

Mortality Among Soviet and Russian Cosmonauts: 1960–2013

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REYNOLDS RJ, DAY SM, NURGALIEVA ZZ. *Mortality among Soviet and Russian cosmonauts: 1960–2013*. *Aviat Space Environ Med* 2014; 85:750–4.

Introduction: Though the mortality of U.S. astronauts has been studied repeatedly in the last 20 yr, little is known about the long-term mortality trends of Soviet and Russian cosmonauts. **Methods:** Using data from 266 cosmonauts accepted into cosmonaut training from 1960 to 2013, we document the causes of death and crude death rates among cosmonauts. Using standardized mortality ratios (SMR), we compared cosmonauts to the general populations of Russia and Ukraine, and to 330 U.S. astronauts. **Results:** Cosmonauts experienced significantly lower all-cause mortality risk compared to the general population. However, cosmonauts were at almost double the risk of all-cause mortality in comparison to U.S. astronauts (SMR = 190, 95% C.I. 154–239). Cosmonauts were also at greater risk of circulatory disease (SMR = 364, 95% C.I. 225–557) and cancer (SMR = 177, 95% C.I. 108–274) compared to U.S. astronauts. Though not statistically significant, cosmonauts experienced fewer fatal accidents (SMR = 88, 95% C.I. = 54–136) than their U.S. counterparts. **Discussion:** Cosmonauts are at much lower risk of all-cause mortality than the general populations of Russia and Ukraine, yet are at greater risk for death by cardiovascular disease and cancer than are U.S. astronauts. This disparity may have common roots with decreases in life expectancy in Russia in recent decades. Further research is needed to understand these trends fully.

Keywords: astronauts, death.

BIOMEDICAL RESEARCH into the effects of space travel on human health has mainly focused on acute physiological outcomes. While this effort has been instrumental in understanding the effects of extended stays in low Earth orbit, longitudinal epidemiological studies are needed to understand the full implications of these exposures, particularly the extent to which, if any, they modify mortality rates and life expectancy. Though we are not aware of any published studies of cosmonaut mortality, the mortality of U.S. astronauts has been studied extensively since the early 1990s. A consistent finding of these studies is that astronauts are at substantially reduced risk of chronic diseases in comparison to the U.S. general population (6,7). The first analysis of astronaut mortality had follow-up through September 1991 and estimated U.S. astronauts to be at less than half the risk of dying of cancer as the general population (6). That study also hinted that astronauts may be at reduced risk of death from all circulatory diseases and ischemic heart diseases. A more recent analysis confirmed these findings (7).

When compared to matched controls from Johnson Space Center in Houston, TX, comparisons were less favorable. In two separate analyses astronauts were

estimated to have more than threefold risk of cancer mortality when compared to the control group (2,3). Another consistent finding is the excess risk due to external causes for U.S. astronauts (primarily vehicular accidents, including spacecraft). All mortality studies to date have found statistically significant increases in the risk of fatal accidents with estimates of relative risk ranging from 10 to 23 depending on the comparison population (3,6,7). However, the most recent analysis (7) demonstrated that by 2009 the standardized mortality ratios (SMR) had declined by almost half compared to those of the 1980s.

The Soviet Union selected its first group of cosmonauts in 1960 and, after the dissolution of the Soviet Union in 1991, the Soviet space program continued under the newly formed Russian space agency, Roscosmos. Russia is now a major partner in the International Space Station and continues to be active in space exploration. With this rich heritage and extensive experience in space, the cosmonaut dataset may provide further insight into the mortality of space explorers.

Because of the similarity of cosmonaut selection criteria and training to that of U.S. astronauts (1), we hypothesized a similar pattern of mortality in the cosmonaut population. In particular, we hypothesized that compared to the Russian/Soviet general populations, cosmonauts would have lower chronic disease mortality rates, higher rates of fatal accidents, and, due to the high rates of fatal accidents, higher all-causes mortality rates. We further hypothesized that all-cause mortality did not differ between U.S. astronauts and cosmonauts, but that Soviet-era cosmonauts were at higher risk of fatal accidents while those in the Roscosmos era are not. We tested these hypotheses using vital data on Soviet and Roscosmos cosmonauts trained and followed between 1960 and 2013.

