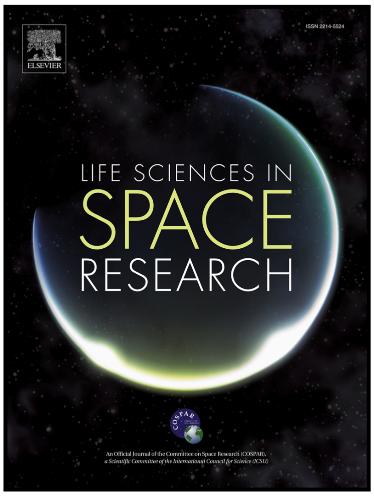
Journal Pre-proof



Population analysis of space travelers

Tatsuya Corlett , Mariya Stavnichuk , Svetlana V. Komarova

PII: S2214-5524(20)30044-4
DOI: https://doi.org/10.1016/j.lssr.2020.06.003
Reference: LSSR 289

To appear in: *Life Sciences in Space Research*

Received date: 20 January 2020
Revised date: 12 June 2020
Accepted date: 13 June 2020

Population analysis of space travelers

Tatsuya Corlett[1*], Mariya Stavnichuk[1,2*], Svetlana V. Komarova[1,2,3**]

[1]Shriners Hospital for Children – Canada, Montréal, QC, Canada

[2]Department of Biomedical Engineering, McGill University, Montréal, QC, Canada

[3]Faculty of Dentistry, McGill University, Montréal, QC, Canada

Short title: Who went to space?

* Both authors contributed equally to this work
**Corresponding author to whom reprint requests should be addressed: Svetlana V. Komarova, Shriners Hospital for Children – Canada, 1003 Decarie Boulevard, Montreal, Quebec, Canada H4A 0A9. Tel: (514) 282-7153, Email: svetlana.komarova@mcgill.ca
Mariya Stavnichuk: mariya.stavnichuk@mail.mcgill.ca
Tatsuya Corlett: tatsuya.corlett@mail.mcgill.ca

Disclosures: All authors state that they have no conflicts of interest.

Abstract

Although many space missions have been completed in the last 60 years, space exploration is still technologically and medically challenging. While large-scale medical studies are impossible in space travelers, meta-analysis allows combining data from small crews that participated in space missions over several decades. Our primary objective was to examine space-travelers' sociodemographic characteristics and spaceflight activities, and their changes with time from the first spaceflight. Our secondary objective was to evaluate the publication practices to assess data availability for health-related meta-analytic studies. Based on state-funded space agencies used as primary sources, and third-party websites used as secondary sources, 565 humans (501 males/64 females) have currently completed spaceflight. The average age of space-travelers increased from 34±4 in the 1960s to 45±4 in the 2010s. While the duration of space missions has increased consistently, the number of missions per year varied in correlation with technological events. Using papers identified in the systematic review of bone health in astronauts, we examined the changes in reporting practices with time. The reported sample size varied from 1 to 58 people, in total providing data for 148 individuals. Data confidentiality significantly improved with time; however, the corresponding decrease in the availability of individual parameters did not allow stratification even by age, sex, and mission duration. Thus, space travelers represent a diverse population suitable for comparative studies, however, it is important to develop reporting practices that ensure consistent, transparent, and ethical presentation of outcomes to support meta-analyses that are critical for understanding the scope of spaceflight-induced health issues.

Keywords: space flight, astronauts, cosmonauts, population, history, demographics

Introduction

Space travel captivates us since the first humans accomplished an orbital spaceflight in 1961 and stepped on the moon surface in 1969 [1]. In our imagination, we are already developing the recourses of the Solar system, travel to other planets, and find love in galaxies far-far away. However, the reality of space travel is much more complex, and many spaceflight-related health problems have been identified, including those in the cardiovascular system [2], immune system [3], bone and muscle health [4], ocular system [5] and metabolism [6]. Different technological and behavioral strategies have been attempted to counteract these problems, including exercise regimes [7], nutrition [8], environmental control [9, 10]. While some successes have been reported, the problems are far from being solved [4, 11, 12]. One potential contributor to the lack of solutions is the nature of space exploration as a technologically difficult and very expensive endeavor, which accommodates only a small number of people at a time, thus precluding any large-scale investigations that would allow to account for biological variability among humans. Combining data from the space travelers who participated in missions performed over a long period of time in an extended meta-analysis can at least partially overcome this problem. An important assumption of such analysis is that the space travel itself is the largest driver of changes, while technological/logistic/demographic co-variates, such as the type of spacecraft, nutrition, and countermeasures underlie secondary effects. In order to explore the potential of such extended secondary meta-analysis, we aimed to qualitatively and quantitatively analyze the population of space-travelers from the first spaceflight till the present time for its suitability for health-related studies. The secondary objective of the study was to evaluate the practices for describing the population of participants in the space-related health science using as an example the systematic review of bone health in astronauts [13] to examine the feasibility of extended analysis of published literature.

