Challenges in Space Medicine

Matthieu J. Guitton

Department of Oto-Rhino-Laryngology and Ophthalmology, Faculty of Medicine, Laval University, Quebec City, QC, Canada

Institut Universitaire en Santé Mentale de Québec, Quebec City, QC, Canada

matthieu.guitton@fmed.ulaval.ca

DOI:10.5963/PHF0103003

***Abstract*- With the emergence of suborbital recreational flights ("space tourism") and plans for manned missions to Mars, the effects of space exploration on the human body will become a subject of critical concern in the coming decades. Space medicine will face new challenges and become one of the new frontiers of public health. Here we show how space medicine is becoming an emerging problem of public health, and describe the threats that space poses for human health, and identify some of the limitations that hinder advances in this discipline. The challenges for human health in space are mostly related to exposure of untrained people of various ages and health conditions to space flight in the short-term context of suborbital recreational flights and in the long-term context of deep space exploration. We will expose some of the potential problems related to long stays in spaceand returning to earth after short or long exposure to space conditions, and, finally, to the particular issue of human reproduction under low gravity conditions. The challenges and limitations in the development of space medicine are mostly related to conceptual issues, to problems of access to space medicine education, to technical limitations related to experimental gravity control, and to limitations related to the very small size of the original astronaut population. We identify some of the issues which will have to be addressed and propose an operative framework to optimize space medicine advances, and to contribute to ensuring safe conditions for human space exploration.**

Keywords*- *Cardiovascular System; Microgravity; Musculo-Skeletal System; Sensory Organs; Space Exploration; Space Tourism; Suborbital Flights; Vestibular System

I. INTRODUCTION

With the upcoming development of suborbital recreational flights ("space tourism") and plans by the USA and China to conduct a manned mission to Mars in the coming two decades, space is becoming the next frontier. Space exploration thus faces new challenges. Among them is the possibility for the human body to adapt to space conditions without taking too much damage, as well as the development of medical approaches to treating the specific pathologies induced by exposure to space flight conditions.

Space medicine is the field of medicine specialising in treating humans exposed to outer space conditions. With "general preventive medicine and public health" and "occupational medicine", "aerospace medicine" is one of the three areas of specialization of the "preventive medicine" medical specialty recognized in the USA by the American Board of Medical Specialties. However, despite this official recognition, and the importance of this field for enabling safe human space travel, space exploration, and, ultimately, space colonization, space medicine is still under-estimated.

Numerous factors can cause health problems during space flights. However, the three main sources of damage for the human body in space missions are exposure to low gravity ("microgravity"), to radiation, and to in-flight cabin contaminants (mostly metal particles). Space missions may have a number of deleterious effect on the human body, including decompression sickness, musculo-skeletal problems (loss in bone density, loss of muscle mass), sensory organ damage (loss of balance, spatial disorientation, loss of eyesight), metabolic dysfunctions (decreased immune system functioning, orthostatic intolerance), and occurrence of sleep disorders [1-4].

Here we identify the challenges that space medicine is facing. After showing how space medicine is becoming an emerging problem of public health, we describe the challenge that space poses for human health and identify some of the challenges that hinder the advancement of this discipline.

II. AN EMERGING PROBLEM

Long reserved to a very limited number of selected astronauts, space flight and space travel are putatively going to affect larger numbers of people, within the short-term ("space tourism"), medium-term (human missions to Mars), and long-term period (deep space exploration).

At a short-term range, probably within a few years, suborbital recreational flights will be a reality. Several commercial operators are developing projects to offer regular suborbital passenger flights. At first, this new form of "space tourism" will be reserved to a limited number of peopledue to economic reasons, as few people will be able to afford a ticket. However, this new form of travel is likely to follow the same fate as other modes of transportation did in the last century, and it could be expected that suborbital recreational flights will undergo democratization in the near future. This would lead to a considerable increase in the number of humans exposed to space flight conditions, as well as an increase in the variability of ages and health profiles of these people.

