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Effect of Repeated Space Flights on Ocular Tracking

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Abstract—This paper reports the results of studying the vestibular and ocular intersensory interactions and eye tracking function in 32 cosmonauts on maiden and repeated missions to the International Space Station. Mission duration ranged from 125 to 215 days. The cosmonauts were tested twice pre launch (baseline data collection) and on days R + 1/2, R + 4/5, and R + 8/9. Video oculography was used to test eye movements. It was found that in the majority of cosmonauts who had no experience of long-duration space missions the eye tracking function remained significantly impaired untill day R + 8/9. In cosmonauts who had already encountered microgravity, obvious changes in eye tracking were observed on day R + 1/2 only and, residual, on day R + 4/5. During post-flight recovery, a new eye tracking strategy was acquired only by cosmonauts who had the first experience of spaceflight microgravity.

Keywords: ocular tracking, smooth tracking, fixation saccades, gaze retention, intersensory interaction, microgravity

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Analysis and processing of the results of studying the vestibular and ocular intersensory interactions and eye tracking function in a pooled group of cosmonauts after long-duration spaceflights revealed several regular changes in ocular tracking [1–3]. However, the experiment Anketa [3] and the interviews of cosmonauts after flight showed that during repeated flights the adaptation and subsequent readaptation to Earth's conditions proceed much easier and faster. Therefore, it was necessary to obtain objective data characterizing the real state of the cosmonauts, in particular, evaluation of their ocular tracking. As the recent studies [4–6] show, the problems of space adaptation syndrome and space motion sickness and the problems of long-term exposure to microgravity on bodies of cosmonauts are still relevant, especially in connection with possible organic and functional visual and eye tracking disorders caused by increased intracranial pressure [7, 8].

This study was carried out using a set of computer simulation tests specially developed bin the Institute of Biomedical Problems of the Russian Academy of Sciences [1–3, 9] using high-precision videooculographic (VOG) equipment [10, 11].

METHODS

The research was carried out by employees of the Institute for Biomedical Problems of the Russian Academy of Sciences during the pre- and post-flight experiment Sensory Adaptation at the Gagarin Scientific Research Center for Cosmonaut Training. 32 Russian crew members of the ISS-8-32/33 missions were examined, who were in the long-duration spaceflight from 125 to 215 days with an average stay in microgravity of 175 days. The age of the cosmonauts ranged from 35 to 54 years, on average 45 years.

All the cosmonauts underwent a detailed medical examination (including an ophthalmologist and neurologist), had no clinical disturbances of the visual and vestibular systems, and did not take medications affecting the central nervous system (CNS) before the examination. The scientific and methodological note of the experiment was reviewed and approved by the Commission on Biomedical Ethics of the Institute of Biomedical Problems of the Russian Academy of Sciences and the Human Research Multilateral Review Board (HRMRB), also the cosmonauts themselves signed Informed consent to participate in the scientific experiment.

In the data processing, the cosmonauts were grouped as follows (Table 1): Group I consisted of 14 cosmonauts who were having their maiden mission and four cosmonauts who had spaceflight experience from 9 to 23 days. However, the interval between spaceflights for the latter was from 4 to 7 years (on average, 6 years); hence, it seemed permissible to

Table 1. Groups of surveyed cosmonauts

Group of cosmonauts	Number of individuals	Age range, years	Prior experience of being in microgravity, days	Interval between spaceflights, years	Spaceflight duration, days
General group	32	35–54 (~45)	0–624	2 – 8	125–215 (~175)
Group I	18	35–53 (~43)	–	–	125–199 (~176)
Group II	14	38–54 (~48)	129–624 (~342)	2–8 (~4)	125–215 (~175)

The average values of the corresponding ranges are given in parentheses.

combine them into one group, which was confirmed by the results of post-flight surveys.

Group II consisted of 14 cosmonauts who had a prior experience of long-duration spaceflights (all cosmonauts, except one, had a prior experience of being in microgravity for more than 190 days, and some for more than 600 days).

Cosmonauts were tested twice before the spaceflight during the period of 60–30 days (baseline) and on days R + 1/2, 4/5, and 8/9 and some cases also on days R + 13/14 (according to indications). The exact date of the post-flight examination (e.g., R + 1 or R + 2) was determined by the conditions of landing and the general state of health of the cosmonaut.

Investigations of tracking movements of cosmonauts' eyes were carried out using a set of computer stimulation programs specially developed by the employees of the Institute for Biomedical Problems of the Russian Academy of Sciences [1–3, 9], which included the following tests:

—smooth tracking (PS);

—fixation saccades (FS);

—gaze retention on a real and imaginary target (GR).

To record eye movements, the method of videooculography (VOG) was used: high-precision recording of eye movements with the possibility of isolating the torsion/rotator component.

Smooth tracking. Smooth tracking eye movements were studied while tracking the linear (with a constant speed of ~5.7°/s) and sinusoidal (with a frequency of 0.33 Hz) movement of the stimulus horizontally and vertically in the range of 20°. The number of iterations of each test ranged from 12 to 16 in each direction.

Fixation saccades. The ability of the eyes to fix and retain the stimulus in the field of view was studied, which included tests for static and dynamic saccades.

Static saccades are a series of quick, jerky movements of the stimulus in the horizontal and vertical directions in the range of 20°, where the stimulus was delayed in each position for 2 s. The number of presented stimuli (saccades) depended on the state of the cosmonaut and ranged from 12 to 16 in each direction.

Dynamic saccades are a series of quick movements of the stimulus (6–8 saccades) with its appearance at the edge of the screen (±10°), followed by a smooth linear movement (with a constant speed of ~ 5.7°/s) in a given direction (right, left, upward, down) in the range of 20° and a quick return to the starting position.