Methods

Construction of space-traveler database

We considered as space-travelers all humans who went to space according to the Fédération Aéronautique Internationale (FAI) definition [14]. As primary sources, we accessed the websites of official state agencies (National Aeronautics and Space Administration (NASA), Roscosmos, European Space Agency, Canadian Space Agency, Japan Aerospace Exploration Agency, China National Space Administration and Indian Space Research Organisation). Secondary sources included third-party websites hosted in the US [15] and Russia [16]. Since state-funded sources did not contain information for space travelers of all origins, the space-traveler database was constructed based on the information provided by the third-party websites. Information in the database was cross-validated with the information provided by the state-funded agencies and if a discrepancy arose, the information provided by the state-funded websites was used as a primary source. The following information was included: 1) identification (official and Romanised name, national database ID number, and retirement status); 2) demographics (nationality, sex, year of birth, year of selection, and military background); 3) career statistics (total time spent in space, number of flights, and extra-vehicular activity (EVA) hours); and 4) data on each mission involving the traveler (the name, year, and duration of each mission; ascent/orbit/descent vehicle; and instances of and total EVA time per mission).

Quantification of data confidentiality

To examine the degree of data confidentiality, we quantified the accuracy with which we could determine the identity of space-travelers from the data disclosed in 57 papers [17-73] systematically identified as reporting the effects of microgravity on human bone [13]. Identification was performed based on information about space travelers' age, sex, and occupation, as well as the year, title, and duration of a mission provided by a paper. The accuracy of identification was presented as a ratio between the sample size of the paper and the number of individuals that fit the identification profile.

Quantification of demographics overlap in publication

To quantify the degree to which space traveler populations overlap in different papers, we counted the appearance of a particular space-traveler data in all papers where subjects were identifiable.

Results and Discussion

Information availability and completeness

We have found that no state-supported agency provided complete datasets for all space travelers, and the formats of data were inconsistent across different agencies. In contrast, secondary sources, third-party websites [15, 16], contained comprehensive, up-to-date information on space travelers of all nationalities. We used secondary sources to construct a database of all space travelers, and primary sources to cross-validate the entries [74].

Changes in the population of space-travelers with the development of space travel

In order to obtain a reasonable size population, meta-analytic studies will need to combine the information from mission performed over several decades, therefore understanding changes in the population of space-travelers with time is important. Historically, the annual number of spaceflights has varied substantially (**Fig. 1A**), which reflects space technology advancements as well as setbacks revealed by fatal accidents (**Fig. 1B**). For example, a drastic change in the number of USA astronauts sent to space in the 80s and 90s can be attributed to the replacement of Saturn IB launch vehicles used in Skylab missions that transported three astronauts at a time by Space Shuttles that transported up to 8 astronauts per mission, while USSR/Russia space program continuously used Soyuz spacecrafts that carry up to 3 astronauts per mission since 1967. All fatal accidents, Soyuz 1 and 11 in 1967 and 1971, Challenger in 1986, and Columbia in 2003, were followed by either complete cancelation or a large decrease in flights the following year (**Fig 1B**). Despite NASA and Roscosmos being state-funded agencies, the spaceflights were less influenced by global economy and major political events (**Fig 1C**), likely due to time delay required for their impact on space-flight activities [75, 76].

The population of space travelers

As of December 2019, 565 humans (501 males/64 females) have completed spaceflights. The USSR and USA started sending humans to space in 1960s, and the majority of space travelers have been from the USA (n = 344) or USSR/Russia (n =122), followed by Germany, Japan, China, Canada and France (n = 10-12), Italy and United Kingdom (n = 5-7), n=2 for Belgium, Bulgaria and Netherlands, and n = 1 for Afghanistan, Australia, Austria, Brazil, Cuba, Czechoslovakia, Denmark, Hungary, India, Israel, Kazakhstan, Korea, Malaysia, Mexico, Mongolia, Poland, Republic of South Africa, Romania, Saudi Arabia, Slovakia, Spain, Sweden, Switzerland, Syria, United Arab Emirates, Vietnam. In recent years, almost 30% of space travelers at the International Space Station (ISS) are from countries other than the USA and Russia (**Fig 1A**). Most space travelers were males (n = 501), while the population of female astronauts (n = 64) continuously increased since the 1980s (**Fig 2A**). The astronaut age at enrolment into the space program has increased with time but remained lower for females compared to males (**Fig 2A**). Most male and female astronauts participated in only one mission; however, the number of astronauts involved in multiple missions increased over the years, with Jerry L. Ross performing a record number of 7 spaceflights in his career (**Fig 2B-C**). While initially, most astronauts had a military background, with time approximately the same number of space travelers were recruited from military and civilian environment (**Fig 2D**).