In addition to this increase in short-term exposures to space flight, political decisions to launch manned missions to the planet Mars within the coming two decades give new momentum to human space exploration. Space exploration is taking a new step, as the official goal of these planned missions to Mars is to pave the way for future deep space missions and long-term human space colonization. In the past, plans for space colonization had typically relied on targets such as Mars or the moons of Jupiter due to the absence of other potentially habitable extra-solar planets. However, recent advances have changed this situation. More than twenty years ago, the discovery of the first extrasolar giant planets around Sun-like stars paved the way for extrasolar targets for human exploration [5-6]. Indeed, the last few years have witnessed a drastic increase in the number of known planetary systems [7-11], culminating with the very recent discovery of several Earth-sized exoplanets [12-14]. Thus, extra-solar colonization has its goal set, and, although still not realistically attainable under our current propulsion methods, the presence of extra-solar telluric exoplanets suitable to accommodate human life is enough to define a workable objective.

The increase in both short-term and long-term space flight opportunities, as well as the possibility of multiple and regular space flights will have the same consequence: considerable exposure to space flight-related conditions by large numbers of untrained passenger from both genders, various ages and various health conditions. With the democratization of space flights, more concerns regarding public health will arise.

III. CHALLENGES FOR HUMAN HEALTH IN SPACE

With the emerging expansion of space flights, space medicine is now facing a new set of challenges. To summarize, these new challenges are mostly related to the exposure of untrained people of various ages and health conditions to space flight in the short-term context of suborbital recreational flights and in the long-term context of deep space exploration. Space exploration also poses potential health problems following the return to earth after short or long exposure to space conditions, as well as issues related to long stays in space and to the particular issue of human reproduction under low gravity conditions.

The emergence of large scale suborbital recreational flights will drastically alter the way space medicine is practiced. So far, only professional astronauts have been sent to space. This situation will change if anybody able to afford a ticket for a space tourism flight. However, while astronauts usually comprise young, healthy, specifically selected and trained personnel, the people likely to engage in space tourism activities will be of all ages (especially older people) and all health conditions (including people putatively suffering from various cardiovascular or metabolic diseases). The physiological reaction to short term space flight of older people or people with existing health problems is simply unknown. Exposure to extremely rapid changes in gravitational forces may be particularly problematic for passengers with cardiovascular vulnerability. Similarly, rapid changes in gravity may induce significant dysfunction of the vestibular system, which would not be compensated in older people as easily as in young astronauts. Ethical common-sense calls for in-depth medical examinations before boarding suborbital recreational flights. But which criteria should such examinations follow? Legal reflection will have to take place, alongside ethical consideration. In order to be optimal, such a debate will need to be supported by validated medical data. Furthermore, people using suborbital recreational flights may get exposed to several suborbital flight episodes, leading to new circumstances of cumulative exposure to space conditions, and repetitive exposure to rapid variations of gravity. Once more, the cardiovascular and vestibular systems are likely to be impaired by such circumstances. Given the known vulnerability of older people to falls, the question of safe re-adaptation upon return to Earth may become a worrying issue.

