount of liquid needed to fill the "valley" up to the

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average height of all "mountains" (the smoother the surface before filling, the less liquid is needed).

A value of 100 arbitrary units (AU) can be seen preflight and a strong decrease in the value by 40% is visible at the first measurement in flight (flight day 15) and values finally settle at about 45 to 50 AU in flight. Nevertheless, the decrease of the parameter volume varies among the individual astronauts, but also within the astronauts over time.

As there were differences in the data situation of the two skin physiological experiments, which were carried out at different times, the question arose as to what the cause could be, although it should not be forgotten that the SkinA study involved data from a single astronaut only.

Between 2006 and 2011, there were a number of changes on the ISS and, unfortunately, insights as to humidity were limited during the pre-Colombus module days (the Columbus module was installed in 2008). Several changes between the two time periods are the change to six astronauts (from three astronauts) and the addition of regenerative life support. The increased crew may have increased the overall level of humidity in the atmosphere and the regenerative life support system changed how humidity was managed on the ISS. Apparently, there may have also been changes concerning the recommended water intake (NASA spaceflight operations; August 2019; personal communication). Another difference relates to the sports equipment.

In the period from 2000–2009, during which SkinA was also performed, the resistive exercise device "Interim Resistive Exercise Device (iRED)" was in use. Here, it is also worth mentioning that the use of the iRED was limited at that time, as it was fixed to the ISS structure and loads were transferred to the structure during some exercises. From 2009 onwards this was replaced by the Advanced Resistive Exercise Device (ARED). With the installation of the ARED the resistive training was increased, which at the same time led to a reduction of the use of the cycle ergometer and treadmill.[10]

In general, the sports training is structured as follows. The planned training time during the flight is 2.5 h/d for all astronauts, including setup, stowage activities, and personal hygiene. The actual time spent on exercising is approximately 1.5 h/d. For European astronauts, sports is mandatory 7 d/wk, with the aim of achieving six to seven resistance and four to seven cardiovascular sessions per week, adapted to the preferences of the crewmembers and based on the European Space Agency (ESA) countermeasure concept.[10] The sports exercises are basically divided into resistance and cardiovascular exercises. Resistance exercises are predominately knee bends, heel raises, and dead lifts, but also crunches and bench presses are included. The individual sports exercises vary from session to session. Cardiovascular sessions are either conducted on the cycle ergometer or treadmill. Each astronaut's daily physical training program varies considerably, depending on the preflight performance, astronauts' feedback, personal preferences, and factors influencing the exercise countermeasure program.[8] With regard to the optimization of in-flight exercises, Jones et al. suggest that in order to maintain aerobic capacity, maintenance cycle ergometry should be preferred over the treadmill and that strength exercises should be performed first and then aerobic exercises.[5] Unfortunately, the data situation did not permit an analysis of both studies. But since the astronauts of the SkinB showed individual difference in the skin physiological data, it was analyzed if sport has an influence on the measured skin physiological parameters. If an effect on the skin parameters can be determined, a change in the astronauts' sports behavior should be considered.

METHODS

Subjects

Of all six astronauts who participated in the SkinB project, their in-flight exercises data were recorded and used for statistical analysis. All participating subjects were informed about the objectives and scope of the study and gave a written consent prior to the start of the study. The study has been approved by the Ethics Committee of the Witten/Herdecke University, Germany (approval number: 51/2012), by the ESA Medical Board, National Aeronautics and Space Administration (NASA) Institutional Review Board (IRB)/Committee for the Protection of Human Subjects, and the Human Research Multilateral Review Board. Approval to publish the data of this manuscript was granted by the NASA IRB.

Procedure

Pre, in-flight, and postflight measurements were of skin hydration, transepidermal water loss, and skin volume. Skin hydration was measured using the Corneometer, skin barrier function (transepidermal water loss) was measured with the Tewameter, and skin volume (depth of wrinkles) was measured by means of surface evaluation of living skin (SELS; VisioScan® VC98 camera; C+K Electronic, Koln, Germany). The measurements have been described in detail in the manuscript: Current effects of a long-term mission on ISS on skin physiological parameters.[1] All measurements were conducted on the same skin area (volar inside of the forearm) and at the same time of day.

