Locomotion Strategy and Magnitude of Ground Reaction Forces During Treadmill Training on ISS

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INTRODUCTION: Creation of the cosmonaut in-flight physical training process is currently based on the leading role of support afferents in the development of hypogravity changes in the motor system. We assume that the strength of support afferents is related to the magnitude of the ground reaction forces (GRF). For this purpose it was necessary to compare the GRF magnitude on the Russian BD-2 treadmill for different locomotion types (walking and running), modes (active and passive), and subjects.

METHODS: Relative GRF values were analyzed while subjects performed walking and running during active and passive modes of treadmill belt movement under 1 G ($N = 6$) and 0 G ($N = 4$) conditions.

RESULTS: For different BD-2 modes and both types of locomotion, maximum GRF values varied in both 0 G and 1 G. Considerable individual variations were also found in the locomotion strategies, as well as in maximum GRF values. In 0 G, the smallest GRF values were observed for walking in active mode, and the largest during running in passive mode. In 1 G, GRF values were higher during running than while walking, but the difference between active and passive modes was not observed; we assume this was due to the uniqueness of the GRF profile.

DISCUSSION: The maximum GRF recorded during walking and running in active and passive modes depended on the individual pattern of locomotion. The maximum GRF values that we recorded on BD-2 were close to values found by other researchers. The observations from this study could guide individualized countermeasures prescriptions for microgravity.

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A prolonged stay in microgravity leads to decreased bone density,[22] structural and functional changes in human skeletal muscles,[13] and many other negative consequences that require countermeasures for successful functioning after returning to Earth or landing on other planets.[9,13] The neurophysiological studies' results have led to the proposal of a muscular hypogravity syndrome.[17,20] The symptoms of this syndrome are "atonia, atrophy, reduced speed and strength properties, and reduced endurance, with the greatest manifestations in the system of extensor muscles."[20] Kozlovskaya has suggested that this syndrome is caused by the decrease in a support afferents during weightlessness.[17,18]

Sufficient afferents from support receptors provide the human body with information about gravity magnitude. Particularly, afferents have been shown to be important for successful function of postural muscles and to providing motor control.[2,11] Remaining in weightless conditions initially leads to functional changes in the muscular system; manifestations begin with decreases in muscle tone and, eventually, muscle structure shows changes in appearance.[13] Studies have shown that foot support zone stimulation reduces the negative effects of simulated weightlessness on the human body, thus validating these ideas.[19,28] We assume that the support afferent magnitude, i.e., sensory inflow into the central nervous system from the support input, was associated with ground reaction force (GRF) magnitude. Based on this assumption we studied GRF as a measure of the support input stimulation intensity.

The proposal that support afferents play a leading role in countering the negative weightlessness effects on the muscular system prompts the need to evaluate GRF values for different locomotion types, i.e., running and walking. Furthermore, exercises in passive mode have been shown to provide a more

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effective countermeasure than in active mode;[24] therefore, the GRF in 0 G should be estimated not only in active mode, which entails moving the belt with the treadmill's motor assistance, but also in passive mode, when the belt is moved only through human efforts. It was also interesting to note whether observed patterns were universal or would be different depending on subjects and conditions (0 G and 1 G).

Studying the GRF under microgravity conditions became popular at the end of the last century. The first studies to determine the GRF value during locomotion under conditions that simulated weightlessness were conducted using horizontal suspension,[6,14,25] overhead suspension,[7] and parabolic flights.[10,12] As the technology became more advanced, GRF could be studied on the International Space Station (ISS) on the treadmill with the vibration isolation and stabilization system (TVIS) and on the second generation treadmill T2, during exercise on the cycle ergometer with the vibration isolation and stabilization system, and on the interim resistive exercise device.[4,9] One of these studies demonstrated that during typical days onboard the ISS, GRF values were higher than 100% of bodyweight (BW) only during running on the treadmill and during some strength exercises, i.e., heel raises and squats, that were performed with a single leg.[4] A relationship between vertical GRF and external loading during locomotion in spaceflight was demonstrated.[9] Moreover, the vertical GRF value was directly proportional to the speed of locomotion in both 0 G[6,25] and 1 G.[5] Similar results were obtained in GRF studies for running in passive mode on the BD-1 treadmill during a parabolic flight.[10]

A biomechanical analysis of the locomotion in a parabolic flight compared to ground studies showed that the biomechanics of running and walking on a treadmill in 0 G and 1 G were very similar.[15] But there were also some significant differences between performing the locomotion on Earth and in microgravity when a pull-down force was generated using a subject loading system. These differences included contact time, peak impact force,[8] peak load rate, and peak vertical force.[15] A study performed onboard the ISS showed lower values of relative peak impact force and relative peak propulsive force in 0 G compared to 1 G. GRF values increased with the bungee force level, but even when the bungee force level was equal to 80–89% BW, relative peak impact force was significantly lower than in 1 G.[9] At the same time, in the Russian countermeasures system, cosmonauts perform locomotor exercises on the Russian BD-2 treadmill[27] with recommended external load (EL) value equal to 60–70% BW, which presumably would lead to even a greater reduction in the GRF magnitude.