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This manuscript was received for review in January 2014. It was accepted for publication in March 2014.

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DOI: 10.3357/ASEM.3957.2014

METHODS

Study Population

Members of the Soviet and Russian Cosmonaut Corps were identified from the listings on the Spacefacts website, which offers detailed information about manned spaceflight, including biographies of astronauts and cosmonauts (12). The study population incorporates all cosmonauts trained by the Soviet Space Agency between 1960 and 1991, as well as all cosmonauts trained by Roscosmos starting in 1992, ending with the TsPK-16 group in 2012. Unlike the U.S. Astronaut Corps, where the National Aeronautics and Space Administration (NASA) selects and trains all candidates, cosmonaut candidates during the Soviet era were selected by several competing design bureaus. The sudden death of Sergey Korolyov, Chief Designer of Rocket-Space Systems, resulted in numerous individuals being selected as cosmonaut candidates who never trained as cosmonauts. Thus we chose to include only those candidates who began cosmonaut training with the space agency and to exclude those candidates who were selected but failed to train. Also excluded were civilian space tourists, movie actors, and journalists, all of whom were trained for single flights only. In accordance with federal regulations concerning the protection of human subjects in research, this study was exempt from institutional review, as the authors made no contact with the cosmonauts under study and the data used in this research are freely distributed public information.

Reference Populations

To calculate SMR comparing cosmonauts to the general population, we used the mortality rates for the Russian and the Ukrainian general populations between 1960 and 2009. We used Russian rates wherever country-specific rates were unavailable, such as for countries formerly under Soviet control and former Soviet Socialist Republics. Mortality rates were in a 5×10 format, meaning the rates applied to 5-yr age groups in 10-yr time periods. U.S. astronaut mortality rates for specific causes between 1960 and 2013 were taken from a database constructed for a previous study (7) and updated for the current study.

Vital Statistics

Vital statistics for the Cosmonaut Corps were taken from biographical sketches available on the Spacefacts website (12) and from NASA's Johnson Space Center website (10). NASA maintains biographical sketches for cosmonauts who have flown on the International Space Station and/or various Space Shuttle missions; we used these sketches to verify biographical details obtained from Spacefacts. We gathered date of birth, date of selection into the Corps, gender, nationality, and cause of death for those who died. In case of a conflict between the two sources, NASA data prevailed.

We found 27 cosmonauts who died, but for whom no cause of death was reported in either source. We therefore

performed a supplemental internet search in an attempt to locate obituaries or news reports related to the deaths of these cosmonauts. After searching both English and Russian websites we located 9 additional causes, leaving 18 as unknown. The observation period for each cosmonaut was the time from the start of Cosmonaut Corps training until either death or December 31, 2013, whichever came first. As in previous studies of U.S. astronauts (6,7), the start date was taken as the 15th day of the month and year in which the selection class was announced, as precise start dates were not reported in some cases.

All-cause mortality rates for the Russian and Ukrainian reference populations were ascertained from the Human Mortality Database (HMD) (11). As rates in the HMD were only available through 2009, we used the 2000-2009 rates for the years 2010-2013. Since this assumes neither an increase nor a decrease in the age-specific rates after 2009, we consider this to potentially bias cosmonaut-general population SMR upward, if anything, owing to the recent "Russian mortality crisis" wherein mortality rates have continued to climb and life expectancy has continued to fall for adults in Russia (9,11,13).

For cause-specific mortality comparisons, rates among U.S. astronauts from 1960 to 2013, through and including Astronaut Group 20 in 2009, were used as reference for comparison with corresponding cosmonaut rates. Cause-specific U.S. rates for categories of age, gender, and period were obtained by dividing the number of deaths due to a specific cause in each category by the number of person-years lived in the category (5). The database included 330 U.S. astronauts who contributed 8488 person-years and 48 deaths through the end of 2013.

Proportional mortality ratios (PMR) provide a measure of the percentage of the total deaths in a cohort that were due to particular causes (5). PMR are calculated as the number of deaths from specific causes divided by the number of deaths from all causes, multiplied by 100. Crude mortality rates provide a basic measure of risk in a population, unadjusted for age. Crude rates were calculated by dividing the number of deaths from particular causes by the amount of time at risk in the cohort (8).