Exercises are captured by Space Medicine as part of the routine health screening. The exercise plan of all crewmembers participating in SkinB was received through a data sharing agreement. The exercises include treadmill running, cycle ergometry, and resistance exercises. All six subjects performed running on the second generation (T2) treadmill, cycling on the Cycle Ergometer with Vibration Isolation System (CEVIS), and resistance exercise on the ARED.

Statistical Analysis

Since only a few measurements of activity on the CEVIS and T2 are available in full for some subjects, only the duration and speed are taken into account, which are available in full in order to exhaust the sample size. From this, a measure of intensity of the exercise unit can be determined based on the distance covered. Since the measurements are available without associated units, but it is assumed that the speed and duration are based on the same units, the distance is given in an imaginary, fixed unit so that the distance results as: distance = duration × speed.

If m_k is the distance traveled on the T2 at time k, then $m_{(0,t)}$ is defined as:

$$m_{(0,t)} = \sum_{k=0}^{t} m_k$$

By analogy, the cumulative distance traveled $b_{(0,t)}$ on the CEVIS is defined. For the resistance exercises using ARED, the exercise, the total sets, the set, and the number of repetitions are available. The repetitions and the corresponding exercise are complete.

Since the weight with which the exercise was performed is not available for some subjects, it was not considered further. Since the skin physiological measurements are made on the forearm, it is useful to take a closer look at the exercises that affect the arms. This includes the exercise as follows:

- Bent Over Row
- Bar Bicep Curls
- Bench Press
- Bicep Curls
- (Cable) Triceps Extension
- Upright Row

This results in the cumulative absolute exercise frequency as follows. If a_k is the number of repetitions of all arm-related exercises at time k, then $a_{(0,t)}$ is defined as:

$$a_{(0,t)} = \sum_{k=0}^{t} a_k$$

The descriptive evaluation of the sports-related data is carried out by means of the cumulative distance or the cumulative exercises over a scatter diagram, where each of the six subjects is considered individually. In the next step, the values of the variables "skin hydration", "transepidermal water loss (skin barrier function)", and "skin volume" are examined with regard to a possible correlation with T2 activity, CEVIS activity, and arm-related exercises during space travel.

Table I. Activities on the Treadmill, the Cycle Ergometer, and Repetitions of the Arm Training Per Subject and the Averaged Values of All Six Subjects.

SUBJECT	TREADMILL (T2)	CYCLE ERGOMETER (CEVIS)	ARM-RELATED REPETITIONS (ARED)
1	1190	17,291	63
2	1838	7847	66
3	1091	13,635	90
4	1535	3915	62
5	1293	14,153	78
6	1241	9619	80
Mean	1364	11,077	73

A Pearson correlation coefficient (r) was computed using R 3.6.1 for Windows by CRAN (https://cran.r-project.org/) to determine the linear association between the variables. Correlation coefficient (r) values were obtained for all pairs of the following variables:

1. between the treadmill and skin hydration;
2. between the treadmill and skin barrier;
3. between the treadmill and skin volume;
4. between the cycle ergometer and skin hydration;
5. between the cycle ergometer and skin barrier;
6. between the cycle ergometer and skin volume;
7. between arm-related exercises and skin hydration;
8. between arm-related exercises and skin barrier; and
9. between arm-related exercises and skin volume.

The results obtained by these calculations were interpreted according to the direction of correlation (positive or negative) and take into consideration the absolute value. A correlation coefficient with an absolute value of 0.5 or higher is regarded as relevant. The results were presented using ggplot (https://ggplot2.tidyverse.org/), gridExtra (https://cran.r-project.org/web/packages/gridExtra/index.html), and Rmisc (https://cran.r-project.org/package=Rmisc).

RESULTS

Test Subjects' Sports Activity

The average distance traveled for all six subjects per day is 1364 AU on the T2 and 11,077 AU on the CEVIS. In addition, the