Gaze retention on a real and imaginary target. The stimulus in a random sequence jumped horizontally or vertically from the central position by ±10°, lingering in each position for 1 s. The cosmonaut followed the initial movement of the stimulus with the help of the saccade eye movement. After 1 s the stimulus disappeared. After the disappearance of the stimulus, the cosmonaut had to hold their gaze in an unchanged position on an imaginary target until the sound command appeared after 9 s. On the sound command, the gaze was returning to the center to the imaginary target and retained for 9 s in the center until a new visible stimulus appeared on the screen. During the test, two movements of the stimulus were carried out in each direction (right, left, up, down) in a random order.

Investigation of visual-induced oculomotor reactions was carried out with a stationary head fixed in an upright position with the help of a soft-fixing headholder (the so-called Shantz collar). The distance from the screen of the monitor to the middle of the bridge of the cosmonaut's nose (50 cm) was fixed by means of a tape wrapping around the back of the neck and fastened to the right and left sides of the monitor.

In the course of visual stimulation tests, the stimulus, which was a point target up to 1° in size, moved according to a given pattern on the monitor screen, and the cosmonaut was tasked to fix the gaze on the stimulus and track its movement across the screen.

All studies were carried out in a completely darkened room; the first tests were carried out after 2–3-min adaptation to darkness. The test for gaze retention on a real and imaginary target was carried out 10–12 min after the beginning of the examination. To prevent parasitic glow from the monitor screen and the trace of the moving stimulus, a special optical filter was attached to the monitor screen.

Registration of eye movements. To record eye movements, the videooculogram (VOG) method and a Chronos Vision ETD system (Chronos Vision, Germany) were used [10–12]. The cosmonaut was wearing a helmet equipped with infrared cameras with a recording frequency of 200–400 Hz.

To calibrate VOG horizontally and vertically, a so-called five-point calibration was used, a sequence of quick movements of the point target by ±10° to the right/left, up/down, and to the center. The final processing of VOG was carried out using the software ETD Iris Tracker with the accuracy of the useful signal isolation <0.05° [12].

In the treatment of oculomotor reactions, we estimated:

—the latent (T_{lat}) and total response time (T_{total}), the peak velocity (V_{FS}), and the efficiency coefficient of fixation saccades (ceFS): the ratio of the eye angle to the angle of stimulus displacement, the amplitude of corrective saccades, and the relative number of corrective saccades: the percentage ratio between the number of correction saccades and the number of basic saccades/iterations of the whole test;

—the amplification coefficient of smooth tracking eye movements (acST): averaged over the half-period, the ratio of instantaneous eye movements and visual stimuli;

—the gaze retention time, the amplitude and the relative number of corrective saccades, and the amplitude of deviation of the eyes while retaining the gaze on a real and imaginary target.

Statistical analysis of the study results was carried out using the MathWorks Matlab mathematical software. For each indicator, we estimated: median, expected value (M), standard deviation (σ), range of variation, and coefficient of variation (CV). In all cases of testing statistical hypotheses (normality of distributions, homogeneity (equality) of variances, reliability of differences, etc.), the significance level α was 0.05. The testing of hypotheses about the presence of statistically significant changes in the value of the indicators before and after the flight was carried out using both parametric and nonparametric methods of analysis of variance: the F test (ANOVA, repeated measurements) with multiple sample comparisons by the Tukey–Kramer and Newman–Keuls tests; the Friedman ANOVA test with pairwise sample comparisons by the Wilcoxon and Mann–Whitney tests with the Bonferroni correction.

The normality of the distributions was verified using the Lilliefors test, the homogeneity of variances using the Levene test, the presence (absence) of pair correlations between the investigated indicators using the Pearson's and Spearman's correlation tests.

RESULTS AND DISCUSSION

The data for the general group of cosmonauts were analyzed first. Despite the revealed statistically significant differences between the pre- and post-flight data of the general group [1–3], due to the high sample variability and the presence of statistically significant differences between the data of Groups I and II (the Mann–Whitney test), each group was analyzed separately with subsequent inter-group comparison.

A sufficient size of the samples of Groups I and II and a significantly smaller variance in comparison with the variance of the sample of the general group made it possible to reveal a number of significant post-flight changes in the studied indicators that were not found in the analysis of the general group. Analysis of intra-group differences (comparison of data for Groups I and II before and after flight) with their subsequent inter-group comparison made it possible to evaluate the effect of repeated spaceflights.

Smooth tracking. Analysis of the smooth tracking eye movements following the linear and sinusoidal movements of the stimulus horizontally and vertically revealed not only disturbances in the function of smooth tracking, but also disintegration of smooth tracking in 12 cosmonauts of Group I. The eye was unable to smoothly follow the stimulus movement and switched to a new tracking strategy, saccadic (the so-called strategy of saccade approximation). Gradual rather than smooth movement of the gaze (a set of microsaccades, Fig. 1) was recorded. The transition to a new tracking strategy led to a sharp two- to threefold) increase in the time of tracking eye responses. The phenomenon of smooth tracking disintegration and transition to saccade approximation was observed only among cosmonauts of Group I.

Quantitative analysis of smooth tracking was carried out using the amplification coefficient of smooth tracking (acST), the ratio of the eye velocity to the stimulus movement velocity (averaged over the iteration of the test, the ratio of instantaneous velocities of eye movements and the stimulus). Prior to the flight, the velocity of smooth tracking eye movements fully corresponded to the stimulus movement velocity, acST ~ 1.0.

The dynamics of post-flight changes in acST is presented in Table 2.