According to previous studies, the GRF was also significantly different during treadmill use in microgravity because of the requirement for a vibration isolation system (VIS) on the ISS; this system reduced the GRF amount.[14] GRF value analysis in microgravity would make it possible to determine the optimal dose for various locomotor training modes that would provide a successful countermeasure against the negative effects of weightlessness.

A distinctive feature of this study in comparison to that described above is the ability to measure the GRF magnitude as a support afferent value indicator in terms of the locomotion execution in active and passive modes involving the same cosmonauts and on the same treadmill installed onboard the ISS. Another distinctive feature of this approach is a comparison of two locomotion types, i.e., walking and running, performed at the same speed and with the same EL produced by the Russian subject loading system (RSLS) on a treadmill equipped with VIS.[27] In this study, attention was concentrated on the cosmonauts' individual locomotion characteristics, which were especially important for the countermeasure personalization. According to available literature, similar studies have not been carried out onboard the ISS.

An individual approach to a spaceflight countermeasure and exercises selection, in our opinion, should be implemented, taking into account the GRF value during locomotion. In this regard, the purpose of this study was to compare the vertical GRF magnitude during different locomotion types and modes at the same speed, on treadmills onboard the ISS and on Earth, taking into account the individual locomotion strategies.

The hypothesis of this study was that maximum GRF values would differ depending on BD-2 modes (active and passive), locomotion types (walking and running), and individual features, which would be observed in both 1 G and 0 G. The answer to this question is important from the theoretical point of view, i.e., for the expansion of knowledge about motor control in microgravity, and from a practical point of view, as based on the Kozlovskaya concept,[16,18,19] that the highest GRF values could be associated with the greatest countermeasure efficiency.

METHODS

Subjects

Four cosmonauts onboard the ISS (mean ± SD; men; age: 44 ± 4 yr; mass: 88 ± 11 kg; mission duration: 169 ± 1 d) and six people on Earth (4 men and 2 women, age 25 ± 2 yr, mass 69 ± 3 kg) participated in this study. The subjects on the ISS and on Earth were different. The physical activity levels were similar in both groups. There were differences in age, but it has been previously shown[21] that age differences are not significant for GRF values at low locomotion speeds.

The subjects were healthy, with no muscular, neurological, or tendon injuries. The study was approved by the Biomedicine Ethics Committee of the RF SRC–Institute of Biomedical Problems, Russian Academy of Sciences (Physiology Section of the Russian Bioethics Committee, Russian Federation National Commission for UNESCO). In accordance with the Declaration of Helsinki, all subjects signed informed consent for participation in the experiment.

Equipment

Vertical GRF was analyzed in the study. GRF values were measured at rates of 100–120 Hz on BD-2 treadmills equipped with sensors to detect the pressure (model MC3A-6, AMTI, Watertown, MA).[27] On Earth, the treadmill was installed on a hard support surface and, on the ISS, the BD-2 was installed on VIS that reduces the transmission of vibrations from the treadmill to the ISS. The RSLS was used on the ISS for gravity simulation during training on the treadmill. It consisted of stretchy cords which are attached to the left and right sides of a special harness. The RSLS provides a continuous load on the cosmonaut's body and enables walking and running in weightlessness.

Procedure

The study consisted of three main parts. All subjects on the ISS and on Earth performed walking in passive mode (WP), running in passive mode (RP), walking in active mode (WA), and running in active mode (RA). All stage durations were 30 s.

In Part 1, we solved the task of comparing the GRF during active and passive modes under 0 G conditions. For the analysis, we used the recording of daily physical exercises onboard the ISS, which, according to the recommended protocols, included walking at the speed of 4 km/h and running at the speed of 8 km/h in both active and passive modes. In the first part, the recorded data for the GRF during onboard training performed on the BD-2 with the RSLS and VIS were analyzed for four cosmonauts. From the dataset the segments of WP and WA at 4 km/h, and RP and RA at 8 km/h were selected. The EL was 57 $\pm$ 5% BW. Cosmonauts chose EL themselves based on standard recommendations and comfort during workouts.

Because the GRF magnitude was dependent on the locomotion speed, we could not compare walking and running stages in the first part. To enable simultaneous comparison of GRF values during different locomotion types (walking and running) and different BD-2 modes in both 1 G and 0 G, in Parts 2 and 3, the study design included locomotion at speeds suitable for both running and walking; i.e., 5 km/h and 6 km/h.

In Part 2, in 1 G, six subjects performed the locomotion test on the BD-2 treadmill according to the following protocol: WP, RP, WA, and RA at speeds of 5 km/h, 6 km/h, and 7 km/h.

In Part 3, one cosmonaut on the ISS performed the locomotion test eight times on the BD-2 with the RSLS and VIS. The EL was constant throughout each trial, but he differed EL values between trials. The minimum EL was 58 kg and the maximum was 66 kg (62 $\pm$ 4% BW). The protocol included WP, RP, WA, and RA at both 5 km/h and 6 km/h.