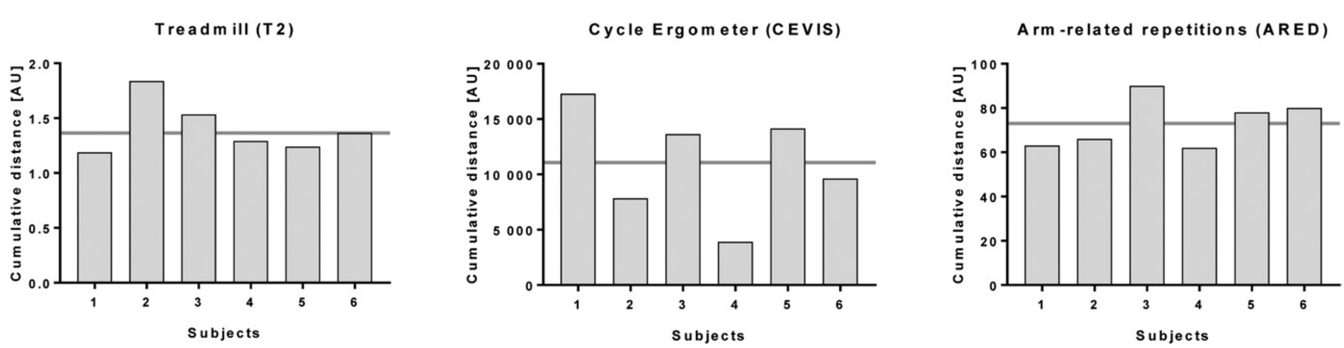

Fig. 1. Bar chart of the accumulated distance (Treadmill - T2/Cycle ergometer - CEVIS) or repetitions (Arm-related repetitions ARED) of each individual subject. The horizontal line shows the average of all subjects.