The time astronauts spent in space increased through spaceflight history, with a recent trend towards missions lasting >480 hours, which is likely related to the launch of the ISS program in 1998 (**Fig 3A**). Of interest, when we examined the total number of hours spent in space per space traveler, two sub-populations of astronauts emerged: those who participated in short missions (< 30 days), and those who served on longer missions (**Fig 3B**). Since the first spacewalk performed by Alexei Leonov in 1965, the number of times extravehicular activity (EVA) was performed steadily increased (**Fig 3C**). From 176 astronauts who performed spacewalks, the majority (106 astronauts) had less than 20 hours of EVA, while 43 performed more than 30 hours of EVA (**Fig 3D**), with the record of 16 EVAs, lasting for the total of 82 hours and 22 minutes held by Anatoly Solovyev. Thus, the space traveler population is abundant and diverse both in their sociodemographic background and in their space-related activities.

Reporting practices

To analyze the practices for describing participants in manuscripts focused on the health issues in space travelers, we used the selection of 57 papers identified using a systematic search of studies reporting on bone health of astronauts [13]. The sample sizes of reported populations varied between 1 and 58. While the average sample population size increased over the years (**Fig 4A**), the studies reporting large-scale statistics were still rare. Next, we attempted to identify space-travelers from the information disclosed in a paper, such as age, sex, mission name, and duration. In early publications, most astronauts were identified uniquely or as one of two mission members; however, in recent years identification has become more difficult (**Fig 4B**). In one of the most recent papers [58], not only the astronaut identification was impossible, but also the important spaceflight characteristics, such as mission duration, were absent, reducing the usefulness of the reported data for the secondary data analysis. Using 30 papers that published data on astronauts' bone density between 1965 and 2010, we examined the extent of the overlap in reported populations. We found that data for the same astronauts were often reported across multiple publications, sometimes as individual data and sometimes as part of groups of a different size (**Fig. 4C**). The extent of overlap was the greatest in papers on Gemini and early Apollo missions, as well as for papers reporting measurements from long-term missions on Mir and ISS, while reports on Skylab and Salyut missions had fewer overlapping populations. Almost all space travelers' data from Skylab, Mir, and ISS appeared in at least one study (**Fig. 4D**). Salyut missions were underrepresented despite being conducted in long-term space station stays. Bone density changes were rarely measured in Soyuz and STS missions, as they were mostly short-duration flights.

Conclusion

Our study demonstrates that the population of space travelers is relatively large and complex, potentially providing an opportunity to examine the influence of age, sex, spaceflight duration, number of missions, and EVA time on spaceflight-related health outcomes. Since spaceflight studies are typically underpowered due to small sample sizes (few astronauts per space mission), meta-analysis can potentially improve data analysis. However, the reporting of spaceflight outcomes was found to be somewhat deficient, with multiple instances of over-reporting (such as reporting the data from the same individuals included in groups of different sizes) and under-reporting (such as not providing sufficient information for meta-analytic studies). Therefore, there is an urgent need to develop reporting practices that ensure consistent and transparent reporting of outcomes tailored to this type of research, while adhering to the highest ethical standards Although conflicting mechanisms and motivations for funding of space exploration by national states may impede such developments, a long-standing history of successful international collaborations – as demonstrated by the construction and utilization of the ISS – provides the groundwork for such a task.

Acknowledgement

The authors are grateful to Haipei Lui for assistance with preliminary article screening, and to Drs. Kerstin Tiedemann and Iris Boraschi-Diaz for help with translation, and to Dr. Ma'n H. Zawati, McGill University, for helpful discussion of the manuscript. MS was supported by NSERC Undergraduate Student Research Award. TC and MS performed data analysis, all authors wrote, edited, and approved the manuscript.

Funding sources

This work was supported by an operating grant from Canadian Space Agency (19HLSRM04) and Natural Sciences and Engineering Research Council (NSERC, RGPIN-288253). MS was supported by The Natural Sciences and Engineering Research Council of Canada - Undergraduate Student Research Award (2017) and Fonds de Recherche du Québec – Nature et technologies (2019).