When exposed to microgravity, human physiology adapts. After a long stay in space, the human body exhibits numerous alterations. Long-term exposure to microgravity triggers major problems in the musculo-skeletal system: astronauts face significant muscle atrophy (loss of muscle mass, even if the astronaut does regular in-flight exercise), and loss in bone density. The loss in bone density, akin to osteoporosis, is often more marked in women. Similarly, deconditioning in space will produce marked diminution of the functional capacity of the cardiovascular system. Metabolic alterations lead to a decrease of immune system effectiveness, and to major alterations of metabolisms and absorption of drugs (consequently the pharmacokinetics of even common drugs in space conditions can be considered as terra incognita). Long stays in space also trigger significant alterations of sensory systems, particularly the cochleo-vestibular and visual systems. Combined with substantial muscle and bone atrophy, this type of damage to sensory organs (loss of balance, spatial disorientation, loss of eyesight) can result in the development of significant problems of balance and coordination upon return to Earth. So far, muscle atrophy and loss in bone density observed after periods of six months in space seem to be reversible upon return to Earth (men recovering slightly faster than women). However, the time-course of this recovery is unknown if exposures to space conditions become longer. Furthermore, although injuries to the musculo-skeletal system seem to recover, the damage to sensory organs is much more problematic. Both the inner ears and the eyes are affected by the loss of gravity. By definition, the vestibular system is a gravity sensor, with the movement of otoliths within vestibular fluids acting as an inertia detector. Microgravity disorganizes the vestibular system in a persistent way. This disorganisation is also contagious to the other sensory organ of the inner ear, the cochlea, leading to the occurrence of tinnitus and hearing dysfunctions. The loss of balance of returning astronauts can be further aggravated by the severe eyesight problems that some astronauts experience [4]. The problem of the return to earth will be even more marked in the context of long-term space missions. This issue points to a complex question: once a human being has spent very long periods of time in space – years or more – will he be able to come back to the Earth?

Long-term missions, which may have duration of months for space exploration, or years in the possible context of space colonization, bear more problems for the health of astronauts. All of the problems that already exist in relation to shorter flights will be exacerbated: loss of muscular mass and bone density will increase, disorientation symptoms will get more critical, and responses to drugs will get more unpredictable. In addition to the exacerbation of known problems, supplementary physiological dysfunctions may arise after longer periods of time in low gravity. In addition to all the biological problems, psychological aspects should not be neglected. The effects of social isolation in small and closed groups can be extremely deleterious for psychological stability. Similarly to the physical and cognitive exercise regimens that are already employed in existing space stations, new avenues will need to be implemented to support social exercise for long-term space missions. Immersive virtual spaces may represent an interesting way to provide such social training in a space mission context [15]. Interestingly, the main alterations appearing following long-term periods in low-gravity environments (muscle and bone atrophy, development of balance and coordination problems, loss of cardiovascular system capacity) seem to mimic the symptoms of an accelerated form of aging [16].

Finally and closely related to the theme of long-term missions, it is the problem of child bearing and maternity. Human reproduction will be a key element of long-term space missions in the context of space colonization. Even outside of such a situation, “accidental” pregnancy may occur in space exploration missions. So far, pregnancy has been avoided in space flights, due to the limited number of female astronauts, and the limited periods of time spent in space. However, an increase in the proportion of females on space missions as well as an increase in the duration of space missions may well change this situation. This problem is far from being trivial, especially since the hormonal strategies commonly used as pharmacological ways of birth control are likely to significantly decrease in effectiveness in long-term space conditions. Indeed, pharmacokinetics of exogenous hormones and other drugs, as well as the reaction of the human body to these substances, may be considerably altered in long-term space flights.

With the possibility of human pregnancy in flight, we will be facing the unknown: nothing is known about human embryogenesis under low gravity conditions. Would a human foetus develop normally in such situation? Studies in vertebrate animal models have demonstrated critical periods of gravity-sensitivity during embryogenesis [17-18], as well as alterations at the proteome level [19-20]. Development of brain structures and sensory organs (particularly the vestibular system), as well as the cardiovascular system, is likely to be disorganised by the absence of gravity cues. Furthermore, the possibility of a human infant conceived and developed in utero under low gravity conditions returning to Earth at a later point of his life is still unknown, as questions regarding the capacity to recover a vestibular system and sense of equilibrium that functions under Earth-gravity conditions are yet unanswered. In addition to “accidental” and unplanned pregnancy events which may occur, this issue is critical for future attempts of space colonization by humanity.

IV. CHALLENGES FOR THE ADVANCEMENT OF SPACE MEDICINE

Advances in our knowledge of human physiology under deep space conditions are critical to support space conquest by humanity. However, the optimal development of space medicine as a major scientific discipline is hindered by several limitations. Each of these limitations represents per se a challenge that will have to be addressed by members of the biomedical community and politicians alike, if we want to be able to face the new challenges of space exploration safely.