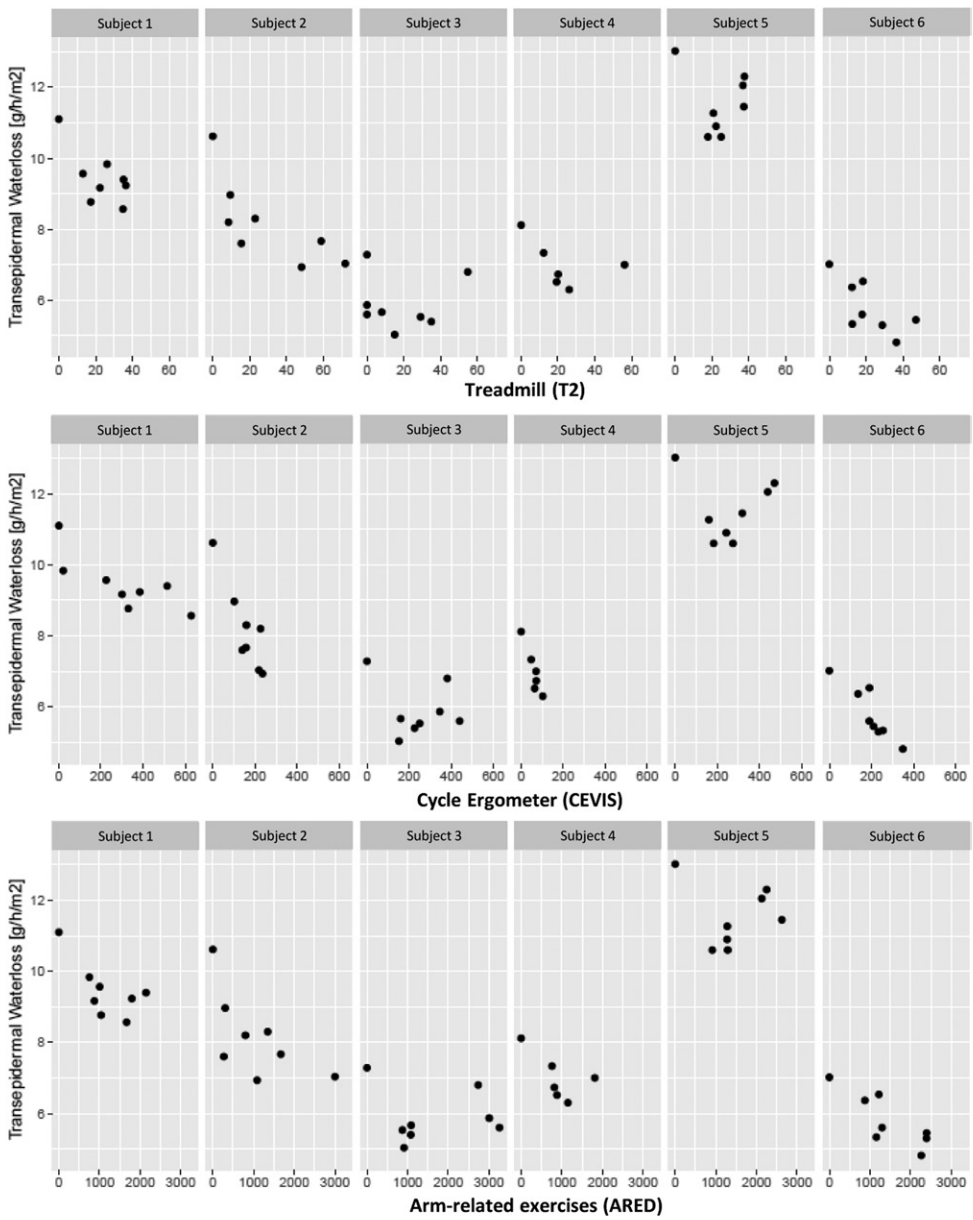

Fig. 2. Correlation between skin hydration and sports activities.

subjects performed an average of about 73 repetitions of all arm-related exercises daily.

In summary, subject 1 used the cycle ergometer the most and subject 4 the least. The treadmill was used most by subject 2 and least by subject 3. Intensive arm-related exercises were done most by subject 3 and least by subject 4. Subjects 5 and 6 were the average (**Table I**, **Fig. 1**). Looking at each subject individually, the following picture emerges.

Subject 1. Subject 1 continuously practiced sports during the entire stay on the ISS. In terms of activity on the treadmill, the subject hardly differs from the average treadmill activity of all subjects. Considering the accumulated distance traveled on the cycle ergometer, subject 1 covered much more distance than the other subjects. The average distance traveled by cycle ergometer is 17,291 AU and is approximately 1.5 times the distance covered per day compared to the average distance.

In the arm-related exercises, a slight reduction in activity compared to the average can be seen. At the beginning of the mission (until about day 40), the intensity does not differ from the average. Afterwards it can be seen that the subject does less exercises or exercise repetitions than the average.

Subject 2. Regarding the activity on the treadmill, it can be seen that subject 2 used the treadmill more sparsely than the average in the first half of the mission; from day 50, however, subject 2 ran more on the treadmill every day (see the gradient of the grey and black straight). Compared to subject 1 but also to the average, significantly fewer units were completed on the cycle ergometer (7847 AU). It can be seen that, in some phases, the bicycle was used more, but in other phases (e.g., day 60 to 85) rather little.

Regarding the arm-related exercises no observations were made in five periods spread over the entire observation period, i.e., the subject did no strength exercises five times over an extended period. However, the average number of repetitions (66 repetitions) of subject 2 is almost identical to the average (73 repetitions). The fact that the grey line in the supplemental data (**Fig. A**; https://doi.org/10.3357/AMHP.5717sd.2021) is shifted downwards can be explained by the fact that the subjects did hardly any strength exercises at the beginning of the mission.

Subject 3. For subject 3 it is noticeable that there are hardly any deviations from the average for the bicycle (13,635 AU) and the arm-related exercises (90 repetitions) throughout the entire mission. However, no activities were recorded on the treadmill from day 90 onwards. Additionally, no activity was recorded on the treadmill between day 15 and day 30.

Subject 4. Subject 4 completed both the treadmill (1535 AU) and arm-related exercises (62 repetitions) as intensively as the