As can be seen from Table 2, Group I demonstrates worsening of the smooth tracking response (a significant decrease in acST compared to the baseline) throughout the entire post-flight period of examinations (for some cosmonauts, up to 13–14 days). In addition, each subsequent post-flight examination shows both a significant improvement (increase) in acST relative to the previous section (on days R + 4/5 compared to days R + 1/2, on days R + 8/9 compared to day R + 4/5) and a significant increase in smooth tracking stability (CV decrease). Despite the fact that on days R + 8/9 acST is close to the baseline values (a significant difference in comparison with the baseline is found only for linear smooth tracking in the vertical direction), the variability of acST (CV) remains high (three-to fourfold higher) compared to the baseline.

In Group II, a significant reduction in acST compared to the baseline is observed on days R + 1/2 and R + 4/5, in addition, on days R + 4/5 there is a signif-

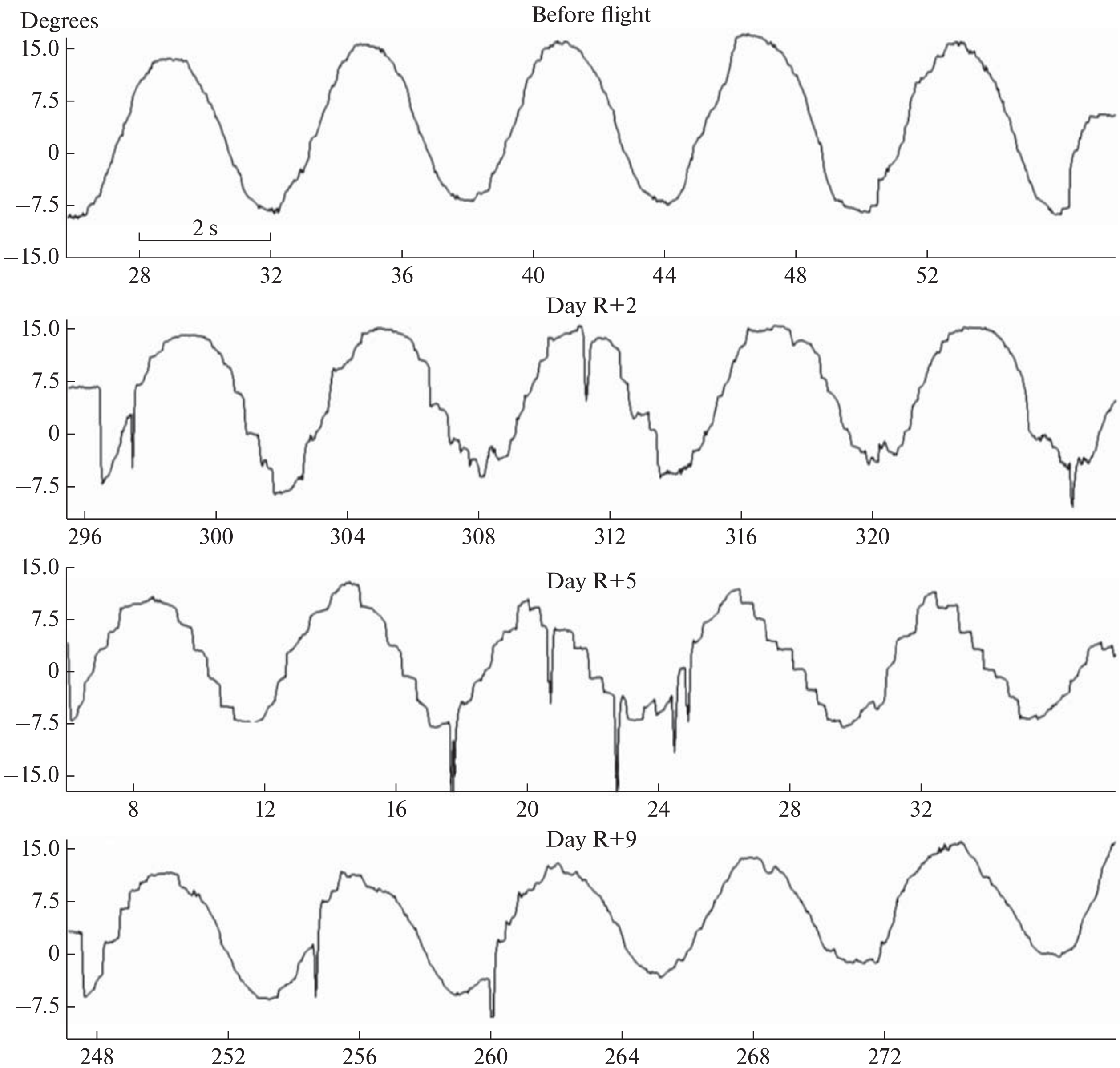

Fig. 1. Smooth tracking before and after spaceflight (VOG).

icant increase in acST in comparison to days R + 1/2. Although for all cosmonauts in Group II the acST almost returns to normal as early as days R + 8/9, a significant increase in variability (CV) and, thus, the instability of acST is preserved, as in the case of Group I, up to days R + 13/14.

A significant distinction between Groups I and II is that Group II lacks significant differences between baseline indices and data on days R + 8/9 and a 1.5–2 times lower variability of acST after flight.

It is also worth noting that no group revealed significant differences in the acST values when following linear (constant velocity) and pendulum (variable velocity) displacement of the stimulus.

Figure 2 presents the difference between acST in Groups I and II (ΔacST), which shows the distinction in the post-flight readaptation of smooth tracking in the absence and presence of spaceflight experience.

As can be seen from the figure, during the entire period of post-flight examinations, acST in Group II was on average ~15% higher than acST in Group I. The intergroup comparison of acST values (the Mann–Whitney test) showed the presence of significant differences between acST values in Groups I and II on days R + 1/2 and R + 4/5.