Declaration of interests

☐The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. National Aeronautics and Space Administration. *Human Spaceflight*. 60 Years and Counting [cited 06/11/2020]; Available from: https://www.nasa.gov/specials/60counting/spaceflight.html.
2. Ramsdell, C.D. and R.J. Cohen, *Cardiovascular System in Space*, in *Encyclopedia of Space Science and Technology*, H. Mark, Editor. 2003. https://doi.org/10.1002/0471263869.sst074
3. Crucian, B.E., et al., *Immune System Dysregulation During Spaceflight: Potential Countermeasures for Deep Space Exploration Missions.* Frontiers in Immunology, 2018. **9**(1437). https://doi.org/10.3389/fimmu.2018.01437
4. Lang, T., et al., *Towards human exploration of space: the THESEUS review series on muscle and bone research priorities.* npj Microgravity, 2017. **3**(1): p. 8. https://doi.org/10.1038/s41526-017-0013-0
5. Taibbi, G., et al., *The effect of microgravity on ocular structures and visual function: a review.* Surv Ophthalmol, 2013. **58**(2): p. 155-63. https://doi.org/10.1016/j.survophthal.2012.04.002
6. Smith, S.M., et al., *Nutritional status assessment in semiclosed environments: ground-based and space flight studies in humans.* J Nutr, 2001. **131**(7): p. 2053-61. https://doi.org/10.1093/jn/131.7.2053
7. Korth, D.W., *Exercise Countermeasure Hardware Evolution on ISS: The First Decade.* Aerosp Med Hum Perform, 2015. **86**(12 Suppl): p. A7-a13. https://doi.org/10.3357/amhp.ec02.2015
8. Government Publishing Office, *Human Adaptation to Spaceflight: The Role of Nutrition*. 2014: U.S. Government Printing Office. Availible from: https://books.google.ca/books?id=CxiibyZpUFgC
9. Daues, K.R., *A history of spacecraft environmental control and life support systems*. 2006: NASA Johnson Sp. Cent p. pp. 1-13. Available from: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080031131.pdf
10. Kliss, M. *Understanding the NASA TA6: Human Health, Life Support, and Habitation Systems Technology Roadmap*. 2016. 46th International Conference on Environmental Systems. Available from: http://hdl.handle.net/2346/67489
11. Aubert, A.E., et al., *Towards human exploration of space: the THESEUS review series on cardiovascular, respiratory, and renal research priorities.* npj Microgravity, 2016. **2**: p. 16031-16031. https://doi.org/10.1038/npjmgrav.2016.31
12. Frippiat, J.-P., et al., *Towards human exploration of space: The THESEUS review series on immunology research priorities.* npj Microgravity, 2016. **2**(1): p. 16040. https://doi.org/10.3389/fimmu.2018.01437
13. Stavnichuk, M., Mikolajewicz, N., Corlett, T. et al. *A systematic review and meta-analysis of bone loss in space travelers*. npj Microgravity, 2020. **6**(13). https://doi.org/10.1038/s41526-020-0103-2
14. FAI Astronautics Commission, FAI Sporting Code FAI Section 8–Astronautics, Fédération Aéronautique Internationale, Editor. 2009, Maison du Sport International: Switzerland. Available from: https://www.fai.org/sites/default/files/documents/sporting_code_section_8_edition_2009.pdf
15. *Astronauts & Cosmonauts*. Available from: https://www.worldspaceflight.com/bios/index.php.

16. *Астронавты и космонавты*. Available from: http://www.astronaut.ru/register/register.htm?reload_coolmenus.
17. Amin, S., et al., *Bone density following long-duration spaceflight and recovery.* Journal of Bone and Mineral Research, 2010. **25**: p. S193. http://dx.doi.org/10.1002/jbmr.5650251303
18. Arnaud, C.D. and C.E. Cann, *Experiment 305: Pathophysiology of Mineral Loss During Space Flight*. 1995, California University: United States. Available from: https://ntrs.nasa.gov/search.jsp?R=19960002602
19. Berry, C.A., *The medical legacy of Gemini.* Life Sciences & Space Research, 1968. **6**: p. 1-19. Available from: https://ntrs.nasa.gov/search.jsp?R=19690033085
20. Biryukov, E.N. and I.G. Krasnykh, *Changes in Bone Tissue Optic Density and Calcium Metabolism of Cosmonauts AG Nikolayev and VI Sevastyanov. [Russian]*. Kosmicheskaya Biologiya i Meditsina, 1970. **4**(6): p. 42-46.
21. Burkhart, K., et al., *Effects of Long-Duration Spaceflight on Vertebral Strength and Risk of Spine Fracture.* Journal of Bone & Mineral Research, 2019. **31**: p. 31. https://dx.doi.org/10.1002/jbmr.3881
22. Caillot-Augusseau, A., et al., *Bone formation and resorption biological markers in cosmonauts during and after a 180-day space flight (Euromir 95).* Clinical Chemistry, 1998. **44**(3): p. 578-85.
23. Caillot-Augusseau, A., et al., *Space flight is associated with rapid decreases of undercarboxylated osteocalcin and increases of markers of bone resorption without changes in their circadian variation: Observations in two cosmonauts.* Clinical Chemistry, 2000. **46**(8): p. 1136-1143.
24. Cavanagh, P.R., et al., *Foot forces during typical days on the international space station.* Journal of Biomechanics, 2010. **43**(11): p. 2182-8.
25. Collet, P., et al., *Effects of 1- and 6-month spaceflight on bone mass and biochemistry in two humans.* Bone, 1997. **20**(6): p. 547-51.
26. Ellman, R., J. Sibonga, and M. Bouxsein, *Male astronauts have greater bone loss and risk of hip fracture following long duration spaceflights than females.* Journal of Bone and Mineral Research, 2010. **25**: p. S44-S45. http://dx.doi.org/10.1002/jbmr.5650251301
27. Grigor'ev, A.I., I.M. Larina, and B.V. Morukov, *Calcium metabolism characteristics in microgravity. [Russian]*. Rossiiskii fiziologicheskii zhurnal imeni I.M Sechenova/ Rossiiskaia akademiia nauk, 1999. **85**(6): p. 835-846.
28. Grigoriev, A.I., et al., *Clinical and physiological evaluation of bone changes among astronauts after long-term space flights. [Russian]*. Aviakosmicheskaia i ekologicheskaia meditsina = Aerospace and environmental medicine, 1998. **32**(1): p. 21-25.
29. Johnston, R.S. and L.F. Dietlein, *Biomedical results from Skylab*. 1977, Washington: Scientific and Technical Information Office, National Aeronautics and Space Administration. Available from: https://ntrs.nasa.gov/search.jsp?R=19770026836
30. Keyak, J.H., et al., *Reduction in proximal femoral strength due to long-duration spaceflight.* Bone, 2009. **44**(3): p. 449-53. http://dx.doi.org/10.1016/j.bone.2008.11.014
31. Kozlovskaya, I.B. and A.I. Grigoriev, *Russian system of countermeasures on board of the International Space Station (ISS): the first results.* Acta Astronautica, 2004. **55**(3-9): p. 233-7.
32. Lang, T., et al., *Cortical and trabecular bone mineral loss from the spine and hip in long-duration spaceflight.* Journal of Bone and Mineral Research, 2004. **19**(6): p. 1006-12. https://doi.org/10.1359/JBMR.040307