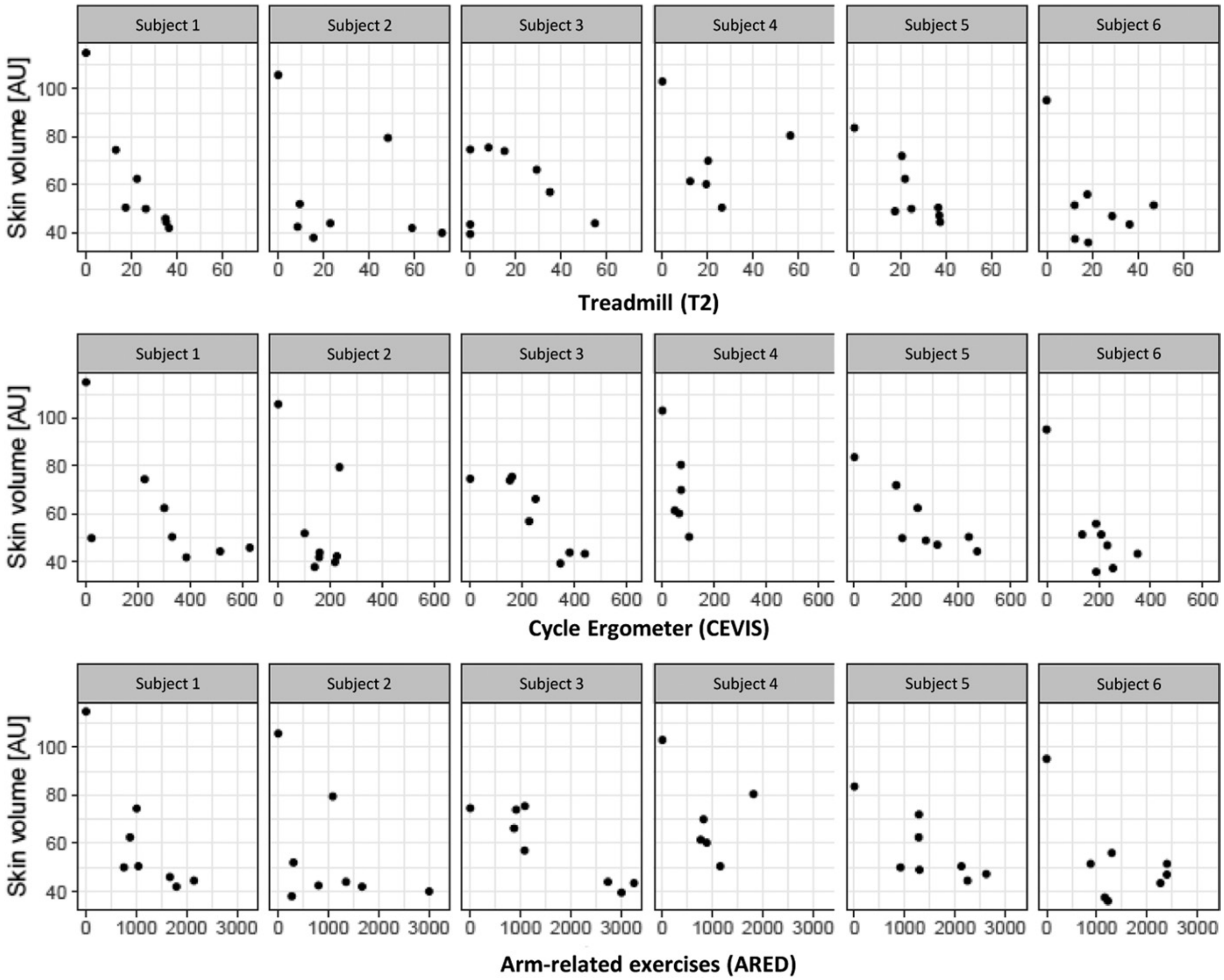

Fig. 3. Correlation between transepidermal water loss (skin barrier function) and sports activities.

average. However, the time spent on the cycle ergometer was significantly less and less intense (3915 AU) than the average. Furthermore, the treadmill was not used at the end of the stay.

Subject 5. Subject 5 corresponds strongly to the average in all three sports: the treadmill (1293 AU), the cycle ergometer, and arm exercises (78 repetitions). On the bicycle subject 5 was even more active (14,153 AU).

Subject 6. As with subject 5, the sports activities in all three areas of subject 6 are also very close to the average.

Table II. Pearson Correlation Values Between the Skin Parameters and Sports Data.

	SKIN HYDRATION	SKIN BARRIER	SKIN VOLUME
Treadmill (T2)	0.151	−0.075	−0.407
Cycle ergometer (CEVIS)	0.262	0.044	−0.604
Arm-related repetitions (ARED)	0.073	−0.186	−0.622

Sport and Skin Physiological Parameters

In the next step we analyzed whether the sport activities of the subjects had an influence on the skin parameters skin moisture, transepidermal water loss (skin barrier function), and skin volume (here representative for the fluid shift). If there was a high correlation between the sporting activity and the measured values of the skin parameters, it indicates a possible effect on the corresponding parameter.

