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SURVIVING SPACE: A REVIEW OF THE MEDICAL CONSIDERATIONS OF ACCELERATION FORCE EXPOSURE IN COMMERCIAL SUBORBITAL SPACEFLIGHT

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ABSTRACT

Commercial space tourism is a rapidly growing industry. Not only are people presently paying to travel across the Kármán line and experience microgravity, but it is expected that soon spaceflight may be used for long-distance passenger travel. With a huge increase in the number of laypeople going to space, there is a growing need for medical recommendations to guide private companies in selecting travellers safely.

Exposure to acceleration forces equivalent to those seen in a suborbital spaceflight profile are rare on Earth, and the data surrounding human factors in space and aviation is largely derived from carefully selected individuals with minimal health concerns. There is a growing foundation of literature regarding response to acceleration exposure in the naïve space traveller, with suggestions for medical guidelines being based predominantly on prior research from groups such as the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA).

This review provides a summary of the available evidence on cardiopulmonary function in hypergravity and current medical recommendations for commercial space travel, with an attempt to highlight the important considerations for policymakers and commercial parties responsible for the safety of future suborbital passengers.

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INTRODUCTION

The rapidly increasing interest for commercial space travel brings with it a concern for participants who are perhaps suboptimal in condition. The literature surrounding acceleration forces and their effect on human physiology has been well-described for some time.[1] However, given the data is largely derived from individuals undergoing astronaut training programs or aviation training, conclusions made from this research are difficult to extrapolate to individuals with less ideal health backgrounds.[2]

The goals for safety in suborbital spaceflight will differ from government space missions, in that the role of participants will be largely passive.[3] For financial justification of space tourism, the inclusion criteria for participants will be greatly broadened, hence the reasoning for this research. These differences to traditional government space travel will change the threshold for ‘fitness to fly’.

This new era of space tourism will require targeted research into the appropriate assessment of untrained customers, often referred to as spaceflight participants (SFPs), and strategies in which to prepare them for spaceflight. We also require applicable knowledge concerning absolute and relative contraindications to suborbital spaceflight. The evidence relating directly to respiratory function in suborbital flight is somewhat lacking. This paper will attempt to collate the literature regarding such areas and suggest important considerations to ensure medical safety in the future.

For suborbital flight in its current form, health issues posed are less significant than orbital travel given the time of flight. However, it is widely hypothesized that suborbital spaceflight in some form will eventually be used for long-distance passenger travel.[4] Further to this, SpaceX have long-term goals of reshaping the travel industry to provide across-the-world flights in around 30 minutes, having already undertaken orbital flights for commercial passengers.[5] This may produce longer exposure to high acceleration forces, microgravity and other potentially risky components of space travel.

SUBORBITAL SPACEFLIGHT

For the purposes of this paper, the dynamics of the New Shepard spacecraft flown by Blue Origin will be considered. It is important to note that other private providers, both current and future, will have varying flight profiles and module designs. Hence, some information may not directly relate to the same.

The New Shepard mission is controlled autonomously by inflight computers, with no human pilots.[6] The expected flight profile has several sustained (long) accelerations and decelerations throughout, reaching a maximum of +2.87G on ascent and +5.12G (both toward Earth) on re-entry within the crew capsule. Transient (short) accelerations are projected to reach up to up to +32G over 50ms, provided by thrusters fired to maintain appropriate attitude. Air pressure within the cabin is to be maintained at 10.1-14.2psi, approximating that of the Earth’s atmosphere within the ‘physiological zone’. The flight profile is shown in figure 1.