33. Lang, T.F., et al., *Adaptation of the proximal femur to skeletal reloading after long-duration spaceflight.* Journal of Bone and Mineral Research, 2006. **21**(8): p. 1224-30. https://doi.org/10.1359/jbmr.060509
34. Leblanc, A., et al., *Antiresorptive treatment for spaceflight induced bone atrophy: Preliminary results.* Journal of Bone and Mineral Research. Conference, 2011. **26**. Available from: https://ntrs.nasa.gov/search.jsp?R=20110008649
35. Leblanc, A., et al., *Bisphosphonates as a supplement to exercise to protect bone during long-duration spaceflight.* Osteoporosis International, 2013. **24**(7): p. 2105-14. https://doi.org/10.1007/s00198-012-2243-z
36. Leblanc, A., et al., *Bone mineral and lean tissue loss after long duration space flight.* Journal of Musculoskeletal Neuronal Interactions, 2000. **1**(2): p. 157-60.
37. Mack, P.B., *Bone Density Changes in the Astronauts during Space Flight.* Nasa, 1971.
38. Mack, P.B., et al., *Bone demineralization of foot and hand of gemini-titan IV, V and VII astronauts during orbital flight.* American Journal of Roentgenology, Radium Therapy & Nuclear Medicine, 1967. **100**(3): p. 503-11. https://doi.org/10.2214/ajr.100.3.503
39. Mack, P.B. and F.B. Vogt, *Roentgenographic bone density changes in astronauts during representative Apollo space flight.* American Journal of Roentgenology, Radium Therapy & Nuclear Medicine, 1971. **113**(4): p. 621-33. https://doi.org/10.2214/ajr.113.4.621
40. McCarthy, I., et al., *Investigation of bone changes in microgravity during long and short duration space flight: comparison of techniques.* European Journal of Clinical Investigation, 2000. **30**(12): p. 1044-54. https://doi.org/10.1046/j.1365-2362.2000.00719.x
41. Michalski, A.S., et al., *Hip load capacity cut-points for Astronaut Skeletal Health NASA Finite Element Strength Task Group Recommendations.* npj Microgravity, 2019. **5**: p. 6. https://dx.doi.org/10.1038/s41526-019-0066-3
42. Miyamoto, A., et al., *Medical baseline data collection on bone and muscle change with space flight.* Bone, 1998. **22**(5 Suppl): p. 79S-82S. https://doi.org/10.1016/s8756-3282(98)00020-9
43. Morey-Holton, E.R. and S.B. Arnaud, *Skeletal responses to spaceflight.* Advances in Space Biology & Medicine, 1991. **1**: p. 37-69. https://doi.org/10.1016/s1569-2574(08)60120-3
44. Morukov, B.V., et al., *Biochemical Markers of Bone Tissue Metabolism in Cosmonauts after a Prolonged Spaceflight. [Russian]*. Fiziologiia cheloveka, 2005. **31**(6): p. 73-77.
45. Morukov, I.B., et al., *Status of the osteoclast-activating system in cosmonauts after long-duration missions to the International Space Station. [Russian]*. Aviakosmicheskaia i Ekologicheskaia Meditsina, 2014. **48**(6): p. 10-5.
46. Nicogossian, A.E., *The Apollo-Soyuz Test Project: Medical report.* 1977 NASA Lyndon B. Johnson Space Center: United States. Available from: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19770023791.pdf
47. Oganov, V.S., et al., *Characteristics and patterns of the human bone reactions to microgravity. [Russian]*. Aviakosmicheskaia i Ekologicheskaia Meditsina, 2006. **40**(4): p. 15-21.
48. Oganov, V.S., et al., *Reactions of the human bone system in space flight: phenomenology. [Russian]*. Aviakosmicheskaia i Ekologicheskaia Meditsina, 2005. **39**(6): p. 3-9.
49. Oganov, V.S. and V.V. Bogomolov, *The human skeletal system in weightlessness: A review of research data, hypotheses, and the possibility of predicting the state in long-term (Interplanetary) missions.* Human Physiology, 2011. **37**(7): p. 768-776. https://doi.org/10.1134/S0362119711070243