Fixation saccades. Fragments of native curves showing the nature of changes in horizontal and verti-

Table 2. acST before and after spaceflight

Test type	Baseline	Days R + 1/2	Days R + 4/5	Days R + 8/9
	$M \pm \sigma$ CV	$M \pm \sigma$ CV	$M \pm \sigma$ CV	$M \pm \sigma$ CV
Group I (no spaceflight experience, 18 cosmonauts)				
Horizontally, linear ST	1.02 ± 0.06 5.8%	0.61 ± 0.14 * ↓ 23.0% * ↑	0.74 ± 0.10 * ↑ 13.5% * ↓	0.89 ± 0.12 ↑ * 13.5% *
Horizontally, sinusoidal ST	0.98 ± 0.03 3.1%	0.63 ± 0.13 * ↓ 20.6% * ↑	0.79 ± 0.09 * ↑ 11.4% * ↓	0.92 ± 0.11 ↑ 12.0% *
Vertically, linear ST	1.01 ± 0.05 5.0%	0.57 ± 0.15 * ↓ 26.3% * ↑	0.72 ± 0.15 * ↑ 20.8% *	0.84 ± 0.13 * 15.5% *
Vertically, sinusoidal ST	0.98 ± 0.04 4.1%	0.60 ± 0.11 * ↓ 18.3% * ↑	0.78 ± 0.12 * ↑ 15.4% *	0.90 ± 0.12 ↑ 13.3% *
Group II (prior spaceflight experience, 14 cosmonauts)				
Horizontally, linear ST	1.0 ± 0.05 5.0%	0.75 ± 0.09 * ↓ 12.0% * ↑	0.85 ± 0.11 * ↑ 12.9% *	0.95 ± 0.13 13.7% *
Horizontally, sinusoidal ST	0.99 ± 0.04 4.0%	0.79 ± 0.07 * ↓ 8.9% * ↑	0.89 ± 0.08 ↑ 9.0% *	0.98 ± 0.08 8.2% *
Vertically, linear ST	0.97± 0.06 6.2%	0.72 ± 0.12 * ↓ 16.7% * ↑	0.83 ± 0.09 * ↑ 10.8% * ↓	0.93 ± 0.12 12.9% *
Vertically, sinusoidal ST	0.99 ± 0.06 6.1%	0.74 ± 0.11 * ↓ 14.9% * ↑	0.88 ± 0.10 * ↑ 11.4% *	0.95 ± 0.11 11.6% *

Here and in Tables 3 and 4: *, a statistically significant difference from the baseline, $p < 0.05$; ↑ or ↓, a statistically significant difference (increase or decrease) compared to the previous section, $p < 0.05$.

cal fixation saccades before and after prolonged exposure to microgravity are given in Fig. 3.

To analyze fixation saccades, a set of temporal, amplitude, and velocity indicators of saccades was used, the post-flight dynamics of which is presented in Table 3, which provides both horizontal (the first row) and vertical (the second row of the corresponding table cell) data.

As can be seen from the table, a significant increase in the latent response time (T_{lat}) was observed only for cosmonauts of Group I on day R + 1/2 for both horizontal and vertical fixation saccades. A significant decrease in the coefficient of variation (CV) on days R + 1/2 and 4/5 as compared to the baseline highlights the unidirectionality of changes (increase) of T_{lat} in Group I. Complete recovery of T_{lat} (no significant differences between values of the indicator and CV in comparison with the baseline) in Group I is observed on days R + 8/9.

Group II shows a slight increase in T_{lat} for days R + 1/2 and R + 4/5, but no significant differences were found compared to the baseline. Absence of statistically significant changes in the indicator itself (already within R + 1/2 the latent response time values lie within the baseline data), as well as the almost unchanged variability make it possible to assume the same response rate to the stimulus being presented.

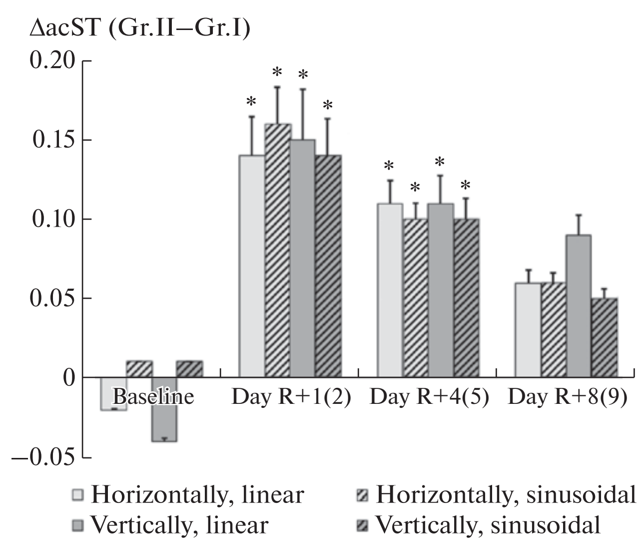

Fig. 2. Difference in acST (ΔacST) in Groups I and II before and after spaceflight; * significant difference between acST in Groups I and II, $p < 0.05$.