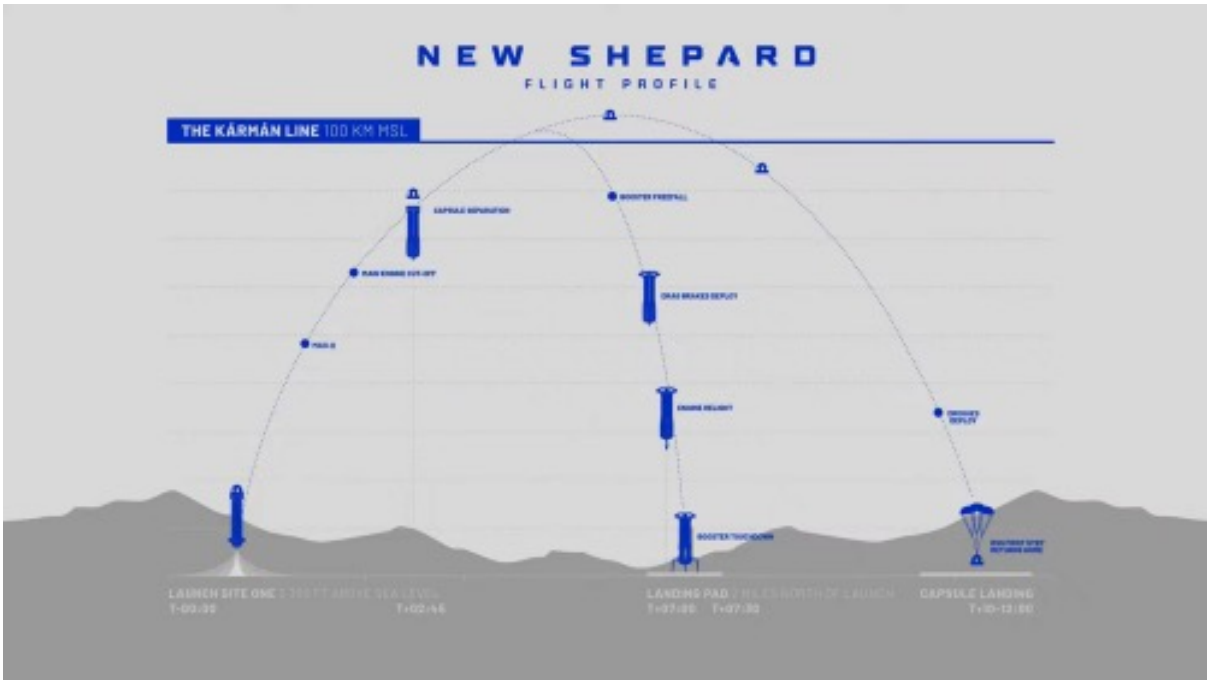

Figure 1: New Shepard Flight Profile[7]

The SFPs are in a supine position, exposing them predominantly to axial acceleration forces (+Gx). This positioning is in accordance with a traditional rocket launch such as the Russian Soyuz, which is used to enhance G tolerance.[8] A slight forward head-tilt substitutes a minor amount of this $+G_x$ force with some $+G_z$ acceleration.[9]

Interestingly, the pre-flight SFP training for the New Shepard is reportedly completed in 2 days.[10] According to FAA regulations for suborbital commercial flights, the only legally required training for SFPs in the United States is how to respond to emergency situations, including smoke, fire, loss of cabin pressure, and emergency exit.[11] This indicates that there is no required training for acceleration force exposure prior to flight. The full curriculum of the Blue Origin training program is not made publicly available, so whether or not it is included is unknown.

ACCELERATION FORCES – CARDIOVASCULAR AND RESPIRATORY EFFECTS

Vertical acceleration forces (Gz)

Vertical forces from head-to-toe ($+G_z$) are known to cause musculoskeletal pain or injury, ventilation-perfusion mismatch due to disrupted air and blood flow, and cardiovascular effects via hydrostatic pressure changes and venous pooling in the limbs.[8]

Lung volumes are affected greatly, with a drop in vital capacity and an increase in functional residual capacity as the diaphragm is pushed downward. The regional differences in lung ventilation are accentuated; the weight of the lung increases towards the base, where the alveoli will approach their closing pressure and shut prematurely. This causes air trapping and prevents basal lung ventilation.

Similarly, regional pulmonary blood flow is affected. Normally, the lung apices are poorly perfused to around 1-2cm. At $+4G_z$, the top half of the lung is no longer perfused. The bottom half of the lung has a relative increase in blood flow from increased hydrostatic pressure below the heart. However, the aforementioned air trapping increases the pressure and consequent vascular resistance, which contributes to a lower arterial pressure.

Overall, a marked alteration in the ventilation-perfusion ratio at the lung bases causes a right-to-left shunt, which is estimated at 50% of cardiac output during $+5G_z$.