50. Oganov, V.S., et al., *Comparative analysis of cosmonauts skeleton changes after space flights on orbital station Mir and international space station and possibilities of prognosis for interplanetary missions. [Russian]*. Fiziologiia cheloveka, 2010. **36**(3): p. 39-47.
51. Oganov, V.S., et al., *Study of the musculoskeletal system of the spine in humans after long-term space flights by the method of computerized tomography. [Russian]*. Kosmicheskaia Biologiia i Aviakosmicheskaia Meditsina, 1990. **24**(4): p. 20-1.
52. Oganov, V.S., et al., *Bone mineral density in cosmonauts after 4.5-6 month flights on board Mir orbital station. [Russian]*. Aviakosmicheskaya i Ekologicheskaya Meditsina, 1992. **26**(5-6): p. 20-24.
53. Oganov, V.S., et al., *The state of human bone tissue during space flight.* Acta Astronautica, 1991. **23**: p. 129-33. https://doi.org/10.1016/0094-5765(91)90109-i
54. Parker, J.F. and V. West, *Biomedical Results of Apollo*, R.S. Johnston, L.F. Dietlein, and C.A. Berry, Editors. 1975 NASA Johnson Space Center: United States. Available from: https://ntrs.nasa.gov/search.jsp?R=19760005580&hterms=biomedical+results+apollo&qs=N%3D0%26Ntk%3DAll%26Ntt%3Dbiomedical%2520results%2520of%2520apollo%26Ntx%3Dmode%2520matchall
55. Prostiakov, I.V., B.V. Morukov, and I.B. Morukov, *Dynamics of changes in bone mineral density and structural organization in cosmonauts following space flight of 6 months in duration. [Russian]*. Aviakosmicheskaya i Ekologicheskaya Meditsina, 2010. **44**(3): p. 24-28.
56. Prostyakov, I.V., B.V. Morukov, and I.B. Morukov, *Changes in bone mineral density and microarchitecture in cosmonauts after a six-month space flight.* Human Physiology, 2012. **38**(7): p. 727-731. https://doi.org/10.1134/S0362119712070201
57. Rice, A.J., et al., *Bone loss and lower extremity loading during long-duration space flight.* Journal of Bone and Mineral Research, 2004: p. 4.
58. Sibonga, J., et al., *Resistive exercise in astronauts on prolonged spaceflights provides partial protection against spaceflight-induced bone loss.* Bone, 2019. **128**: p. 112037. https://doi.org/10.1016/j.bone.2019.07.013
59. Sibonga, J.D., et al., *Use of Quantitative Computed Tomography to Assess for Clinically-relevant Skeletal Effects of Prolonged Spaceflight on Astronaut Hips.* Journal of Clinical Densitometry, 2019. **26**: p. 26. https://dx.doi.org/10.1016/j.jocd.2019.08.005
60. Smith, S., et al., *TBS (trabecular bone score) expands understanding of spaceflight effects on the lumbar spine of long-duration astronauts.* Journal of Clinical Densitometry, 2014. **17**: p. 423-424. Available from: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140005963.pdf
61. Smith, S.M., et al., *Bone metabolism and renal stone risk during International Space Station missions.* Bone, 2015. **81**: p. 712-20. https://doi.org/10.1016/j.bone.2015.10.002
62. Smith, S.M., et al., *Collagen cross-link excretion during space flight and bed rest.* J Clin Endocrinol Metab, 1998. **83**(10): p. 3584-3591. https://doi.org/10.1210/jcem.83.10.5169
63. Smith, S.M., et al., *Calcium metabolism before, during, and after a 3-mo spaceflight: Kinetic and biochemical changes.* American Journal of Physiology, 1999. **277**(1): p. R1-R10. https://doi.org/10.1152/ajpregu.1999.277.1.r1
64. Smith, S.M., et al., *Bone markers, calcium metabolism, and calcium kinetics during extended-duration space flight on the mir space station.* Journal of Bone and Mineral Research, 2005. **20**(2): p. 208-18. https://doi.org/10.1359/JBMR.041105