Looking at all subjects, there was no correlation between sports activities and the skin parameters skin moisture and skin barrier function measured by transepidermal water loss (**Fig. 2** and **Fig. 3**, **Table II**). There is also no visible trend in the illustrations of all individual subjects. However, a negative meaningful linear relationship can be seen for the parameters cycle ergometer and skin volume as well as arm-related exercises and skin volume (**Fig. 4**, Table II). This means that a decreasing trend in skin volume (more fluid) can be observed in subjects with increasing activity on the bicycle or more repetitions of arm-related exercises.

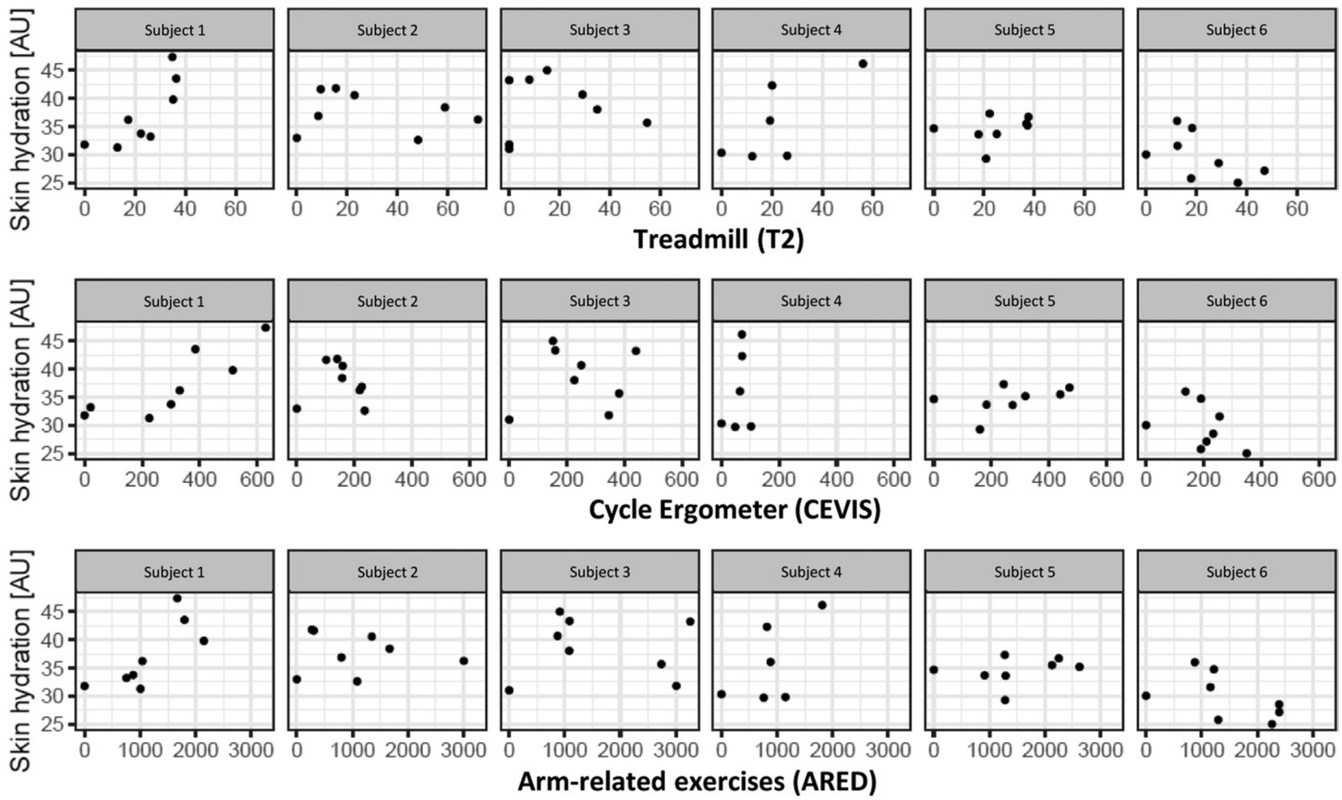

Fig. 4. Correlation between skin volume and sports activities.

Fig. 2, Fig. 3, and Fig. 4 show the pairwise scatter plots of skin hydration, skin barrier or skin volume, and the physical activity for each individual subject. Overall, we observed that sports has some influence on the parameter skin volume, but no influence on skin hydration and transepidermal water loss.