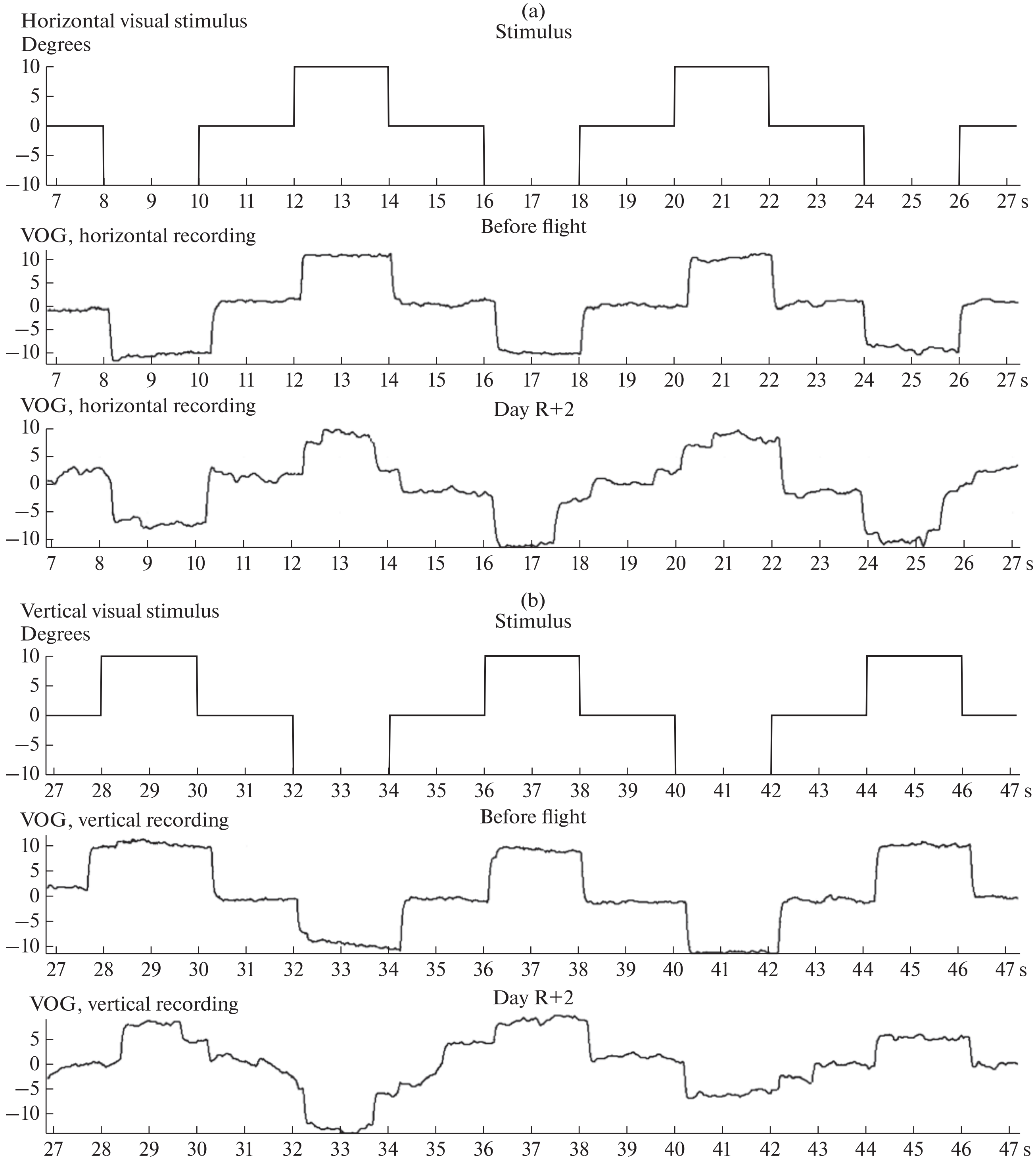

Fig. 3. Fixation saccades before and after spaceflight (VOG): (a) horizontally; (b) vertically.

The analysis of the total response time (T_{tot}) in Group I showed the presence of a statistically significant increase in the indicator up to days R + 13/14 when tracking horizontal saccades and up to R + 8/9 when tracking vertical ones.

In Group II, a significant increase in T_{tot} after the flight was observed only on days R + 1/2 and R + 4/5, while on days R + 8/9 the indicator returned to the pre-flight value. Despite the absence of changes in T_{tot} on days R + 8/9, a significant increase in variability