Statistical Analysis

We analyzed relative maximum and minimum values and the amplitude of the vertical GRF, along with GRF trajectories (profiles). On Earth, GRF values were normalized by the subject's weight and on the ISS by the EL magnitude in each data segment. Thus, relative vertical GRF values would be shown. The recorded GRF data were analyzed using specially developed software. The analysis involved 10 pairs of steps at the beginning of each stage of walking or running. Left and right legs' strides were analyzed together. The steps were identified based on the local minimum points on the GRF curves. Comparison of GRF values was performed, taking into account the treadmill operating mode (passive or active).

GRF profiles were compared using graphs generated in Microsoft Excel 2013. We analyzed GRF trajectories on the basis of superimposed GRF curves for 10 pairs of steps at the beginning of each locomotion stage at a constant speed. The comparison of GRF curves was carried out visually and statistically. We analyzed the number of local peaks at each step and maximum GRF values.

For each subject we searched differences in maximum GRF values depending on the BD-2 mode (active and passive) and the type of locomotion (walking and running). According to the Kolmogorov-Smirnov analysis, the data received were not normally distributed. We used the nonparametric Mann-Whitney U-test. In Parts 1 and 2, we compared 20 GRF peaks for each subject and case (WP, WA, RP, RA). In Part 3, where one cosmonaut performed the locomotor test eight times, we compared eight average GRF peaks for each case (WP, WA, RP, RA).

For the individual GRF values analysis, we compared between subjects using the Mann-Whitney U-test. We also studied the general differences in maximum GRF values for the whole group of subjects (in Part 2 in 1 G) depending on the mode and the type of locomotion. For this task we used the nonparametric Wilcoxon *t*-test and compared pairs of mean values (of 20 GRF peaks) for 6 subjects in WP, WA, RP, and RA. There were no controls in the statistics for multiple comparisons. All statistical analyses were carried out using IBM SPSS Statistics software (Version 21.0). Statistical significance was accepted as $P \leq 0.05$.

RESULTS

In Part 1, we analyzed GRF values depending on the BD-2 mode under the 0 G condition. The vertical GRF for running and walking in active and passive modes were compared in microgravity for four cosmonauts (**Fig. 1A**). For all cosmonauts, the GRF during running were higher in passive mode ($P < 0.001$) than in active mode. During walking, no differences were observed between active and passive modes for three of the cosmonauts. Only for subject X, the GRF were higher in passive mode ($P = 0.002$) than in active mode. We identified individual differences for cosmonauts in GRF values ($P \leq 0.01$). However, general patterns were the same for all cosmonauts.

In Part 2 we performed similar analysis in 1 G for six subjects (**Fig. 1B**). One set of subject data was partially unfit for processing because of incorrect data recording during active mode stages. So the data are presented for five subjects. Significant differences between subjects in maximum GRF values were observed ($P \leq 0.01$).

The differences in maximum GRF values between active and passive modes also depended on the individual. In particular, subject D had the lowest maximum GRF during walking in passive mode among all the subjects in the experiment ($P <$ 0.001) and, during running in passive mode, subjects D ($P <$ 0.001) and E ($P = 0.024$) had the largest values.