DISCUSSION

It is known that sports serve to keep the whole body healthy. People who exercise regularly and take a lot of exercise generally have fewer concomitant diseases and a longer life expectancy.[2] Sport has a positive effect on the body's metabolism, especially on the liver, skeletal muscles, and the cardiovascular system.[7,11,14] Safdar et al. also showed, for the first time, in mouse studies that sports can prevent a deterioration of the skin status.[12] The same group of researchers showed that regular exercise can reduce skin aging in both mice and humans. The cytokine IL-15 seems to play a decisive role in this. IL-15 is controlled by the AMP-activated protein kinase, and elimination of muscle AMPK led to a deterioration of the skin. In addition, it was shown that an IL-15 therapy imitated the skin antiaging effects in mice.[4] Due to the described positive effects of sports on the skin, the effect of different sports activities on skin physiological parameters in astronauts during long-term missions was investigated. Unfortunately, the data situation did not permit an analysis of both studies SkinA and SkinB. However, not all sports data for the SkinB subjects were complete, so that only complete data sets could be used for analysis here. However, due to the fact that there were also differences within the SkinB subjects in terms of skin physiological data, the first step was to examine their sporting activities in more detail.

In the adaptation phase, the first 2–3 wk on the ISS, where training begins at the earliest on the second day after reaching the ISS, the training intensity is relatively low.[10] This explains the negative intercepts at the beginning of the missions. Since the first days have only a low weighting when estimating the balance lines, the formula assumes more sports in the first days.

In general, it could be shown that the subjects preferred certain sporting activities and different intensities, depending on their personal preferences. In the next step, whether there is a correlation between the different sports activities and the skin physiological data was examined. However, no relevant significant differences could be found between sports activities and the skin parameters skin moisture and skin barrier function measured by transepidermal water loss. However, a decreasing trend in skin arm volume (more fluid accumulation) can be observed in subjects with increasing activity on the bicycle or more repetitions of arm-related exercises. For this reason, the fluid shift and countermeasure will be discussed in more detail here.

During spaceflight, the volume in the lower extremities is reduced by about 10% (1 to 2 L of fluid) compared to preflight. The puffy face with reduced volume of the lower extremities is, therefore, anecdotally called “Puffy Face-Bird Leg” syndrome. It is thought that the fluid shift, which includes blood, plasma, cerebrospinal fluid, lymph, and interstitial fluid, is due to the lack of gravity. Investigations on a single cosmonaut showed a swelling of the face, especially during the first 3 d of the mission. This swelling is due to storage of fluid volume in the interstitial tissue matrix, facial tissue, head, and neck. After that it was less visible as the cosmonaut experienced an increasing negative water balance.[6] A stay in space leads to a 10–15% reduction in plasma and blood volume and thirst and fluid intake are reduced overall.[3,16] However, after a couple of weeks the body reaches a homeostatic distribution of the fluid that is retained during a stay in space. Overall, fluid shift plays a significant role in various physiological responses. The fluid shift leads to nasal congestion and sinusitis, the cortisol and antidiuretic hormones are increased in the blood, and the cephalic fluid redistribution may also be responsible for visual impairment and intracranial pressure.[9] To what extent the fluid shift influences skin physiological parameters has not been investigated so far. Since aerobic exercise expands blood volume,[13] in-flight exercise training may help to prevent fluid loss.[17] However, in this study it could be shown that increased activity on the cycle ergometer and increased arm-related exercises had a medium negative impact on the parameter skin volume and thus reflected more fluid content in the skin.

In summary, it can be seen how individually different sports activities were performed. Although no influence of sports activity on the skin physiological parameters skin moisture and skin barrier function was found, a decreasing meaningful trend of skin volume can be observed in subjects with increasing activity on the bicycle and more repetitions of arm-related exercises. Here, the skin volume measured on the volar forearm represents fluid retention on the skin due to the fluid shift. This skin physiological parameter is a simple, noninvasive measurement, which can be easily performed by the astronauts to obtain information about the fluid shift and should be routinely checked. The combined effects of exercise and fluid shift in microgravity on skin physiological changes needs to be investigated in future studies.