Table 3. FS indicators before and after spaceflight

Indicators of fixation saccades	Baseline	Days R + 1/2	Days R + 4/5	Days R + 8/9
	$M \pm \sigma$ (horiz.) $M \pm \sigma$ (vert.)	$M \pm \sigma$ (horiz.) $M \pm \sigma$ (vert.)	$M \pm \sigma$ (horiz.) $M \pm \sigma$ (vert.)	$M \pm \sigma$ (horiz.) $M \pm \sigma$ (vert.)
Group I (no spaceflight experience, 18 cosmonauts)				
Latent time (T_{lat}), s	0.27 ± 0.05 0.25 ± 0.07	0.33 ± 0.04 * 0.36 ± 0.06 * ↑	0.30 ± 0.04 0.31 ± 0.05	0.26 ± 0.05 0.29 ± 0.08
Total response time (T_{tot}), s	0.35 ± 0.06 0.30 ± 0.07	0.77 ± 0.16 * ↑ 0.81 ± 0.19 * ↑	0.57 ± 0.11 * ↓ 0.67 ± 0.11 *	0.48 ± 0.13 * 0.37 ± 0.13
ceFS	0.98 ± 0.03 0.96 ± 0.04	0.65 ± 0.10 * ↓ 0.59 ± 0.13 * ↓	0.79 ± 0.08 * ↑ 0.70 ± 0.14 *	0.92 ± 0.08 ↑ 0.91 ± 0.09 ↑
Peak velocity of saccades (V_{FS}), °/s	375.6 ± 20.1 363.5 ± 21.4	264.3 ± 72.5 * ↓ 252.3 ± 68.9 * ↓	308.7 ± 69.2 * 289.1 ± 94.5 *	334.3 ± 78.0 330.8 ± 76.3
Corrective saccades, %	3.9 ± 2.8 7.2 ± 2.8	22.4 ± 6.3 * ↑ 44.2 ± 7.1 * ↑	12.6 ± 4.8 *↓ 27.3 ± 5.1 * ↓	7.5 ± 3.9 * ↓ 12.0 ± 3.7 * ↓
Group II (prior spaceflight experience, 14 cosmonauts)				
Latent time (T_{lat}), s	0.26 ± 0.06 0.27 ± 0.06	0.31 ± 0.05 0.31 ± 0.08	0.30 ± 0.05 0.30 ± 0.06	0.27 ± 0.06 0.26 ± 0.05
Total response time (T_{tot}), s	0.36 ± 0.07 0.33 ± 0.08	0.52 ± 0.12 * ↑ 0.57 ± 0.14 * ↑	0.42 ± 0.13 * ↓ 0.51 ± 0.17 *	0.33 ± 0.10 ↓ 0.36 ± 0.11 ↓
ceFS	0.99 ± 0.04 1.02 ± 0.06	0.72 ± 0.08 * ↓ 0.64 ± 0.11 * ↓	0.88 ± 0.12 * ↑ 0.79 ± 0.08 * ↑	1.01 ± 0.07 ↑ 0.96 ± 0.08 ↑
Peak velocity of saccades (V_{FS}), °/s	364.8 ± 28.3 377.2 ± 34.6	292.0 ± 83.4 * ↓ 295.1 ± 70.9 * ↓	335.1 ± 76.2 * 343.6 ± 91.1 *	370.3 ± 81.1 352.6 ± 83.5
Corrective saccades, %	2.1 ± 4.2 3.2 ± 3.9	16.7 ± 9.3 * ↑ 27.5 ± 10.2 * ↑	8.7 ± 4.3 * ↓ 14.0 ± 9.3 * ↓	3.7 ± 5.1 ↓ 8.9 ± 6.2

(CV) and instability of the indicator were observed up to days R + 13/14.

When comparing Groups I and II, one can note the similarity in the post-flight dynamics of T_{tot}; however, while the cosmonauts of Group II, who had prior spaceflight experience, showed an increase in the total response time by a factor of 1.5, in cosmonauts of Group I, who had their maiden missions, it was increased by a factor of two to three.

The dynamics of the post-flight changes in acST (the ratio of the eye movement amplitude to the stimulus movement amplitude) and V_{FS} was similar in both the groups of cosmonauts for both horizontal and vertical fixation saccades: acST and V_{FS} statistically significantly decreased and their variability (CV) statistically significantly increased by days R + 1/2 and R + 4/5 compared with the baseline and returned to normal on days R + 8/9. In addition, during the post-flight readaptation, there was a statistically significant change in acST on every day of the examination compared with the previous section (days R + 1/2 compared to the baseline, days R + 4/5 compared to days R + 1/2, and days R + 8/9 compared to days R + 4/5).

The difference between Groups I and II consisted in a statistically significant increase in the acST variability on days R + 8/9 compared with the baseline in Group I, and a stable, statistically significantly not different from the baseline, coefficient of variation (CV) of acST in Group II.

A statistically significant increase in CV of acST and V_{FS} after flight indicates a scatter in the indicators, which is a consequence of both the large instability of these indicators and the individual characteristics of the cosmonauts during readaptation to Earth's conditions.

Analysis of fixation saccades on days R + 1/2, R + 4/5, and R + 8/9 revealed in most cosmonauts an increase in the percentage of additional corrective saccades (the whole group of cosmonauts was characterized by an increase compared to the baseline from 4 up to 19% when tracking horizontally and from 6 to 34% when tracking vertically).

In Group I, there was a significant increase in the percentage of corrective saccades compared to the baseline up to days R + 13/14, with significant changes every 24 h compared with the previous section.