SMR were determined by the indirect method of standardization. In brief, the steps were the following:

1. Observed numbers of deaths for the Cosmonaut Corps were determined separately for men and women within 5-yr age groups and within each decade or partial decade from 1960 to 2013.
2. Total person-years lived within each age group and decade were determined based on the cosmonaut's date of entry into the corps and the end of follow-up, either a cosmonaut's date of death or the end of the study period (December 31, 2013). Total person-years lived were then summed across cosmonauts within each sex, age group, and decade.
3. General population mortality rates for the reference populations were determined for each gender, 5-yr age group, and decade from the HMD or the U.S. astronaut database.

4. Expected numbers of deaths for each gender, age, and decade were determined by multiplying the mortality rates determined in step 3 by the person-years determined in step 2. The results were then summed by decade without regard to age or gender.
5. SMR were determined by dividing the observed numbers of deaths (step 1) by the corresponding expected numbers (step 4).
6. Confidence intervals for the SMR were determined based on the assumption that the observed numbers of deaths follow a Poisson distribution (8).

Data processing and statistical analyses were performed using R statistical software and Microsoft Excel 2007.

RESULTS

The cosmonaut dataset included 266 individuals who contributed 83 deaths and 7612.2 person-years of observation time between March 15, 1960, and December 31, 2013. The average age at selection was 31.3 yr (SD = 5.4 yr), with a mean follow-up time of 28.6 yr (range = 0.9 to 53.8 yr). The average age at death was 59.3 yr (SD = 13.8 yr), while the average age of survivors at the end of the study was 60.2 yr (SD = 14.6 yr). The person-years in the cosmonaut cohort were 73% Russian and 14% Ukrainian. The remaining 13% of the person-years were contributed by cosmonauts from 16 other nations. Female cosmonauts contributed 618 of the 7612 person-years (8%).

Table I provides a list of the causes of death among cosmonauts and the counts, PMR, and crude mortality rate for each. The table stratifies these data by period: 1960-1989 (the Soviet era), 1990-2013 (post-Soviet/Roscosmos era), and the entire study period, 1960-2013. Of the known causes of death among cosmonauts, circulatory diseases (primarily heart attack and stroke) have claimed the most lives (21 deaths), followed closely by accidental deaths and cancers (20 deaths each). There were 18 deaths due to unknown causes, all of which were in the Roscosmos era. Of those, eight were listed simply as “natural causes” meaning they were due to illness rather than external causes such as accidents or injuries. The PMR for circulatory diseases was 25.3 and

24.1 for each of accidents and cancers, meaning that those three causes together accounted for almost three-quarters of all cosmonaut deaths. About a fifth of the deaths were due to unknown causes.

Some of the PMR and crude rates in Table I display marked differences by period. For example, the PMR for fatal accidents in the Soviet era was 70.6 and the crude rate was 3.81 per 1000 person-years, while the PMR and crude rate were 12.1 and 1.79 per 1000 person-years, respectively, in the Roscosmos era. The rate of death by circulatory disease and cancer reversed this trend: both of those rates climbed from under 1 death per 1000 person-years in the early period to about 4 deaths per 1000 person-years in the late period. However, the PMR for cancer climbed only 8% between the two periods, whereas the PMR for circulatory diseases jumped from 6 to 30%.

Table II presents the SMR and 95% confidence intervals for all causes of death combined. An SMR of 100 indicates equal mortality rates for cosmonauts compared to the respective comparison population. SMR greater than 100 indicate increased risk of death for cosmonauts; SMR less than 100 indicate reduced risk. SMR in Table II are displayed separately for the Soviet era, the Roscosmos era, and both combined. Cosmonaut/general population SMR are also presented separately for Russians, Ukrainians, other nationalities, and for all cosmonauts together. Two SMR are provided for the combined cohort, comparing cosmonauts to the Russian/Ukrainian general population and to U.S. astronauts, respectively.