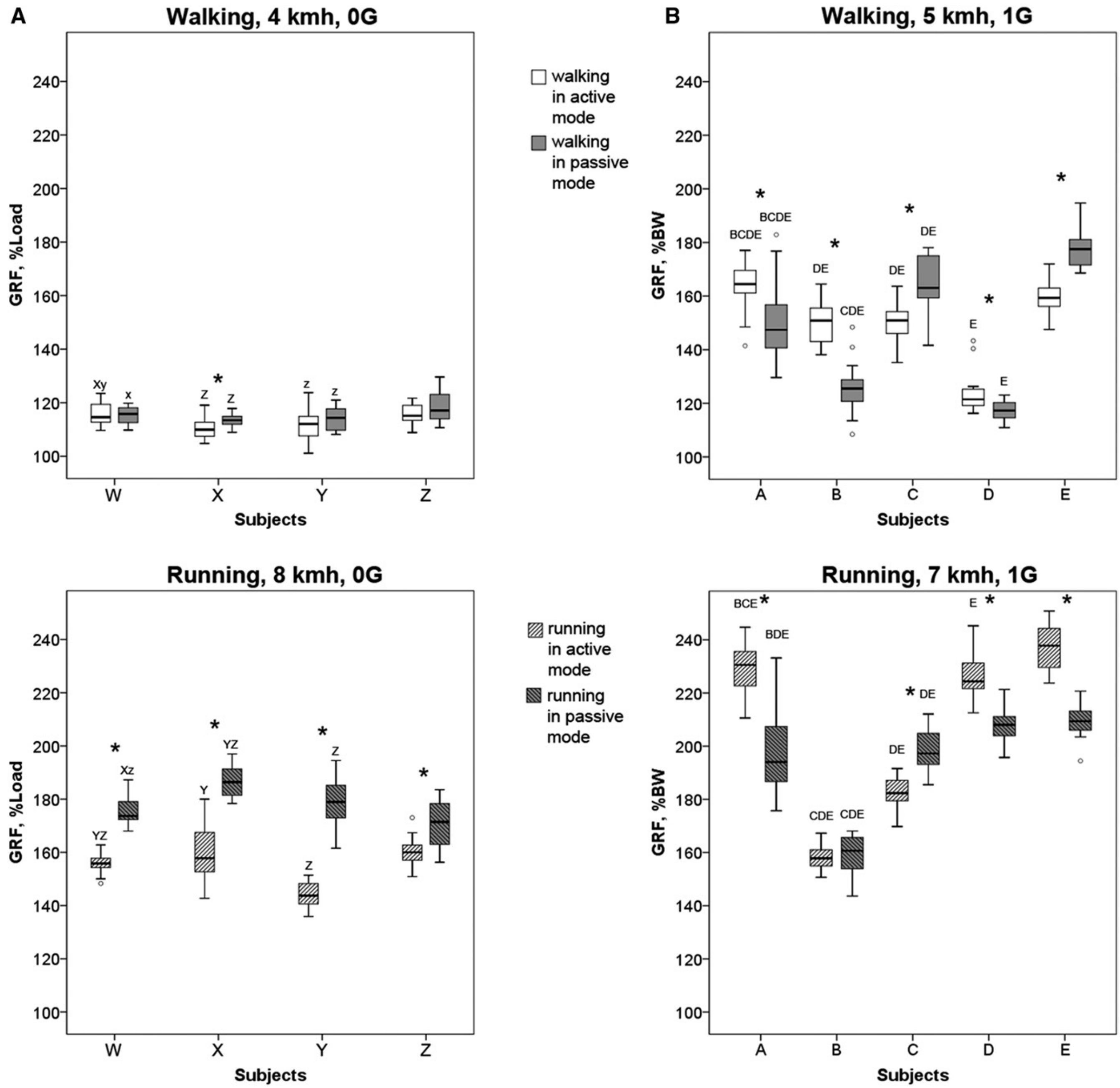

Fig. 1. The comparison of maximum ground reaction force individual values (% Load, % BW) for each subject in A) 0 G and B) 1 G. x (y, z) indicate a significant difference compared with subject X (Y, Z, respectively) ($P \leq 0.05$); X (Y, Z, B, C, D, E) indicate a significant difference compared with subject X (Y, Z, B, C, D, E, respectively) ($P \leq 0.01$); *indicates a significant difference between active and passive modes ($P \leq 0.01$); the small white circles are extreme values very different from the average.

We assumed that individual differences in maximum GRF values were due to the individual locomotion profiles. Visual GRF curve comparisons in Part 2 showed that GRF profiles during locomotion were both unique and stable (**Fig. 2**). During walking, several GRF peaks were clearly observed in most subjects (A, B, D, E, F). Unlike the others, subject C had a clearly defined single GRF peak, which could be related to tiptoe walking.

In addition to the GRF profiles, minimum and maximum GRF values were specific to each individual (**Table I**). During walking in passive mode at the speed of 6 km/h, minimum GRF values were below 37% BW for subjects C and E, and above 53% BW for the other subjects. The maximum GRF varied from 134 ± 10% BW for subject B to 186 ± 11% BW for subject E. In 0 G, during walking in passive mode at the speed of 4 km/h, no apparent differences between subjects were observed in maximum GRF values. At the same time, minimum GRF values varied from 76 ± 3% load for subject Y to 85 ± 2% load for subject W.

GRF maximum value analysis during locomotions at speeds suitable for both running and walking in Part 2 (1 G) and