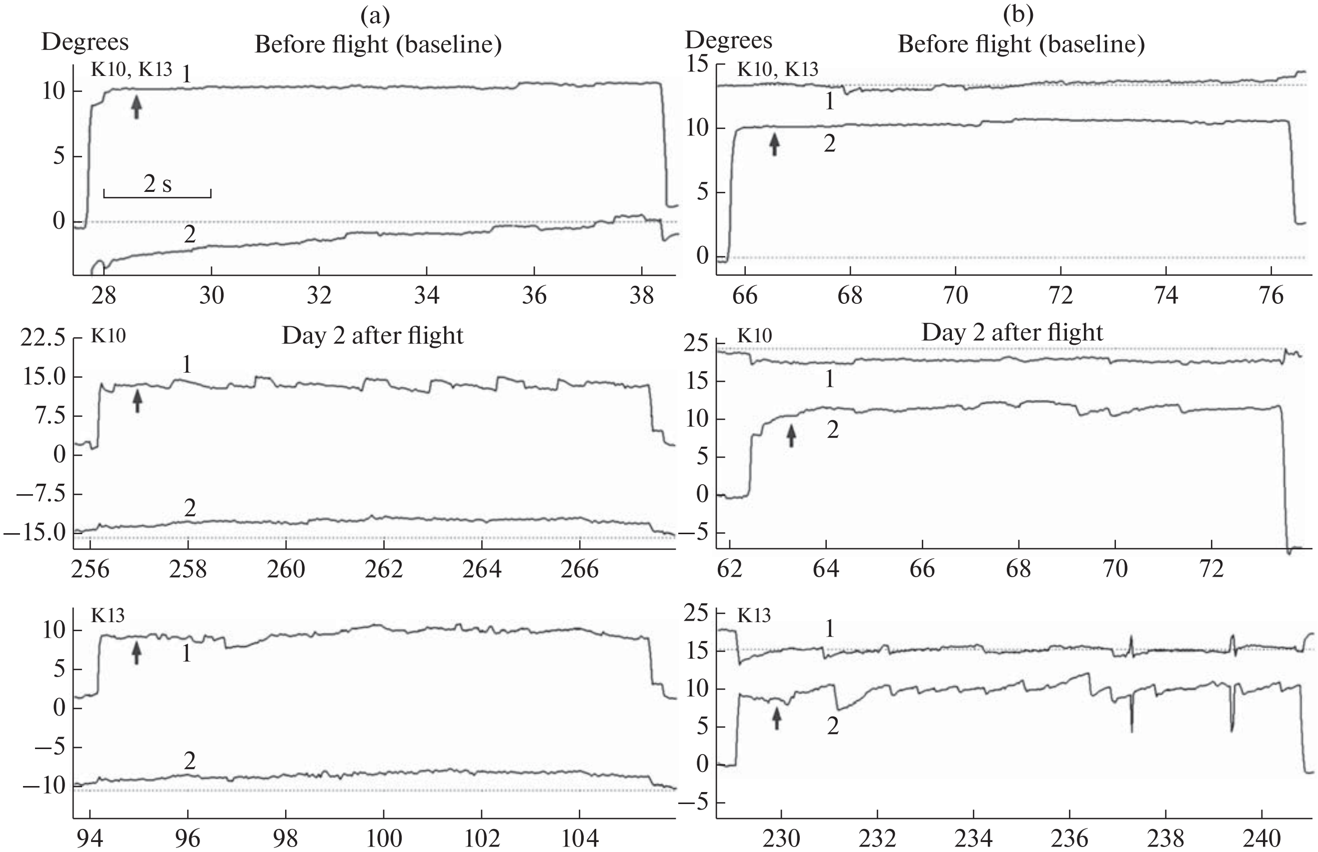

Fig. 4. Gaze retention before and after spaceflight: 1, horizontal VOG; 2, vertical VOG; ↑, disappearance of the stimulus.

In Group II, a significant increase in the percentage of corrective saccades after the flight was observed only on days R + 1/2 and R + 4/5.

The baseline value of CV of the percentage of corrective saccades, significantly exceeding the post-flight values, is due to intragroup differences in cosmonauts: while before flight 19 out of 32 cosmonauts lacked corrective saccades, and in the rest, their percentage was from 3 to 8%, on days R + 1/2 and R + 4/5 in all cosmonauts without exception when tracking horizontally the corrective saccades accounted for ~12–27% of the number of presented stimuli and ~24–52% when tracking vertically.

Gaze retention on a real and imaginary target. Figure 4 shows fragments of native curves of two cosmonauts at eccentric retention on a real and imaginary target before flight and on day R + 2. After flight, at the eccentric position of the gaze on an imaginary stimulus, gaze-evoked nystagmus was observed in seven cosmonauts.

The gaze retention test was carried out in 15 cosmonauts of Group I and 11 cosmonauts of Group II. The dynamics of the investigated gaze retention parameters before and after spaceflight is shown in Table 4, which provides data both horizontally (the first row) and vertically (the second row of the corresponding cell of the table).

As can be seen from the table, Group I shows a significant deterioration in the gaze retention indicators after flight and changes in their variability on days R + 1/2, R + 4/5, and R + 8/9. A significant decrease in the variability (CV) in the post-flight period is due to unidirectional changes in the gaze retention indicators: if the intra-group scatter of the indicators is high enough, then on days R + 1/2 and especially R + 4/5 almost all cosmonauts in Group I are characterized by a higher number of corrective saccades, weakening of the gaze retention response, and greater gaze deviation.

In Group II, significant changes in the gaze retention indicators as compared with the baseline both horizontally and vertically are observed on days R + 1/2 and R + 4/5. On days R + 8/9, the gaze retention indicators return to normal, however, as in the case of Group I, there is a sharp increase in the variability of the indicators (significant change in CV) up to R + 13/14.

Correlation analysis. In addition to the actual statistical analysis of the significance of differences in the values of the accuracy of ocular tracking before and

Table 4. GR indicators before and after spaceflight

Gaze retention indicators	Baseline	Days R + 1/2	Days R + 4/5	Days R + 8/9
	M ± σ (horiz.) *M* ± σ (vert.)	*M* ± σ (horiz.) *M* ± σ (vert.)	*M* ± σ (horiz.) *M* ± σ (vert.)	*M* ± σ (horiz.) *M* ± σ (vert.)
Group I (no spaceflight experience, 15 cosmonauts)				
Gaze retention time, s	5.1 ± 1.4 5.0 ± 1.3	2.2 ± 1.3 * ↓ 1.9 ± 0.9 * ↓	3.4 ± 0.7 * ↑ 2.7 ± 1.0 *	3.2 ± 1.0 * 3.5 ± 0.8 *
Corrective saccades, %	47.5 ± 24.1 51.2 ± 20.3	134.3 ± 46.8 * ↑ 168.5 ± 53.9 * ↑	85.7 ± 30.0 * ↓ 119.3 ± 42.8 * ↓	74.9 ± 41.3 87.6 ± 31.5 * ↓
Amplitude of corrective saccades, deg	1.5 ± 0.4 1.6 ± 0.5	3.1 ± 0.8 * ↑ 3.6 ± 1.0 * ↑	2.7 ± 0.7 * 3.0 ± 0.9 *	2.4 ± 0.9 * 2.1 ± 0.7 ↓
Amplitude of gaze deviation, deg	0.9 ± 0.3 1.2 ± 0.4	2.5 ± 0.6 * ↑ 2.9 ± 0.6 * ↑	1.7 ± 0.8 * ↓ 2.1 ± 0.8 * ↓	0.9 ± 0.5 ↓ 1.0 ± 0.7 ↓
Group II (prior spaceflight experience, 11 cosmonauts)				
Gaze retention time, s	5.3 ± 1.1 4.9 ± 0.9	2.7 ± 1.4 * ↓ 2.2 ± 1.3 * ↓	4.2 ± 1.2 * ↑ 3.5 ± 0.8 * ↑	4.9 ± 0.8 5.6 ± 1.1
Corrective saccades, %	30.0 ± 17.5 40.3 ± 27.9	120.1 ± 53.4 * ↑ 135.0 ± 62.6 * ↑	54.4 ± 41.2 * ↓ 89.6 ± 35.3 * ↓	42.5 ± 28.0 34.3 ± 25.0
Amplitude of corrective saccades, deg	1.3 ± 0.5 1.4 ± 0.6	3.5 ± 1.0 * ↑ 3.7 ± 0.9 * ↑	2.1 ± 0.9 * 2.5 ± 0.8 *	1.7 ± 1.2 1.6 ± 0.9 ↓
Amplitude of gaze deviation, deg	1.0 ± 0.3 1.4 ± 0.4	2.4 ± 0.8 * ↑ 2.5 ± 1.0 * ↑	2.1 ± 1.0 * 1.9 ± 0.9	1.2 ± 0.5 ↓ 1.5 ± 0.7