All SMR comparing cosmonauts to general populations were statistically significant (95% confidence intervals excluding 100). Point estimates of the cosmonaut-general population SMR were quite low for both nations and all periods, and did not differ greatly between nations or over time. Estimated SMR ranged from a low of 10 to a high of 18, with a study total SMR of 11 for all cosmonauts combined. Though the differences were small, the SMR within nations were always higher in the Soviet era than in the Roscosmos era. Across eras

TABLE I. DISTRIBUTION OF DEATHS AND BASIC MEASURES OF MORTALITY, 1960-2013.

Cause	1960-1989			1990-2013			1960-2013		
	3146.9 Person-Years			4465.3 Person-Years			7612.2 Person-Years		
	Count	PMR*	Rate†	Count	PMR*	Rate†	Count	PMR*	Rate†
All Causes	17	100.0	5.40	66	100.0	14.78	83	100.0	10.90
All Accidents	12	70.6	3.81	8	12.1	1.79	20	24.1	2.63
Airplane Crashes	5	29.4	1.59	2	3.0	0.45	7	8.4	0.92
Spacecraft Accidents	4	23.5	1.27	0	0.0	0.00	4	4.8	0.53
All Other Accidents	3	17.6	0.95	6	9.1	1.34	9	10.8	1.18
Cancer	3	17.6	0.95	17	25.8	3.81	20	24.1	2.63
Circulatory	1	5.9	0.32	20	30.3	4.48	21	25.3	2.76
Other Natural	1	5.9	0.32	3	4.5	0.67	4	4.8	0.53
Unknown Causes	0	0.0	0.00	18	27.3	4.03	18	21.7	2.36
Unknown Natural	0	0.0	0.00	8	12.1	1.79	8	9.6	1.05

*Proportional mortality ratio.

†Crude death rate, expressed as deaths per 1000 person-years.

TABLE II. STANDARDIZED MORTALITY RATIOS (SMR), ALL CAUSES OF DEATH, 1960-2013.

Cosmonaut Group	Comparison Population	1960-1989	1990-2013	1960-2013
		SMR (95% CI)	SMR (95% CI)	SMR (95% CI)
Russians only	Russia	13 (6-22)	10 (7-14)	11 (8-14)
Ukrainians only	Ukraine	18 (4-51)	13 (7-24)	14 (8-24)
All other nations	Russia	15 (2-53)	11 (5-20)	11 (6-20)
All cosmonauts	Russia/Ukraine*	13 (8-22)	11 (8-14)	11 (9-14)
All cosmonauts	U.S. astronauts	82 (48-131)	292 (229-377)	190 (154-239)

* Ukrainian cosmonauts matched to the Ukrainian general population, all others matched to the Russian general population.

the SMR for Russian cosmonauts were the lowest while SMR for Ukrainian cosmonauts were the highest. The SMR comparing cosmonauts to U.S. astronauts for all causes of death was 82 in the Soviet era, suggesting a small advantage for cosmonauts, though it was not significant. However, in the Roscosmos era the SMR was 292, and for the entire period it was 190, both of which reached statistical significance.

Table III presents cause-specific comparisons with U.S. astronauts. In the Soviet era there were reductions in cosmonaut mortality risk due to plane crashes, spacecraft accidents, and all accidents combined. In the Roscosmos era there was essentially no difference in the rates of plane crashes, the overall risk for accidental death was slightly increased for cosmonauts, and there were no deaths from spacecraft accidents for cosmonauts. However, in no era were the SMR for any accidental deaths statistically significant. Though there were no significant differences in the rate of death from cancers in the two subperiods, the SMR for cancer was significantly elevated overall. Rates of circulatory disease, though not significantly elevated in the Soviet era, were significantly greater than those for U.S. astronauts in the Roscosmos period and the study period overall.

TABLE III. STANDARDIZED MORTALITY RATIOS (SMR), SPECIFIC CAUSES OF DEATH, 1960-2013.