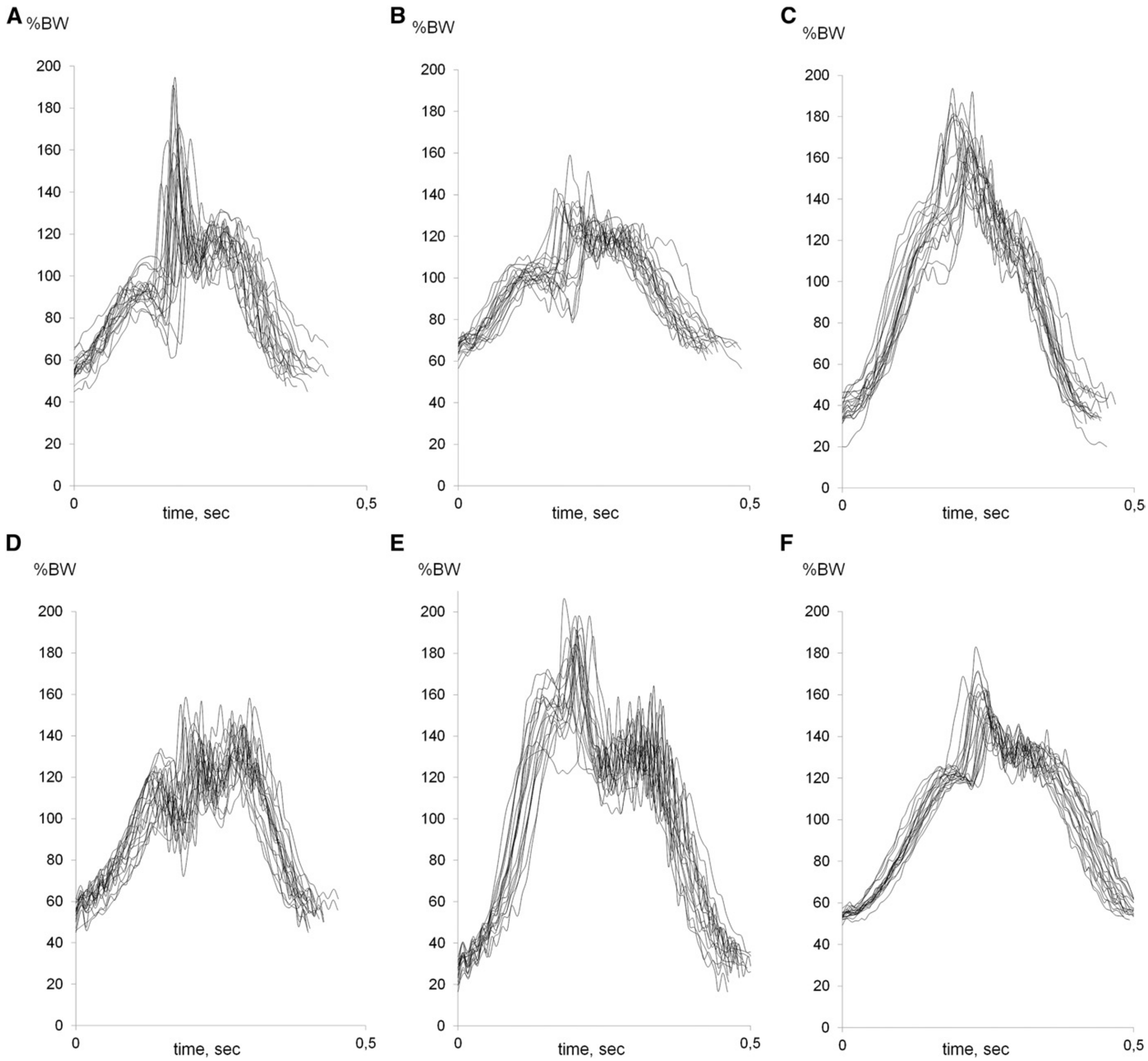

Fig. 2. The individual strategies of locomotion during walking in passive mode at 6 km/h in 1 G (superimposed GRF curves of 10 pairs of steps).

Part 3 (0 G) showed that for both 5 km/h and 6 km/h speeds the relative GRF value during running was larger than that while walking; this was shown for both active and passive modes under both 0-G and 1-G conditions ($P < 0.001$).

In addition to the maximum GRF value, the GRF profile was also dependent on the type of locomotion. During walking, there were few GRF peaks in each step. As we assume, these peaks may correspond to the heel and toe strikes. However, the limiting factor of our study was the absence of video analysis synchronized with the GRF registration. The GRF curves had a smooth shape during running with more distinct peaks corresponding to each step. This shape was found for both 1 G and 0 G. The vertical GRF amplitude during running was higher than during walking ($P < 0.001$) when performed in both 0 G and 1 G.

Under the condition of 1 G at 5 km/h, the maximum GRF during walking was lower than during running (**Fig. 3**); this difference was observed in both active ($P < 0.001$) and passive ($P < 0.001$) modes. At 6 km/h, significant differences between walking and running were also found for both active ($P < 0.001$) and passive ($P < 0.001$) modes. Thus, in 1 G at 5 km/h, the lowest GRF was observed for walking in active mode and the largest was found during running in active mode. At 6 km/h, the smallest GRF was observed for walking in passive mode and the highest during running in active mode.

A similar GRF analysis in weightlessness was conducted for one cosmonaut in Part 3. In 0 G, a more pronounced difference was observed between the maximum GRF for different types

Table I. The Comparison of Minimum and Maximum Ground Reaction Force Individual Values for Each Subject During Walking in Passive Mode at 6 km/h (1 G, % BW) and at 4 km/h (0 G, % Load) (Mean ± SD).

CONDITION & SUBJECTS	MINIMUM GRF	MAXIMUM GRF
1 G		
A	55 ± 5	158 ± 19
B	66 ± 4	134 ± 10
C	36 ± 6	171 ± 13
D	54 ± 5	146 ± 8
E	26 ± 5	186 ± 11
F	54 ± 2	159 ± 10
0 G		
X	84 ± 1	113 ± 3
Y	76 ± 3	113 ± 2
W	85 ± 2	114 ± 4
Z	80 ± 3	118 ± 5

and modes of locomotion (**Fig. 4**). Maximum GRF values at the speed of 5 km/h were recorded during running in passive mode; the value was 142 ± 6% load, which was higher than during running in active mode ($P < 0.001$) and during walking in active ($P < 0.001$) and passive ($P < 0.001$) modes. The lowest GRF was observed for walking in active mode.