The first limitation that space medicine is facing is a conceptual one. Since the earliest days of the space exploration era, the main focus has always been on the technological aspects rather than on human factors. Space flights have been considered as an engineering and technical issue first and foremost. If the critical issues that humans face in travelling outside of the atmosphere are indeed the technological challenges, the impact of such progress on human health has been under-considered. Space medicine (the practice of medicine on astronauts) was mistaken as astronautical hygiene (technology applied to the prevention or control of exposure to the potential hazards of space flight). Although these two aspects are clearly related and interconnected, their central focus is however different. This situation where the conceptual approach is mostly machine-centered rather than human-centered is related to the training of people involved in space medicine and space research in general, people who are primarily engineers rather than biomedical scientists. For obvious reasons, most of the research in space medicine is performed by national space agencies. Since its beginning, space exploration has evolved within the military context; the history of space conquest has been tightly linked with the military history of the last century. However, in order to face the new challenges of space exploration, space medicine will have to undertake a Copernican revolution, and to re-center their focus on humans.

This first limitation reflects a problem in space medicine education. While each major country maintains numerous excellent aeronautical or aerospatial engineering education programs, very few medical or biomedical university programs specifically oriented towards space medicine or human biology in outer space are available worldwide. A program with a space medicine curriculum should not face difficulties in recruiting students. Indeed, space exploration is a fascinating topic for many young people. However, despite the importance of space medicine for effective human space exploration and colonization, it is surprising to note that incredibly few opportunities for space medicine education are available currently [21]. Thus, despite evoking interest, space medicine training is still a difficult goal to reach [21]. This hinders the future of the field: for a promising student, getting involved in space medicine research can become an obstacle course with too many added barriers that discourage potentially interested individuals [21]. Due to these difficulties regarding curriculum accessibility,the very low number of such curricula, and the fact that they are relatively poorly publicized, recruitment of the most promising candidates from a broad base is compromised. This situation not only leads to a lack of candidates, but also to a consecutive lack of specialists in this field, which could become critical in light of the growing needs and challenges that face humanity.

In addition to these two first issues related to concepts and training, space medicine development also faces two important practical issues. The first practical issue is the limitations linked to the control of gravity conditions. One important difference between Earth and space conditions is gravity. However, manipulating gravity in biology-related experimental settings is something rather complicated to achieve. Although conditions of hypergravity can be reached experimentally on Earth using devices such as rotating chambers or ultracentrifugation, gravity lower than the one observed on Earth is harder to obtain. So far, the best way to conduct scientific experiments in low gravity (microgravity) settings has been to use suborbital or orbital flights or research stations. Obviously, the opportunities are limited, and only few research teams have access to such a possibility. With the increase of suborbital commercial flights, new possibilities are emerging for researchers.

Finally, a major issue slowing down the advancement of knowledge acquisition in the field of space medicine is the relatively small size of the population which can be studied. So far, the population of people exposed to space flights have consisted only of astronauts – mostly highly trained men in an overall excellent health condition. This situation prevented the generalization of experimental data, but also limited the number and type of experimental protocols which could be carried out in an orbital space station. Furthermore, this obviously prevented the development of large preventative epidemiological studies. Such a situation also forced biomedical researchers to greatly adapt research protocols, putting space medicine more in a "reaction" stance rather than in a purely "action" type, investigative, hypothesis-driven research. In addition, some of the most critical questions of human biology and health relevant to space exploration, such as reproduction and foetus development in low gravity, have remained inaccessible, hence unanswered. If the increase in the number of space flights and the greater human variability of space explorers will increase the size of the population, anticipatory efforts will be required in order to avoid dramatic consequences in long-term deep space missions. On the other hand, the increase in the number of space flights will provide new and exciting opportunities for scientists by increasing the size of the population available for study [22].