65. Stupakov, G.P., et al., *Evaluation of Changes in Axial Skeleton Bones during Prolonged Space Flight. [Russian]*. Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina, 1984. **18**(2): p. 33-37.
66. Vico, L., et al., *Effects of long-term microgravity exposure on cancellous and cortical weight-bearing bones of cosmonauts.* Lancet, 2000. **355**(9215): p. 1607-1611. https://doi.org/10.1016/s0140-6736(00)02217-0
67. Vico, L., et al., *Cortical and Trabecular Bone Microstructure Did Not Recover at Weight-Bearing Skeletal Sites and Progressively Deteriorated at Non-Weight-Bearing Sites During the Year Following International Space Station Missions.* Journal of Bone and Mineral Research, 2017. **32**(10): p. 2010-2021. https://doi.org/10.1002/jbmr.3188
68. Vogel, J.M., *Bone-mineral measurement - skylab experiment M-078.* Acta Astronautica, 1975. **2**(1): p. 129-139. Available from: https://lsda.jsc.nasa.gov/Experiment/exper/432
69. Vogel, J.M. and R.J. Friedman, *Photon absorptiometry measurements of bone mineral in Apollo 14 and 15.* Revue de Medecine Aeronautique et Spatiale, 1973. **12**(46): p. 322-326.
70. Vogel, J.M. and M.W. Whittle, *Bone Mineral Changes: The Second Manned Skylab Mission.* Aviation Space & Environmental Medicine, 1976. **47**(4): p. 396-400.
71. Vose, G.P., R*eview of roentgenographic bone demineralization studies of gemini space-flights.* American Journal of Roentgenology, 1974. **121**(1): p. 1-4. https://doi.org/10.2214/ajr.121.1.1
72. Yegorov, A.D., *Results of medical studies during long-term manned flights on the orbital Salyut-6 and Soyuz complex*. 1979 NASA: United States. Available from: https://ntrs.nasa.gov/search.jsp?R=19800007537
73. Zwart, S.R., et al., *Dietary acid load and bone turnover during long-duration spaceflight and bed rest.* Am J Clin Nutr, 2018. **107**(5): p. 834-844. https://doi.org/10.1093/ajcn/nqy029
74. [dataset] Stavnichuk, M. and T. Corlett, *Astronaut database*. 2020, Mendeley Data. https://doi.org/10.17632/86tsnnbv2w.1
75. Logsdon, J. *Ten Presidents and NASA*. 50th Magazine - 50 Years of Exploration and Discovery 2009 [cited 2018 15.11.]; Available from: https://www.nasa.gov/50th/50th_magazine/10presidents.html.
76. Johnson, S., *The political economy of spaceflight* in *Societal impact of spaceflight*, S.J. Dick and R.D. Launius, Editors. 2007, National Aeronautics and Space Administration, Office of External Relations, History Division: Washington, DC. p. 141-192. Available from: https://history.nasa.gov/sp4801-chapter9.pdf

Figure legends

Figure 1. Chronological analysis of space traveller population. (A) Annual number of humans who travelled to space between 1961 and 2019. USSR/RF: Union of Soviet Socialist Republics/ Russian Federation; USA: United States of America. (B) Timeline of space programs conducted by the USA (*dotted line*), the USSR/RF (*solid line*), and the international community for the ISS (*dotdash line*). Fatal accidents are indicated. (C) Timelines of global economic events (*top*) and major political changes that occurred in the USA (*solid line*) and the USSR/RF (*dotted line*).