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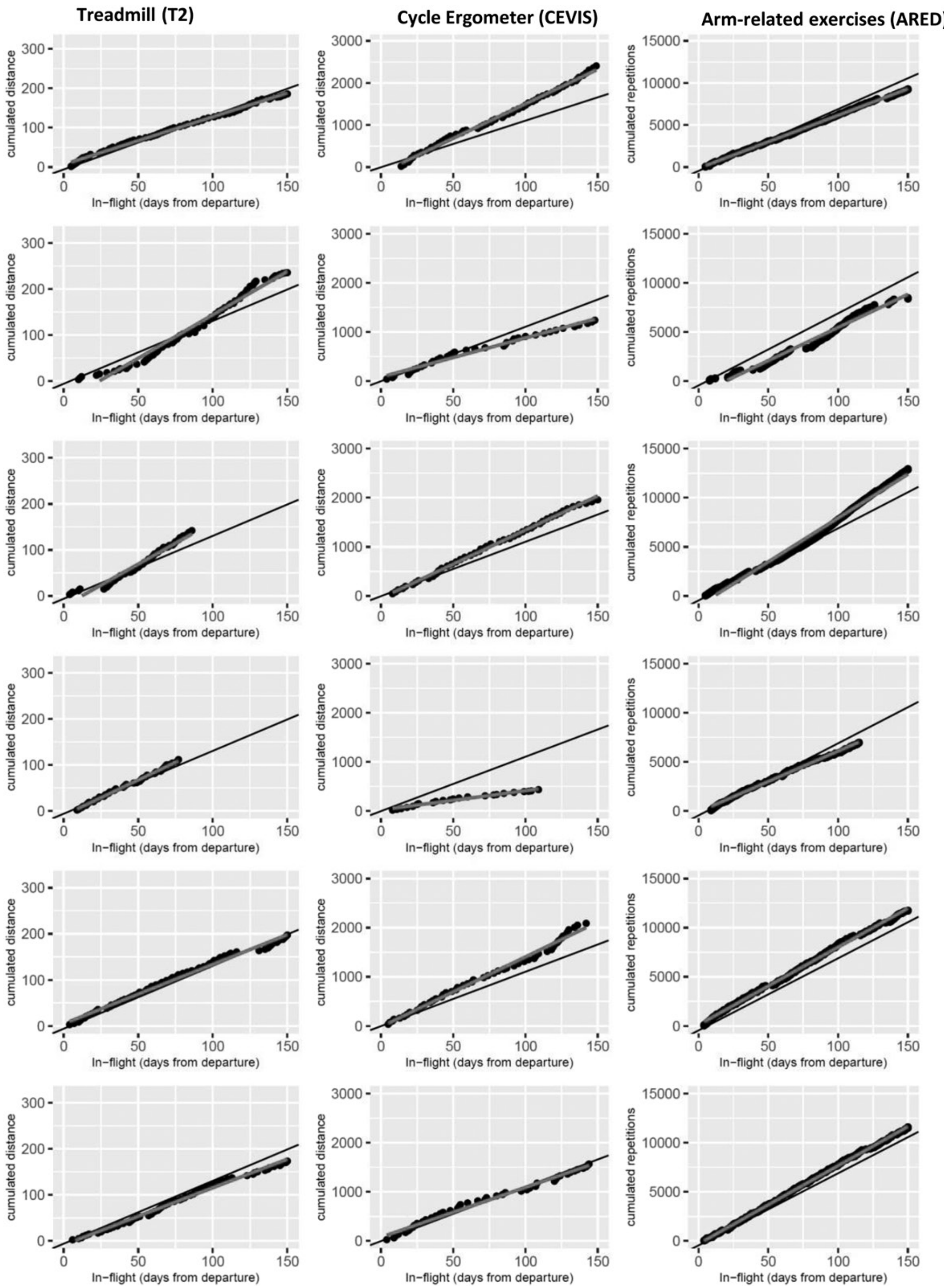

Fig. A. Overview of the sporting activities of the astronauts. The x-axis shows the duration of the stay on the ISS and the y-axis shows the cumulative distance covered on the T2 treadmill, the CEVIS space bike, and the cumulative repetitions of arm-related exercises. The black dots represent the observed cumulative data of the respective astronaut. The grey line corresponds to the person-related and the black line to the averaged compensation values. Here, the greater the gradient of the straight line, the more intensively an astronaut has trained.