V. CONCLUSIONS

Space flights, either suborbital flights or longer space exploration missions, are going to become more and more common. What was reserved to limited elite of astronauts will in the near future impact a larger part of the population. This will create problems of public health, but will undoubtedly create fascinating new opportunities. However, to take advantage of these opportunities, the challenges described in this paper will have to be addressed. To face these challenges in due time, the number of experts and researchers working on space medicine and space life sciences will need to be drastically increased, so the biomedical research community will be ready to react to these emerging problems. In this context, the absence of clear training in space medicine is likely to represent a problem: space medicine needs to acquire its autonomy as a mature research field and as an autonomous medical specialty in order to integrate optimally the various aspects of human health in space conditions. Historically, space medicine discoveries contributed to the amelioration of health in the general population. Indeed, understanding of the alterations of human physiology in space coupled with the technological breakthroughs accompanying space exploration have contributed to advancing prevention and treatment of various medical conditions. Thus, increasing research in the field of space medicine will allow us to take full advantage of new opportunities related to the fascinating exploration of this new frontier.

ACKNOWLEDGMENT

This work was supported by the Canadian Institutes of Health Research (CIHR – Grant No. 89699) and by the Natural Sciences and Engineering Research Council of Canada (NSERC – Grant No. 371644). MJG holds a Career Grant from the "Fonds de la Recherche en Santé du Québec" (FRSQ).

REFERENCES

[1] D. DeGroot, J. A. Devine, and C. S. Fulco, "Incidence of adverse reactions from 23,000 exposures to simulated terrestrial altitudes up to 8900 m," *Aviat. Space Environ. Med*., vol. 74, issue 9, pp. 994-997, Sep. 2003.

[2] E. M. Fincke, G. Padalka, D. Lee, M. van Holsbeeck, A. E. Sargsyan, D. R. Hamilton, D. Martin, S. L. Melton, K. McFarlin, and S. A. Dulchavsky, "Evaluation of shoulder integrity in space: first report of musculoskeletal US on the International Space Station," *Radiolog*y, vol. 234, issue 2, pp. 319-322, Feb. 2005.

[3] G. MacPherson, "Altitude decompression sickness susceptibility," *Aviat. Space Environ. Med*., vol. 78, issue 6, pp. 630-631, June 2007.

[4] T. H. Mader, C. R. Gibson, A. F. Pass, L. A. Kramer, A. G. Lee, J. Fogarty, W. J. Tarver, J. P. Dervay, D. R. Hamilton, A. Sargsyan, J. L. Philips, D. Tran, W. Lipsky, J. Choi, C. Stern, R. Kuyumjian, and J. D. Polk, "Optic disc edema, globe flattening, choroidal folds, and hyperopic shifts observed in astronauts after long-duration space flight," *Ophthalmology*, vol. 118, issue 10, pp. 2058-2069, Oct. 2011.

[5] D. W. Latham, T. Mazeh, R. P. Stefanik, M. Mayor, and G. Burki, "The unseen companion of HD114762: a probably brown dwarf," *Nature*, vol. 339, issue 6219, pp. 38-40, May 1989.

[6] M. Mayor, and D. Queloz, "A Jupiter-mass companion to a solar-type star," *Nature*, vol. 378, issue 6555, pp. 355-359, Nov. 1995.

[7] J. P. Beaulieu, D. P. Bennett, P. Fouqué, A. Williams, M. Dominik, U. G. Jørgensen, D. Kubas, A. Cassan, C. Coutures, J. Greenhill, K. Hill, J. Menzies, P. D. Sackett, M. Albrow, S. Brillant, J. A. Caldwell, J. J. Calitz, K. H. Cook, E. Corrales, M. Desort, S. Dieters, D. Dominis, J. Donatowicz, M. Hoffman, S. Kane, J. B. Marquette, R. Martin, P. Meintjes, K. Pollard, K. Sahu, C. Vinter, J. Wambsganss, K. Woller, K. Horne, I. Steele, D. M. Bramich, M. Burgdorf, C. Snodgrass, M. Bode, A. Udalski, M. K. Szymański, M. Kubiak, T. Wieckowski, G. Pietrzyński, I. Soszyński, O. Szewczyk, L. Wyrzykowski, B. Paczyński, F. Abe, I. A. Bond, T. R. Britton, A. C. Gilmore, J. B. Hearnshaw, Y. Itow, K. Kamiya, P. M. Kilmartin, A. V. Korpela, K. Masuda, Y. Matsubara, M. Motomura, Y. Muraki, S. Nakamura, C. Okada, K. Ohnishi, N.