Acceleration atelectasis may also occur with inspiration of high oxygen concentration, causing a further shunting of 20-25% of cardiac output which can be precipitated within 30 seconds of $+G_z$ exposure.[12]

Foot-to-head acceleration forces $-G_z$ work in an opposite fashion.[8] The cardiovascular effects result in a sensation of increased pressure in the head accompanied by severe discomfort; thus pilots tend to have a lower threshold for $-G_z$. A massive parasympathetic response is seen due to increased carotid sinus baroreceptor stimulus, leading to a vagal response with bradycardia, asystole or unconsciousness. This leads to accentuated effects of any $+G_z$ forces immediately after, known as the "push-pull effect".

Axial acceleration forces (Gx)

Axial acceleration is known to be less influential on human physiology than $+G_z$.[8] The cardiovascular effects are relatively minimal, and pulmonary changes are typically responsible for limitations to $+G_x$ exposure.

The intrabdominal contents displace the diaphragm upwards, restricting inspiratory and expiratory capacities. The ventilation-perfusion distribution pattern is similar to that of an upright position, but instead from an anterior-posterior perspective. At $+6G_x$, there is minimal ventilation of the posterior one third of the lungs, with a right-to-left shunt dropping arterial saturations to 80-87%.

These breathing difficulties can be minimised with a 15-25° forward head-tilt. A caveat to this positioning is the small head to toe ($+G_z$) hydrostatic pressure gradient introduced.

A crucial centrifuge study from Pollock, Jolley et al. uncovered key physiological changes in respiration under acceleration.[13] There was evidence of reversal of normal ventilation distribution from posterior to anterior, resulting in gas-trapping anteriorly (proportional to $+G_x$ magnitude). There was an increase in neural respiratory drive (and therefore breathlessness) that was not accompanied by an increase in overall ventilation, due to the decrease in tidal volume. This phenomenon was termed "neuroventilatory uncoupling". Work of breathing and neural respiratory drive were both higher than values seen in severe COPD or obesity. These effects were comparable to a short-lived respiratory failure which may not be tolerated well in older, unhealthy people. Importantly, 73% of subjects reported musculoskeletal chest pain with exposure above $+4G_x$, and a small proportion reported persistent pain 2 days after testing.

Another 2021 study furthered this knowledge by showing that at $+4G_x$ (but not $+6G_x$) participants varied in their ability to compensate for the pulmonary effects of hypergravity with muscle force, which was dependent on their physical fitness.[14]

A 2003 study hypothesized that posterio-anterior acceleration ($-G_x$) was less impactful on arterial oxygenation than $+G_x$.[15] Currently, this is rarely seen given the need for controls and visibility in front of the pilot.8 In $-G_x$, unventilated anterior lung is comparably improved to $+G_x$, with arterial saturations increasing from 80% to 94%, resulting in an increased tolerance.

G Force Mitigation Strategies

From what can be ascertained in a recording of a Blue Origin New Shepard flight in 2022, the SFPs do not attempt anti-G straining manoeuvres, nor do they wear anti-G garments.[9] Most of the acceleration appears to be $+G_x$ with a small forward tilt leading to some $+G_z$ force. This slight offset of the force vector may support breathing as the anterior chest wall weight will be decreased, improving the ventilation-perfusion mismatch. Substituting this force is a minor amount of $+G_z$ acceleration which, if tolerable from a cerebral perfusion perspective, may provide a safer descent to Earth.

Microgravity (μG)

The presence of microgravity offers a unique environment in space. Both ventilation and perfusion appear more homogenous in microgravity compared to the standard heterogenous distribution across the lung on Earth's gravity.[16] Despite this, it has been demonstrated that different lung regions are still exposed to different volumes of ventilation despite being in microgravity. This complicates the idea of gravity-affected ventilation patterns. However, it may be assumed that this inherent change in ventilation is minor enough that it is overcome when introducing increased acceleration force.