At the speed of 6 km/h, similar differences between running in passive mode and other types and modes of locomotion were found ($P < 0.001$). Increasing the locomotion speed from 5 to 6 km/h led to a significant increase in the maximum vertical GRF during passive mode for both walking ($P = 0.020$) and running ($P = 0.001$); at 6 km/h the extent of the GRF difference during running in passive mode compared with other regimes was more pronounced.

DISCUSSION

We have shown that the GRF magnitude recorded under conditions of normal gravity and zero gravity depends on many factors. In particular, the maximum vertical GRF differs depending on the treadmill mode. In previous studies, conflicting data about the GRF magnitude in active and passive modes have been reported. Under the condition of simulated weightlessness on a vertical treadmill, the maximum GRF in active mode was higher than that in passive mode.[6] In parabolic flight, DeWitt et al. demonstrated that in passive mode GRF values were greater than those in active mode.[10] In another study, no differences between motorized and nonmotorized treadmills were shown in peak propulsive forces for condition of normal gravity.[23] In the present study, GRF values in active and passive modes during spaceflight were compared for the first time. It was shown that in 0 G, during running, the GRF was higher in passive mode than in active mode and, during walking, no differences were observed. In 1 G, differences between active and passive modes depended on individual features. These findings revealed the need to analyze individual locomotion features. It was shown that GRF profiles, and minimum and maximum GRF values, were specific for each subject. Individual profiles could be substantially different for active and passive BD-2 modes, as well as for running and walking.

Consequently, when choosing an optimal training program during spaceflight, it will be necessary to consider the specific features of cosmonauts. For example, to create the greatest support afferents during spaceflight, one cosmonaut could be recommended exercise in passive mode and another one in active mode.

We have also shown that the maximum vertical GRF during locomotion at the same speed significantly differed depending on the locomotion type. During running, the GRF was higher than during walking on both ISS and Earth. In our opinion, this difference was due to the force moment redistribution during contact

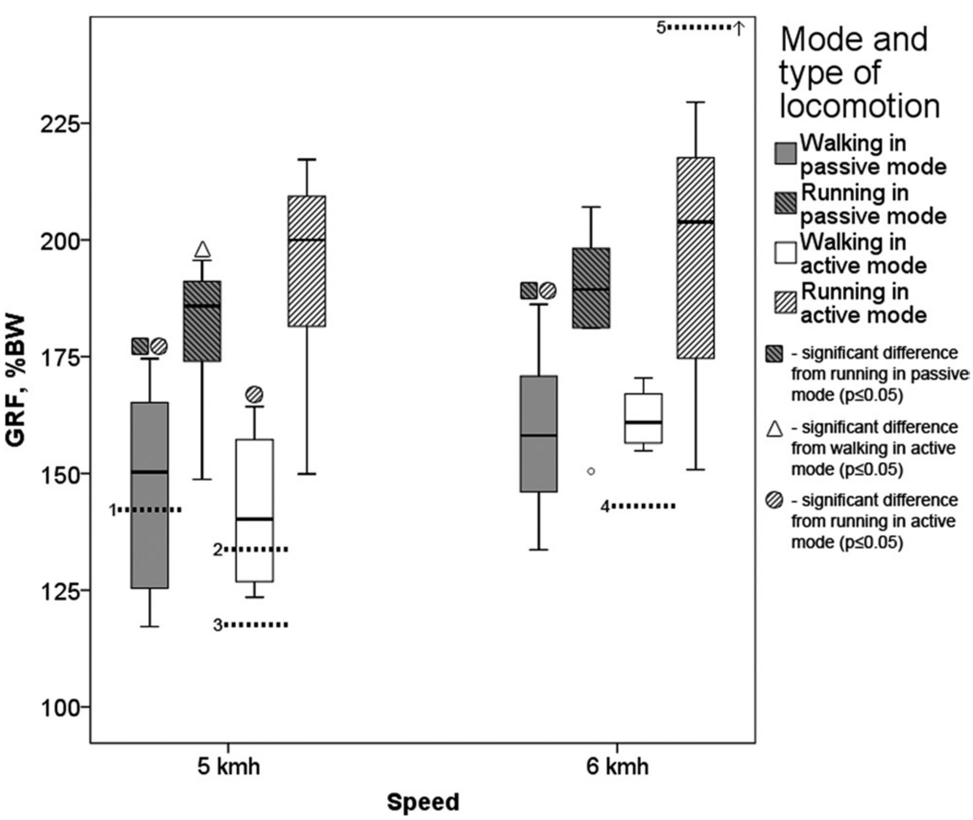

Fig. 3. The comparison of maximum ground reaction forces (% BW) during walking and running in active and passive modes in 1 G. Previously published data is indicated by the dashed line: 1) 145 ± 15% BW (DeWitt et al.[10]); 2) 137% BW, 120 steps/min (Bernstein[3]); 3) 118% BW (Cavanagh et al.[4]); 4) 144% BW, 130 steps/min (Bernstein[3]); 5) ~260% BW (McCrory et al.[25]).