J. Rattenbury, T. Sako, S. Sato, M. Sasaki, T. Sekiguchi, D. J. Sullivan, P. J. Tristram, P. C. Yock, and T. Yoshioka, "Discovery of a cool planet of 5.5 Earth masses through gravitational microlensing,"*Nature*, vol. 439, issue 7075, pp. 437-440, Jan. 2006.

[8] C. Lovis, M. Mayor, F. Pepe, Y. Alibert, W. Benz, F. Bouchy, A. C. Correia, J. Laskar, C. Mordasini, D. Queloz, N. C. Santos, S. Udry, J. L. Bertaux, and J. P. Sivan, "An extrasolar planetary system with three Neptune-mass planets," *Nature*, vol. 441, issue 7091, pp. 305-309, May 2006.

[9] C. Marois, B. Zuckerman, Q. M. Konopacky, B. Macintosh, and T. Barman, "Images of a fourth planet orbiting HR 8799," *Nature*, vol. 468, issue 7327, pp. 1080-1083, Dec. 2010.

[10] L. R. Doyle, J. A. Carter, D. C. Fabrycky, R. W. Slawson, S. B. Howell, J. N. Winn, J. A. Orosz, A. Prša, W. F. Welsh, S. N. Quinn, D. Latham, G. Torres, L. A. Buchhave, G. W. Marcy, J. J. Fortney, A. Shporer, E. B. Ford, J. J. Lissauer, D. Ragozzine, M. Rucker, N. Batalha, J. M. Jenkins, W. J. Borucki, D. Koch, C. K. Middour, J. R. Hall, S. McCauliff, M. N. Fanelli, E. V. Quintana, M. J. Holman, D. A. Caldwell, M. Still, R. P. Stefanik, W. R. Brown, G. A. Esquerdo, S. Tang, G. Furesz, J. C. Geary, P. Berlind, M. L. Calkins, D. R. Short, J. H. Steffen, D. Sasselov, E. W. Dunham, W. D. Cochran, A. Boss, M. R. Haas, D. Buzasi, and D. Fischer, "Kepler-16: a transiting circumbinary planet," *Science*, vol. 333, issue 6049, pp. 1602-1606, Sep. 2011.

[11] J. J. Lissauer, D. C. Fabrycky, E. B. Ford, W. J. Borucki, F. Fressin, G. W. Marcy, J. A. Orosz, J. F. Rowe, G. Torres, W. F. Welsh, N. M. Batalha, S. T. Bryson, L. A. Buchhave, D. A. Caldwell, J. A. Carter, D. Charbonneau, J. L. Christiansen, W. D. Cochran, J. M. Desert, E. W. Dunham, M. N. Fanelli, J. J. Fortney, T. N. Gautier 3rd, J. C. Geary, R. L. Gilliland, M. R. Haas, J. R. Hall, M. J. Holman, D. G. Koch, D. W. Latham, E. Lopez, S. McCauliff, N. Miller, R. C. Morehead, E. V. Quintana, D. Ragozzine, D. Sasselov, D. R. Short, and J. H. Steffen, "A closely packed system of low-mass, low-density planets transiting Kepler-11," *Nature*, vol. 470, issue 7332, pp. 53-58, Feb. 2011.