after flight, a correlation analysis was also carried out using Pearson's test to identify the presence or absence of direct (linear) connections between the readaption changes in the eye tracking function (FS, ST, GR) and the state of individual levels of the vestibular system [1–3].

It should be noted that the nature of the correlation between the parameters of the vestibular and ocular tracking functions during the readaptation was changing. While on days R + 1/2 after flight there was a positive correlation between the parameters of the otolith reflex and the smooth tracking function ($r = 0.4$) in both groups of cosmonauts, on days R + 4/5 only Group I was characterized by a sharp rearrangement of the correlation connections between the amplitude of the otolitho-cervical-ocular reflex (OCOR) and all indicators of ocular tracking: a change in the sign of the correlation coefficient and a decrease in its value to $r = -0.4 \ldots -0.3$ were observed. On days R + 8/9, the correlation associations in both groups were again reconstructed with the predominance of values characteristic for days R + 1/2.

The correlation coefficient between the indicators of fixations saccades (the peak velocity and the percentage of corrective saccades) and spontaneous eye movements (SEMs) in Group II almost did not differ from zero throughout the entire post-flight period of examinations. As for Group I, on days R + 1/2 the correlation coefficient was $r = -0.6 \ldots -0.5$, on days R + 4/5 it increased to $r = -0.1 \ldots -0.2$ (in the case of the peak FS velocity up to $r \sim 0.1$) with return to the initial values of –0.6...–0.5 on days R + 8/9.

In addition, disturbances in the eye tracking function were observed in those cosmonauts of Group I who, along with a decrease in tonic (static) vestibular excitability (OCOR indicators), also had central changes in the vestibular system and the nature of its interaction with other CNS systems (SEM indicators).

Significant improvement in the eye tracking function indicators and a reduction in the time of their post-flight recovery in cosmonauts who have prior spaceflight experience can apparently be explained as follows.

In the maiden mission under microgravity conditions, the integrative structures of the central nervous system of cosmonauts undergo a disruption of the earth's gravitational "nervous model of sensory stimuli" formed during phylogenesis and the formation of a new agravitational "nervous stimulus model" that works throughout the flight, providing adequate behavior under microgravity conditions. A new representation of unusual sensory information is deposited to long-term memory in the hippocampus. As is known [13], the hippocampus performs the function of storing short-term memory and its subsequent transfer to long-term memory. The formation of a new nervous model of sensory information in the short-term memory of the hippocampus and its continued presence in long-term memory provide faster adaptation/re-adaptation of cosmonauts to the altered sensory environment. Thus, the ability of the hippocampus to memorize and code the surrounding space and become active, whenever it is necessary to adjust to the conditions of the external environment, enables the body to quickly formulate a behavior strategy.

CONCLUSIONS

(1) The majority of cosmonauts who have their maiden long-duration spaceflight missions (Group I), are characterized by:

—significant deterioration of the ocular tracking indicators (reduction in amplitudes and velocities of fixation saccades and smooth tracking, an increase in latent and general response times) throughout the entire post-flight period of surveys with a partial return to baseline indicators on days R + 8/9;

—disturbances of the eye tracking function were observed in those cosmonauts of Group I who, along with a decrease in tonic (static) vestibular excitability (otolith reflex indicators), also had central changes in the vestibular system and in the nature of its interaction with other CNS systems (spontaneous eye movement indicators).

(2) In cosmonauts who had a prior experience of being in microgravity conditions (Group II), significant changes in the parameters of ocular tracking were observed on days R + 1/2 and, partially, on days R + 4/5 with a return to the baseline values on days R + 8/9.

(3) Comparison of Groups I and II has shown that:

—despite the similarity of the character of post-flight readaptation in both the groups, the post-flight impairment of ocular tracking in Group II is less pronounced;

—both groups after flight showed a statistically significant increase in the variability (coefficient of variation, CV) of the studied indicators, which implies a scatter in the indicators and is a consequence of both the large instability of these indicators and the individual characteristics of cosmonauts in terms of readaptation to Earth's conditions;

—during readaptation to Earth's conditions, a new strategy of ocular tracking develops (tracking of the target movement is accompanied by a set of saccadic movements), which is characteristic only of cosmonauts who had their maiden missions (Group I).

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