Cause of Death and Period	SMR* (95% CI)
All Accidents	
1960-1989	74 (38-130)
1990-2013	120 (52-237)
1960-2013	88 (54-136)
Plane Crashes	
1960-1989	72 (23-168)
1990-2013	97 (12-351)
1960-2013	78 (31-160)
Spacecraft Accidents	
1960-1989	47 (13-122)
1990-2013	0 (0-215)
1960-2013	39 (11-101)
Cancer	
1960-1989	293 (60-855)
1990-2013	166 (97-265)
1960-2013	177 (108-274)
Circulatory Disease	
1960-1989	120 (3-671)
1990-2013	405 (247-626)
1960-2013	364 (225-557)

* Comparison population: U.S. astronauts.

DISCUSSION

Cosmonaut deaths have been largely due to chronic diseases such as heart disease, stroke, and cancer. This has been especially true since 1990 when the oldest of the cosmonauts moved into their sixth decade of life. External causes (aviation, spacecraft, and training accidents) have played a secondary role, being responsible for about a quarter of the deaths.

The SMR in Table II make clear the mortality benefits of being a cosmonaut, at least in comparison to the general populations of Russia and Ukraine. It is hardly surprising that cosmonauts—who are selected for and maintain high levels of health and physical fitness and are under constant medical supervision while on active duty (1)—should have lower mortality than the general population, particularly given the Russian mortality crisis after the dissolution of the Soviet Union (9,13). It is remarkable that the all-cause SMR comparing cosmonauts to the general populations of Russia and Ukraine are below 100 even with 20 accidental deaths to cosmonauts. This is in direct contrast to the mortality experience of U.S. astronauts, where, until recently, high numbers of deaths by external causes resulted in elevated all-cause SMR (7). These low cosmonaut SMR are testament to the magnitude of risk reduction for other causes of death that cosmonauts enjoy.

Primary among the cause-specific, cosmonaut/astro-naut SMR findings was the fact that cosmonauts were equally likely to suffer an accidental death as were NASA astronauts. This is true even though fewer cosmonauts than astronauts have been killed in spacecraft accidents (4 cosmonauts vs. 14 astronauts). Instead, training accidents, plane crashes, and other accidents have kept the accidental death mortality rate for the two groups roughly equal.

In no subperiod were the cosmonaut/astro-naut SMR for cancers statistically significant, though point estimates were consistently elevated, ranging from 166 to 293. Over all periods combined, cosmonauts were at significantly greater risk of cancer mortality than U.S. astronauts. It is possible that the risk of cancer mortality may be greater among cosmonauts owing to more long-duration mission experience in low Earth orbit—particularly in the comparatively high-radiation orbits of the Salyut, Mir, and International Space Station. If true, this implies a greater incidence rate of cancers for cosmonauts. Differences in the timely diagnosis and treatment of tumors in countries outside the United States could also yield

higher mortality rates for cancer, even in the presence of equal incidence rates; this would imply a greater case fatality rate for cancers among cosmonauts. The relationship is further complicated by a lack of information on lifestyle factors such as diet, alcohol and tobacco use, and life-long physical fitness. Research examining radiation exposure and lifestyle, as well as continuing surveillance of cancer mortality in the years to come will be essential to understanding these trends as the oldest of the cosmonauts become octo- and nonagenarians.

The risk of death from circulatory disease (primarily heart attacks) was elevated among cosmonauts (compared to astronauts) in the Roscosmos period, but not the Soviet period. The PMR between periods shows that circulatory disease became responsible for 30% of the deaths in the Roscosmos period, up from 6% in the Soviet period. This is in keeping with a cohort effect: those cosmonauts trained in the Soviet era reached peak risk of death by circulatory disease in the Roscosmos era. The crude circulatory-specific mortality rates in Table I support this notion as well, as they climbed 10-fold between periods, in tandem with the aging of the cohort. However, the overall SMR is statistically significant at 364. This implies that cosmonauts may be at an elevated risk of death from circulatory disease not just at the oldest ages, but potentially starting as early as the fourth decade of life. Indeed, as three circulatory deaths were at ages less than 50 yr, this may well be the case. However, these results are again complicated by a lack of information on lifestyle among both cohorts.