[12] F. Fressin, G. Torres, J. F. Rowe, D. Charbonneau, L. A. Rogers, S. Ballard, N. M. Batalha, W. J. Borucki, S. T. Bryson, L. A. Buchhave, D. R. Ciardi, J. M. Désert, C. D. Dressing, D. C. Fabrycky, E. B. Ford, T. N. Gautier 3rd, C. E. Henze, M. J. Holman, A. Howard, S. B. Howell, J. M. Jenkins, D. G. Koch, D. W. Latham, J. J. Lissauer, G. W. Marcy, S. N. Quinn, D. Ragozzine, D. D. Sasselov, S. Seager, T. Barclay, F. Mullally, S. E. Seader, M. Still, J. D. Twicken, S. E. Thompson, and K. Uddin, "Two Earth-sized planets orbiting Kepler-20," *Nature*, vol. 482, issue 7384, pp. 195-198, Dec. 2011.

[13] S. Charpinet, G. Fontaine, P. Brassard, E. M. Green, V. Van Grootel, S. K. Randall, R. Silvotti, A. S. Baran, R. H. Ostensen, S. D. Kawaler, and J. H. Telting, "A compact system of small planets around a former red-giant star," *Nature*, vol. 480, issue 7378, pp. 496-499, Dec. 2011.

[14] D. Queloz, "Extrasolar planets: An Earth-sized duo," *Nature*, vol. 482, issue 7384, pp. 166-167, Feb. 2012.

[15] M. J. Guitton, "The immersive impact of meta-media in a virtual world," *Comp. Human Behav.*, vol. 28, issue 2, pp. 450-455, March 2012.

[16] J. Vernikos, and V. S. Schneider, "Space, gravity and the physiology of aging: parallel or convergent disciplines? A mini-review," *Gerontology*, vol. 56, issue 2, pp. 157-166, March 2010.

[17] S. Wakayama, Y. Kawahara, C. Li, K. Yamagata, L. Yuge, and T. Wakayama, "Detrimental effects of microgravity on mouse preimplantation development in vitro,"*PLoS One*, vol. 4, issue 8, pp. e6753, Aug. 2009.

[18] E. R, Horn, and M. Gabriel, "Gravity-related critical periods in vestibular and tail development of *Xenopuslaevis*," *J. Exp. Zool. A Ecol. Genet. Physiol.*, vol. 315, issue 9, pp. 505-511, Nov. 2011.

[19] D. Grimm, P. Wise, M. Lebert, P. Richter, and S. Baatout, "How and why does the proteome respond to microgravity?," *Expert Rev. Proteomics*, vol. 8, issue 1, pp. 13-27, Feb. 2011.

[20] G. Tedeschi, L. Pagliato, M. Negroni, G. Montofrano, P. Corsetto, S. Nonnis, A. Negri, and A. M. Rizzo, "Protein pattern of *Xenopuslaevis* embryos grown in simulated microgravity," *Cell Biol. Int.*, vol. 35, issue 3, pp. 249-258, March 2011.

[21] S. M. Grenon, and J. Saary, "Challenges in aerospace medicine education," *Aviat. Space Environ. Med.*, vol. 82, issue 11, pp. 1071-1072, Nov. 2011.

[22] E. B. Wagner, J. B. Charles, and C. M. Cuttino, "Opportunities for research in space life science aboard commercial suborbital flights," *Aviat. Space Environ. Med.*, vol. 80, issue 11, pp. 984-986, Nov. 2009.

Matthieu J. Guitton is Associate Professor in the Faculty of Medicine of Laval University (Quebec City, QC, Canada), and Senior Researcher and Group Leader in the "InstitutUniversitaire en Santé Mentale de Québec". He obtained his MSc (Neuroscience) from the University Paris VI (France) and his PhD (Neurobiology) at the Faculty of Medicine of the University of Montpellier (France), and did his postdoctoral fellowship at the Weizmann Institute of Science (Rehovot, Israel) as Koshland Scholar. His expertise ranges from sensory systems (particularly auditory system) to multimodal sensory integration, artificial cognition, and human behavior in virtual spaces.