Pressurised cabins

Hypoxia risk due to ventilatory impairment in suborbital flight may be amplified by the lower atmospheric pressure of the cabin, an effect similar to that seen in standard airplane passengers.[17] The aforementioned study from Pollock, Jolley et al. showed that with subjects exposed to $+6G_x$ for a sustained period, minimum arterial oxygen saturation was 7% lower when comparing air to 15% oxygen inspiration (simulating an airline-style cabin pressurisation).[13] The authors concluded that respiratory physiology is disrupted by suborbital spaceflight, potentially "…causing substantial hypoxemia and breathlessness that are exacerbated by simulated pressure cabins." [13]

MEDICAL CONDITIONS AFFECTED BY ACCELERATION

In a similar fashion to current international passenger flights, recommendations regarding flying with comorbidities will likely be adopted with the introduction of point-to-point suborbital space travel. For the time being, the small volume of data from actual commercial suborbital flights and from simulated centrifuge studies has meant that recommendations and suggestions are merely estimations of what is acceptable medically for these flights.

Interestingly, the Federal Aviation Administration (USA) acknowledge the novelty of ordinary untrained individuals going to space, but omit any specific recommendations and adopt an approach of informed consent.[18] The current regulations (continuing through 2023) "require crew and spaceflight participants to be informed, in writing, of mission hazards and risks, vehicle safety record, and the overall safety record of all launch and reentry vehicles." [19]

Minimal government oversight is clearly in the best interests of commercial parties. Less regulation will allow spaceflight providers to broaden their prospective customer base by minimising restrictions on medical requirements for flight, thus increasing financial feasibility.

Some of the earliest articles regarding medical guidelines for commercial spaceflight participants were published by the Aerospace Medical Association Task Force on Space Travel in the early 2000s.[20] They provided broad recommendations, with an emphasis on the need for special consideration for those with "… unstable conditions or an underlying disposition for sudden incapacitation". They also made note of the significance of having little to no medical supplies on board in the event of a medical emergency. Law et al.[21] later attempted to identify concerns using previous data from NASA. These authors highlighted the high risk of behavioural and psychological conditions, as well as environmental concerns such as microgravity adaptation sequalae and acute musculoskeletal injury. These themes have been consistent throughout the literature ever since.[3]

The Federal Aviation Administration sponsored a report written by the Center of Excellence for Commercial Space Transportation (COE-CST) evaluating the medical requirements for aircrew and SFPs.[22] A table was developed outlining what a consortium of experts believed to be the pertinent points of a medical history and examination for an aerospace medicine specialist that would be significant to an SFP for a suborbital flight (Table 1).

History	Physical Examination
Otitis, sinusitis, bronchitis, asthma, or other respiratory disorders	Vital signs (heart rate, blood pressure, respiratory rate, and temperature)
Dizziness or vertigo	Head, face, neck, scalp exam
Fainting spells or any other loss of consciousness	Nose, sinuses, mouth, throat, and ears (including eardrum integrity & function and Eustachian tube function)
Seizures	
Tuberculosis	Ophthalmologic evaluation (including pupil function and ocular motility)
Surgery and/or other hospital admissions	
Mental disorders, anxiety, or history of hyperventilation	Lungs and chest
Claustrophobia	Upper extremities
Attempted suicide	Lower extremities
Use of medications	Spine
Alcohol or drug dependence or abuse	Lymphatics
Current pregnancy, recent post-partum (less than 6 weeks), or recent spontaneous or voluntary termination of pregnancy	Rectal, pelvic, and breast exams will be performed only if indicated by medical history
Visits to a health care provider in the last 3 years	Heart (including precordial activity, rhythm & rate, sounds, and murmurs)
History of decompression sickness (DCS) or the “bends”	Peripheral vascular system
Anemia or other blood disorders	General neurological evaluation
Heart or circulatory disorders, including implanted pacemaker or defibrillator	General psychiatric evaluation (appearance, behavior, mood, communication, and memory)
Disability or deformity requiring accommodation	Abdomen and viscera (including hernia)
Recent significant trauma	Genitourinary system
Diabetes	
Cancer	
Rejection for life or health insurance	
Given the specific flight parameters, are there any known medical conditions that may require possible accommodation	

Table 1: COE-CST recommendations on appropriate history and physical examination components for a suborbital SFP medical review.[22]

They outlined the need to address conditions that may lead to certain outcomes, such as in-flight death, preventing appropriate function during emergency, or putting excessive risk of harm on any SFP or crewmember. For any prospective SFP that had a condition meeting these criteria, risk mitigation strategies were recommended such as training (e.g., parabolic flight, hypoxia exposure, centrifuge exposure, etc.) or re-evaluation after medical intervention.[22]

Over the last decade, a series of articles have been published by Blue et al. regarding different medical conditions and how they are influenced by centrifuge-simulated suborbital spaceflight profiles.[23] Collectively, these articles indicate that the acceleration forces experienced during nominal suborbital spaceflight in its current form will likely be well-tolerated by most individuals with well-controlled medical conditions.[23-27] This research included patients with various health backgrounds and conditions that will be discussed below.