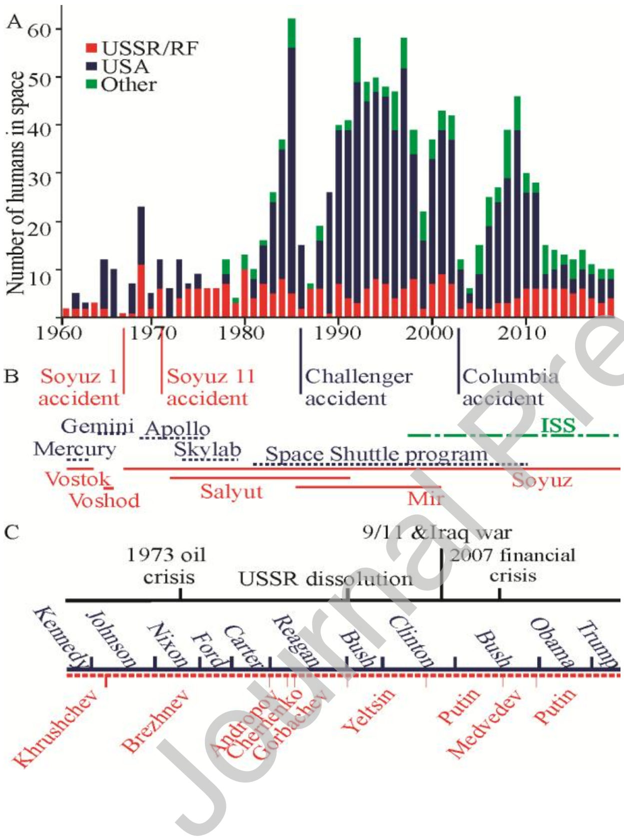


Figure 2. Demographic characteristics of space traveler population. (A) Average age of male and female space travelers during spaceflights. Means ± SD, n = 1135 missions completed by 501 male space travelers, n = 143 missions completed by 64 female space travelers. (B) Time-dependent change in the proportion of space travelers who participated in one\or multiple missions. (C) Number of male and female space travelers who participated in their n^{th} mission. D) Proportion of space travelers recruited from military or civilian background in the 6 decades of spaceflight.

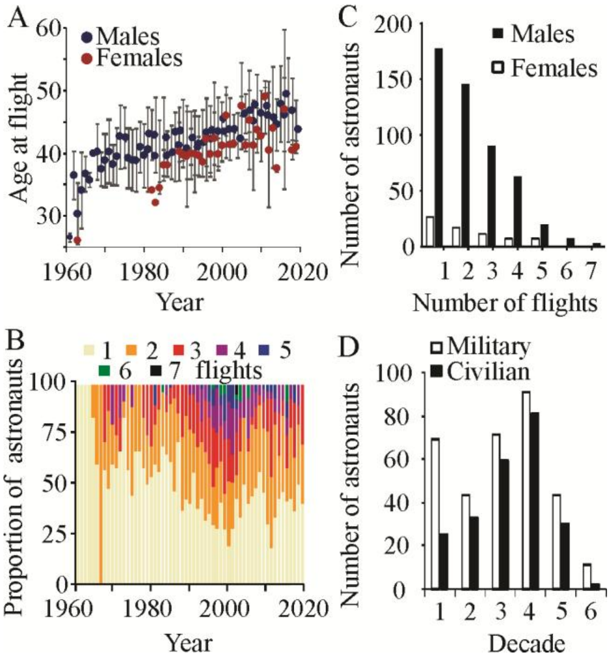


Figure 3. Spaceflight activities of space travelers. (A) Proportion of space travelers that participated in short (< 96 h), intermediate (96 to 480 h) and long (> 480 h) spaceflights. (B) Cumulative number of spaceflight hours of each astronaut as a function of the year of selection into a space program . (C) Number of extravehicular (EVA) operations per year. (D) Proportion of space travelers who performed indicated number of cumulative EVA hours.

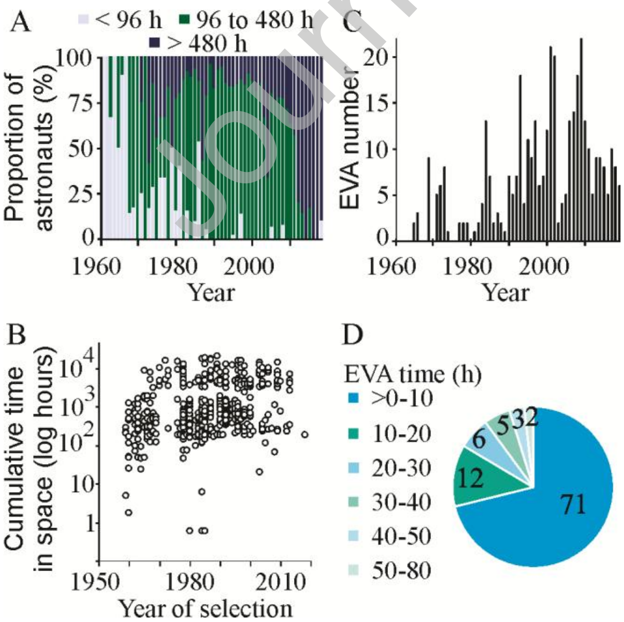


Figure 4. Reporting practices in spaceflight studies. (A) The sample size of the reported population as a function of publication year. (B) Space traveler identification accuracy defined as high [1/(1-2): astronaut identified uniquely or as one of 2 candidates], intermediate [1/(3-10): space traveler identified as one of 3-10 candidates] or low (<1/10) as a function of publication decade. (C) The degree to which bone density data of a particular space traveler is repeatedly reported in multiple publications. The space traveler ID in order of their flight year was plotted on the x-axis, and the manuscript ID in order of the publication year was plotted on the y-axis. The darker shade indicates the larger the number of papers (1 to 8) that reported data from the same individual after the same flight. (D) The proportion of space travelers from different space programs whose data was reported in literature out of all space travelers who participated in the program.