As ischemic heart disease and stroke are among the leading causes of death in the Russian general population (9), it is believable that the risk of death for cosmonauts from circulatory diseases is elevated in comparison to U.S. astronauts. What is most interesting, however, is the integration of this finding with that of the cosmonaut/general population SMR. Cosmonauts have only 11% the risk of death due to any cause compared to the general population (for whom circulatory disease is a major killer), but are at more than three times the risk of death from circulatory disease compared to U.S. astronauts. Whatever causes such high rates of circulatory disease in the Russian and Ukrainian general populations—whether genetic, behavioral, environmental, or some combination—seems to affect cosmonauts as well. Any explanation offered here would be speculative; further research is needed.

A limitation of our study is low statistical power surrounding some estimated SMR. Low power results in wide confidence intervals around SMR, as in Table III. It has been recommended by the Institute of Medicine that statistical significance alone not be the standard by which to judge the importance of findings in studies of U.S. astronauts (4). We agree and believe this should extend to the studies of cosmonaut mortality as well.

A further strain on statistical power in the cause-specific SMR is the large number of causally unclassified deaths. About 20% of the total cosmonaut deaths were due to

unknown causes, mostly in the Roscosmos period. While all-cause SMR would be unaffected by assigning causes to these deaths, properly classifying them could drive some cause-specific SMR to statistical significance. For example, one additional cosmonaut cancer death in the Roscosmos period would make that SMR significant. Hence, the cause-specific SMR presented in Table III should be considered lower bound estimates of the true effects, since the reassignment of deaths to specific categories would only increase the point estimates of the SMR and tighten their confidence intervals.

With the focus of biomedical research concerning spaceflight centered primarily on acute physiological outcomes, studies of the comparative mortality of space explorers may seem irrelevant or unimportant. However, understanding the effects of space travel on the body is of no use if we do not know how those effects in turn modify life span. Together, both types of research bring us closer to understanding the challenges we face in voyaging beyond our home planet. Continuing such research will, therefore, be a crucial preparatory step toward the next phase of human exploration in space.

ACKNOWLEDGMENT

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REFERENCES

1. Bugrov SA, Voronia LI, Voronokov YI, Korotayev MM, Senkevich YA. Selection and biomedical training of cosmonauts. *Adv Space Res* 1992; 12:347–50.
2. Hamm PB, Billica RD, Johnson GS, Wear ML, Pool SL. Risk of cancer mortality among the Longitudinal Study of Cosmonaut Health (LSAH) participants. *Aviat Space Environ Med* 1998; 69:142–4.
3. Hamm PB, Nicogossian AE, Pool SL, Wear ML, Billica RD. Design and current status of the longitudinal study of astronaut health. *Aviat Space Environ Med* 2000; 71:564–70.
4. Longnecker DE, Manning FJ, Worth MH Jr, eds. Review of NASA's Longitudinal Study of Astronaut Health. Washington, DC: The National Academies Press; 2004.
5. Merrill RM. Introduction to epidemiology, 5th ed. Sudbury, MA: Jones and Barlett; 2010.
6. Peterson LE, Pepper LJ, Hamm PB, Gilbert SL. Longitudinal study of astronaut health: mortality in the years 1959-1991. *Radiat Res* 1993; 133:257–64.
7. Reynolds RJ, Day SM. Mortality among U.S. astronauts: 1980–2009. *Aviat Space Environ Med* 2010; 81:1024–7.
8. Rosner B. Fundamentals of biostatistics, 7th ed. Boston: Brooks/Cole, Cengage Learning; 2011.
9. Shkolnikov VM, Cornia GA, Leon DA, Mesle F. Causes of the Russian mortality crisis: evidence and interpretations. *World Dev* 1998; 26:1995–2011.
10. National Aeronautics and Space Administration. Cosmonaut bios. Retrieved 21 December 2013 from <http://www.jsc.nasa.gov/Bios/>.
11. University of California at Berkeley (USA) and Max Planck Institute for Demographic Research (Germany). Human Mortality Database. Retrieved 21 December 2013 from <http://www.mortality.org>.
12. USSR/Russian cosmonaut biographies. Retrieved 21 December 2013 from http://www.spacefacts.de/english/bio_cosm.htm.
13. Walberg P, McKee M, Shkolnikov V, Chenet L, Leon DA. Economic change, crime, and mortality crisis in Russia: regional analysis. *BMJ* 1998; 317:312–8.