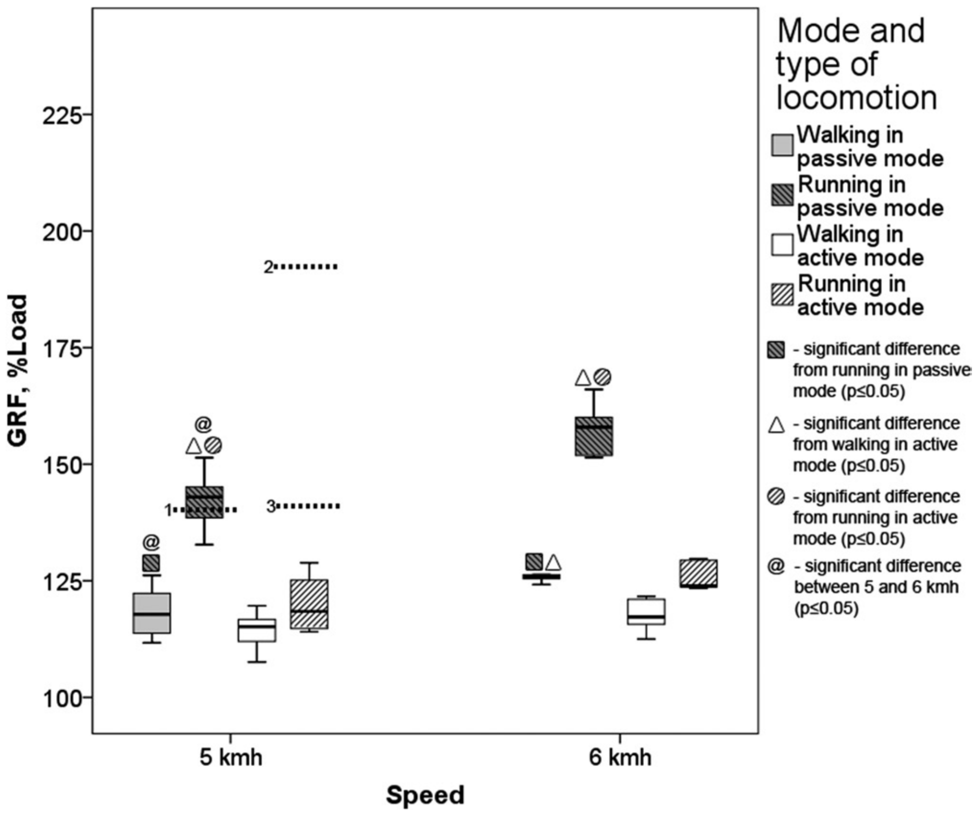

Fig. 4. The comparison of maximum ground reaction forces (% Load) during walking and running in active and passive modes in 0 G. Previously published data is indicated by the dashed line: 1) 144 ± 14% Load (DeWitt et al.[10]); 2) 191% Load (109% BW) (DeWitt et al.[8]); 3) 147% Load (130% BW) (DeWitt et al.[8]). All these studies were performed during parabolic flights.

between the foot and the treadmill. During walking, there were a few local peaks, whereas there was one clearly defined peak during running. Thus, countermeasure running efficiency could be higher in comparison with walking at the same speed.

We confirmed the hypothesis of this study that for different BD-2 modes and types of locomotion maximum GRF values would differ in both 1 G and 0 G. We also assumed that the GRF differed due to the use of the RSLS and VIS onboard the ISS. In our opinion, it influenced the locomotion biomechanics and the GRF magnitude.

One of the tasks of this study was to compare GRF values, which we registered on the BD-2, with previously published data. Maximum vertical GRF values that we recorded were close to values reported by other researchers (Fig. 3 and Fig. 4). For example, for walking in active mode in 1 G at speeds of 120 and 130 steps per minute, Bernstein reported that GRF values were 137% BW and 144% BW, respectively.[3] Barela et al. showed that, during walking at self-selected comfortable speeds, GRF peaks were 127 ± 13% BW.[1] Kulmala et al. found that for walking at 5.76 km/h, GRF values were equal to 124 ± 7% BW.[21] For walking in active mode, we recorded values of 142 ± 19% BW at the speed of 5 km/h and 162 ± 7% BW at 6 km/h. According to available sources, only one investigation has evaluated the GRF during walking in passive mode in 1 G, and it was 145 ± 15% BW at 5 km/h;[10] we measured 147 ± 25% BW for this type of locomotion.

For running at 6 km/h in active mode in 1 G, McCrory et al. reported that the GRF was close to 260% BW.[25] According to other authors, such GRF values when running in active mode at speeds exceeding 16 km/h were achieved.[3,9,26] Unfortunately, other data on the maximum vertical GRF magnitude during running at 5 and 6 km/h in 1 G were not found in the sources available to us. However, for 8 km/h, the GRF corresponds to 136 ± 17% BW, for 9.7 km/h: 144 ± 18% BW,[9] and for 10.8 km/h: 157 ± 35% BW.[26] In our study, during running in active mode in 1 G, the GRF was equal to 192 ± 27% BW for the speed of 5 km/h and 195 ± 32% BW for 6 km/h. The GRF during running in passive mode in 1 G was previously only recorded at 8 and 14 km/h; these values were equal to 187 ± 16% BW and 224 ± 10% BW, respectively.[10] We have shown that at 5 km/h, the GRF was 179 ± 19% BW, and for 6 km/h, 185 ± 21% BW.