Pulmonary Conditions

Fifteen subjects with either asthma, chronic restrictive lung disease, or a history of lung surgery were included. This pulmonary subgroup of participants had significantly increased subjective work of breathing, with more instances of coughing during $+G_x$ exposure. The authors hypothesised that acceleration atelectasis caused increased airway reactivity under high G. However, these participants showed no evidence of adverse clinical events and did not require medical intervention. Furthermore, those with a smoking history showed no correlation with increased work of breathing, dyspnoea, or chest discomfort.

An area of concern is for individuals ordinarily at risk of hypoxia. Evidence surrounding respiration in $+G_x$ exposure shows that anterior air trapping and neuroventilatory uncoupling lead to an effect similar to a short-lived respiratory failure.[13] It is hypothesised that some populations will not cope with this ventilatory impairment, such as those with chronic obstructive pulmonary disease.[28] A decreased cabin pressure may contribute to this. Research is needed to address these potential relationships.

Cardiac Conditions

Chronically hypertensive subjects in the centrifuge study experienced less greyout; this was attributed to the protective nature of baseline hypertension.[23] They showed no other significant differences to control subjects.

Neither of the two subjects with implanted permanent pacemakers had abnormal physiological responses, and there was no evidence of lead displacement, damage, or malfunction of either implanted device.[25] A larger sample size is needed to verify these results, but the evidence showed that it may certainly be possibility that patients with cardiac implanted devices will be able to tolerate suborbital spaceflight. Similar conclusions were made for those subsets of patients with cardiac malformations or insulin pumps.[24, 26]

Cardiac dysrhythmias have long been known to occur frequently in exposure to $+G_z$ exposure.[29] Premature ventricular contractions and premature atrial contractions are both common.[30] Transient ventricular tachycardias have been seen in centrifuge studies, but these spontaneously resolved with termination of the run and did not produce any clinical signs, nor did they require intervention.[29] It has been stated that most aberrant rhythms associated with $+G_z$ are benign and self-limiting.[30] Another study related to the 2014 centrifuge study by Blue et al. found that a relative bradycardia was the most commonly seen dysrhythmia in the subjects' exposure to $+G_x$, but concluded it was a benign finding.[27] The authors hypothesised that $+G_x$ led to aortic and heart compression, increasing pressures, and consequently triggering the baroreceptor reflex. Provided SFPs are subjected to $+G_z$ as well as $+G_x$, the authors believe that the vertical acceleration force may provoke enough sympathetic response to attenuate the incidence of bradycardia.

Obesity

Tolerance to $+G_x$ is typically limited by the increased work of breathing due to the anterior chest wall and abdominal content weight pushing on the lung.8 Therefore, increased BMI may have a considerable effect on tolerance, by exacerbating ventilatory compromise and arterial saturation drop, potentially precipitating adverse clinical events. This is especially prudent given the evidence that obese individuals already devote a higher percentage of total oxygen demand towards respiration, which predisposes them to respiratory failure in the setting of hypoxia.[31]

Other associations with obesity include an increased oxygen consumption and obesity hypoventilation syndrome.[32, 33] The relationship between these features and $+G_x$ lung effects is unknown, but it is reasonable to assume there could be a further predisposition for respiratory compromise given the increased oxygen burden, increased weight of the chest wall, and inherent complications with respiratory drive.

More research is needed to clarify this link, which may provide recommendations for safe weight parameters in suborbital flight. Anthropomorphic characteristics will also influence seating equipment, weight distribution and emergency egress. This is one example of many concerns that require further study to develop holistic guidelines for pre-flight medical reviews.

Age

The age of commercial SFPs will be different than that of historical astronauts. In 2021 Wally Funk and William Shatner consecutively broke the world record for the oldest person to reach space, aged 82 and 90 respectively.[34] The elderly, who were once considered ineligible for spaceflight, will soon be flying above the Kármán line. So too will younger individuals, with the first Blue Origin commercial flight taking the youngest person into space at the time, Oliver Daemen.[35]

The 2014 centrifuge study showed no significant haemodynamic, subjective or neurovestibular differences associated with age.[23] The only noticeable change in older patients was a lower incidence of greyout during acceleration due to a higher baseline mean arterial pressure (protective of greyout).

Despite promising results, the prevalence and types of disease, and the frailty of older participants cannot be ignored. Just as the extremes of age influence commercial airline flight suitability, they will undoubtedly have an effect on participation in suborbital spaceflight. There is a wealth of literature regarding the increase in alveolar to arterial gradient with age.[36] In a similar manner to obesity, it is hypothesised that there may be an additive effect of this age-related mismatch to that of acceleration exposure, further predisposing the elderly to respiratory compromise. Age may also be further implicated in tolerance for $+G_x$, given evidence that physical fitness an effect on pulmonary compensation.[14]

Medications

Medication in aviation is a continually evolving field with the constant introduction of new pharmaceutical developments, and changes in aircrew demands and expectations. All medications are considered hazardous by Australia's Civil Aviation Safety Authority (CASA), with the exception of a small number.[37] There are many medications with potentially dangerous side effect profiles for aviation; the same applies for aerospace travel and suborbital flights, but to a lesser extent given the passive role of SFPs.

A great example of this is the use of adrenergic antagonists, specifically beta blockers. The 2014 centrifuge study by Blue et al.[23] showed that the heart rate of subjects taking beta blockers significantly lowered when exposed to acceleration forces as expected. Despite this response, they did not exhibit any adverse effects or clinical signs, and it was determined that suborbital flight would be no more harmful for these subjects in comparison to those not on beta blockers. Suresh et al.[27] went on to discuss the effects of relative bradycardia and came to a similar conclusion, but emphasised the possibility that these medications may lower tolerance of dysrhythmias and lead to clinical decompensation.

RECOMMENDATIONS

Guidelines for spaceflight

Developing guidelines for medical assessment prior to suborbital spaceflight requires much more data than is currently available. The centrifuge studies have proven useful in showing that most patients with well-controlled chronic conditions will tolerate acceleration on launch and re-entry.[23] Currently, the COE-CST recommendations may be employed by aerospace medicine specialists as a guide to screening SFPs for potential illness relevant to their flight.[22] As more data are gained from an increasing population of suborbital flight passengers, the goal is that these guidelines can be reviewed and refined.

One reasonable method of assessing SFPs pre-flight was suggested by Schroeder et al., which is to stratify individuals into risk categories to determine any need for risk mitigation prior to flight. This will allow practitioners to devise suitable plans for future SFPs (which will be discussed in the next section of this paper).

Exclusion criteria used in the 2014 centrifuge study by Blue et al. included extremes of blood pressure, a HbA1c above 8.0%, continuous supplemental oxygen requirements, implanted defibrillators, and a number of other conditions.[23] A similar list, albeit less stringent, may be used to determine individuals who are either not fit to fly, or who may need further evaluation or risk mitigation prior to flying.

Research is needed in a multitude of fields to develop standardised guidelines. This should primarily include data pertaining to acceleration forces and their effect on common physiological states and pathophysiological conditions. The centrifuge studies conducted by Blue et al. in 2014 only represented a small portion of conditions.[23] Some areas that need to be addressed include but are not limited to SFPs of increasing age or weight, and those with common medical conditions such as hypertension, diabetes, lung disease and musculoskeletal disorders. Hopefully this may lead to a well-defined list of absolute and relative contraindications to suborbital spaceflight that can be used worldwide. Recommendations regarding medications are also needed. The evidence concerning drugs in aviation may be adapted to suborbital spaceflight, with recognition of the change in scope as individuals move from the active responsibility of aircrew to the passive SFP role.

In-flight medical emergencies will eventually occur during suborbital spaceflights, regardless of any risk mitigation strategies in place. Recommendations differ for which medicines and medical equipment should be available on commercial spaceflights. A starting point may be to include those seen onboard commercial aircraft, with the addition of anything specific to spaceflight, such as anxiolytics given the high prevalence of anxiety seen in previous studies.[38, 39] Autonomous flights require a different strategy considering the lack of trained crewmembers available to administer treatment.