It was previously published that on the ISS the GRF during walking in active mode was 89% BW at 5 km/h (EL value was not specified).[4] Impact forces are assessed in ground based simulations using the enhanced Zero Gravity Locomotion Simulator (eZLS), which suspends the subject in a horizontal position while walking or running on a vertically oriented treadmill. During walking in active mode on the eZLS at 4.82 km/h the peak impact GRF was 108 ± 8% BW (EL = 88% BW) and 95 ± 4% BW (EL = 57% BW). In a parabolic flight at the same speed and EL values, the peak impact GRF was 96 ± 10% BW and 76 ± 4% BW, respectively.[8] We obtained a value of 114 ± 4% load, which corresponds to 75 ± 3% BW for the EL of 60% BW. To date, there are no available data showing GRF values during walking in passive mode onboard the ISS. It has been shown that during walking in passive mode at 5 km/h in a parabolic flight, the GRF magnitude was equal to 144 ± 14% load (EL = 71 ± 9% BW).[10] In our study, during walking in passive mode in 0 G, the GRF value was equal to 115 ± 4% load at 4 km/h, 118 ± 5% load at 5 km/h, and 126 ± 9% load at 6 km/h. We assume that DeWitt found higher GRF values in his parabolic flight experiment since the treadmill was installed without VIS, whereas both we and Cavanagh used treadmills equipped with vibration isolation systems.

At speeds of 5 km/h and 6 km/h, the GRF value during running in active mode in 0 G has not been analyzed by other authors. However, DeWitt et al. reported that during running on the eZLS at 11.27 km/h in active mode, the peak impact GRF was equal to 173 ± 50% BW (EL = 88% BW) and 138 ± 44% BW (EL = 57% BW). In parabolic flight, the peak impact GRF was equal to 130 ± 26% BW and 109 ± 25% BW, respectively.[8] On the ISS during running in active mode on the T2 treadmill at 8 km/h, values of 78 ± 12% BW (EL = 50–59% BW) and 100 ± 11% BW (EL = 60–69% BW) were obtained.[9] In the present study, during running in active mode on the ISS, a value of 79 ± 4% BW was obtained at 5 km/h and 83 ± 2% BW at 6 km/h (EL = 60% BW). During running at 8 km/h, the GRF was equal to 93 ± 5% BW (EL = 60% BW). The GRF analysis during running in passive mode on the ISS has not been reported in the available sources. In a parabolic flight during running in passive mode, the GRF was equal to 184 ± 13% load at 8 km/h, and 230 ± 15% load at 14 km/h (EL = 70 ± 9% BW).[10] At the speed of 8 km/h for running in passive mode we obtained a value of 178 ± 9% load (107 ± 6% BW, EL = 60% BW).

Thus, for the most part, the data obtained in our study were similar to previously published results. The differences between these data could be explained by the BD-2 features in comparison with other treadmills. In our study, the BD-2 running surface dimensions were 1080 × 400 mm; BD-1 dimensions were 840 × 400 mm; TVIS: 1117.5 × 330 mm; and T2: 1200 × 400 mm. Perhaps different treadmills' length and width could lead to different locomotion strategies, such as changes in the step length.

For different treadmills on the ISS, VIS were also different. TVIS had an active VIS, but the BD-2 and the T2 have passive VIS. By systems' constructive design, VIS were completely different for the T2, the BD-2, and TVIS. While it appears that VIS affects GRF during weightlessness, there are not sufficient data yet to definitively draw these conclusions.

Passive mode comparison on each of the treadmills could also be influenced by the differences in the resistance to belt movement. The belt moving force was not more than 5.7 kg for TVIS, 3 kg for the T2, and 4 kg for the BD-2. This may also have influenced GRF analysis results on different treadmills during locomotion in passive mode.

However, in our study, comparative locomotion analysis performed in both 0 G and 1 G revealed differences in the GRF magnitude accompanying various types and modes of locomotion. In 0 G, the lowest GRF was found for walking while the largest was for running in passive mode. In 1 G, the GRF was higher while running than during walking; differences between active and passive modes were not found.

Preservation of individual strategies during locomotion was observed. The locomotion profile differed significantly for all subjects on both Earth and ISS. Therefore, we considered individual strategies of locomotion and maximum GRF values to be the basis for training process individualization in long-term spaceflight. Global regularity that we found to confirm our assumptions was a significant decrease in the vertical GRF onboard the ISS compared with Earth. In our opinion, the observed features were related to two factors: the EL creating approximately 60% BW using the RSLS and installing the treadmill on VIS.

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