In the long-term, with the growth of a point-to-point space travel industry, commercial feasibility will require a much broader base of potential customers, thus relaxing many of the rules regarding medical fitness to fly. Individualisation of review will be necessary to ensure patient safety whilst increasing the number of potential customers.

Centrifuge training

Centrifuge training would be beneficial for selection and preparation of SFPs. Firstly, it will allow for individualised evaluation of patients from a medical point of view, whilst providing a safer environment with more immediate access to medical intervention if required.[13] Secondly, it may assist in reducing anxiety for the actual flight – particularly by using high-fidelity centrifuge simulations with acceleration profiles closer to that of a suborbital flight – which should contribute positively to customer experience and satisfaction.[38] Finally, it will provide data for individual variability of reactions to acceleration which may be used for further research.

Difficulties with the simulation of hypergravity including access and cost are current barriers to centrifuge training. There is also concern that a ‘push-pull effect’ akin to that seen in fast jet aviation will be present in a suborbital flight profile.[23] The inability to effectively simulate microgravity in between periods of hypergravity render studies pertaining to this difficult to approach.

Parabolic flight, hypoxia training (e.g. hypoxia training devices or hypobaric chambers), and emergency egress training have also been suggested as methods to increase patient comfort and safety.[3, 40] G-force resistance training (i.e. anti-G straining manoeuvre education) seems to be impractical given the minor magnitude of $+G_z$ in suborbital flight.

Participant enjoyment is paramount to suborbital spaceflight, so minimising training time where possible is crucial.[42, 43] Research shows that increased length of centrifuge exposure is less impactful than high-fidelity simulation.[38] More training also incurs higher costs for commercial providers. Therefore, it is expected that short, high-fidelity centrifuge training may have beneficial effects without impacting negatively on participant experience. In the future, this training may be useful for assessing only those deemed to be at high-risk of medical compromise.

Medical Safety Management System

Development of a Medical Safety Management System (MSMS) has been proposed to provide a 'business-like approach' for the detection and mitigation of medical risks in suborbital spaceflight.[3, 42] This strategy was described in depth by Antuñano et al.[3] The four key principles of such a system are the policy, risk management, assurance and promotion of medical safety. The overarching basis of an MSMS is to ensure that every space vehicle occupant is provided with appropriate medical screening, training and monitoring throughout each stage of spaceflight, and that there is an organised method of risk assessment and risk management that will provide the best medical safety for current and future customers.

Given expectations that the commercial space tourism industry is likely to grow exponentially in coming years, there is an opportunity to create something of a universal database to log in-flight events and guide further recommendations for flight.[40] This was supposedly suggested for the commercial aviation industry, but did not occur as the idea was envisaged too late in the development of the sector.[40] Ideally, an international database could be setup before private companies start collating their own data individually without standardisation. Unfortunately, there are some major challenges that will likely prevent such a database from being created. Financial costs, privacy issues, commercial competition and liability concerns all present hurdles that will most likely prevent this from being created.[42]

Therefore, it is recommended that private providers of commercial suborbital spaceflight adopt an MSMS that ensures maximum participant availability for financial viability without compromising on safety.

CONCLUSION

Space travel does not come without its risks, both known and unknown. As outlined by NASA regarding a trip to Mars; space radiation, isolation, distance from Earth, gravity fields, and hostile/closed environments are expected to have a profound impact on the human experience of space.[44] Exactly which of these and how they may apply to commercial suborbital space flight is not yet known. Whilst human safety has always been paramount in the pursuit for furthering our knowledge of the universe, the surge in space commercialisation this millennium has seen an ever-increasing propensity for companies attempting to innovate the field without fear of failure.[45]

At the time of writing, very few commercial passengers have experienced suborbital space flight. With increasing push for private spaceflight, this number is expected to drastically increase over the coming years.[4] Collective flight data over time should provide more insights into how best to prepare these inexperienced patients for flight.

Perhaps this modernisation of space exploration, together with the need for more primary data, will allow medical professionals to quickly gain a better understanding of the effects of suborbital spaceflight on the ordinary individual and how medical policy and guidelines pertaining to the safety and efficiency of human suborbital flight can be provided.

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