Acta Astronautica 201 (2022) 224–229

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Exercise countermeasure preferences of three male astronauts, a preliminary qualitative study

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ARTICLE INFO

Keywords:
Astronaut
Spaceflight
Exercise countermeasures
Astronaut preferences

ABSTRACT

Background: A single flywheel exercise countermeasure has been chosen for use on-board the Orion Multi-Purpose Crew Vehicle for spaceflight missions of up to 30 days. As previous missions have typically involved the use of multiple exercise countermeasures there is a concern that the use of only flywheel may lead to boredom and reduce astronaut adherence to exercise prescriptions, presenting a risk to their health and the operational success of the mission. To determine if this will be a concern, this qualitative work identified astronaut-reported operational considerations for the implementation of an exercise countermeasure device for use during spaceflight, and if current plans for the implementation of a single flywheel exercise countermeasure device may affect astronaut adherence to exercise prescriptions.
Methods: The responses of three male astronauts to an open-ended qualitative survey were analysed using thematic analysis. All participants were required to currently be taking part in, or have previously taken part in, human spaceflight.
Results: Astronaut preferences for the use of an exercise device during spaceflight were categorised into three broad themes: exercise device ease of access, motivational and behavioural considerations, and operational and technical considerations. The three astronauts considered a single flywheel-based exercise device suitable for use as the sole exercise countermeasure on-board the Orion MPCV, and similar capsular spacecraft, so long as it met several conditions. The device should engage astronauts in a varied exercise prescription. The device should also meet the physiological expectations required of exercise countermeasures for spaceflight deconditioning. The device should be enjoyable to use, and measures should be put in place to reduce boredom (via variety in exercise prescription). The device should be easy to access in terms of both use and setup/takedown. Finally, the device should only be used without other exercise countermeasures for missions of 30 days or less.
Conclusion: Individual crewmember preferences should be taken into consideration following crew selection to ensure the greatest adherence to exercise prescriptions. The data reported here should be used to supplement, not entirely inform, the development and use of future exercise countermeasures.

1. Introduction

Exposure to microgravity during spaceflight results in the deconditioning of human physiological systems due to the unloading of the body [1]. Physiological deconditioning may then affect crew performance and safety, impacting the capabilities of astronauts to perform prolonged or strenuous tasks [2]. While physical exercise is used as a countermeasure to reduce or prevent microgravity deconditioning [3], a previous systematic review of grey literature has indicated that future exploration spacecraft may be limited by technical constraints that would present major challenges to the use of current exercise countermeasures [4].

For one of these future spacecraft, the Orion Multi-Purpose Crew Vehicle (MPCV), NASA has opted to use a single flywheel exercise countermeasure for missions of up to 30 days [5]. One concern for the use of a flywheel exercise device is that astronauts may become bored using only a single exercise device [5]. Previous studies have indicated boredom is a risk factor in failing to adhere to exercise prescriptions [6], and failure to adhere to exercise prescriptions during spaceflight could result in health risks to the astronauts and impact the chance of operational mission success [2]. It is important to determine if astronauts

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https://doi.org/10.1016/j.actaastro.2022.09.012
Received 28 March 2022; Received in revised form 18 August 2022; Accepted 6 September 2022
Available online 14 September 2022
0094-5765/

would become bored using a single exercise countermeasure. Furthermore, it is unclear if astronauts would be comfortable with the use of only a single exercise countermeasure device, as previous exercise prescriptions during spaceflight have often involved multiple exercise countermeasure devices [7,8]. To assist in the prescription of exercise countermeasures for use on-board future spacecraft, such as the Orion MPCV, it would be beneficial to carry out a qualitative survey of astronauts to identify astronaut preferences for the use of exercise countermeasures during spaceflight, including if the use of a single exercise countermeasure would be preferable to them for use during a spaceflight mission of up to 30 days, and what additional design considerations may need to be accounted for.

Reflexive thematic analysis, the approach to qualitative research used here, is a widely used method in sport and exercise research [9]. Thematic analysis can be used to identify, analyse, and report common themes (patterns of meaning) across the experiences of participants within a qualitative dataset, such as interview transcripts [10]. This can be useful for informing policy or decision making, generating patient-reported insights, and generalising large bodies of data [10]. In this study, we use such an approach to identify the common preferences for exercise countermeasure use and make some preliminary recommendations based upon the experiences of three male astronauts. Thematic analysis considers and reflects upon the common (shared) experiences of individuals [10], and is not necessarily intended to be generalised to wider populations, and may not represent the positions, feelings, or opinions of astronauts in general. It is implemented here as a preliminary approach to consider the individual experiences and concerns of this sample of astronauts in relation to the use of exercise countermeasures during spaceflight. Likewise, this qualitative analysis does not evaluate the effectiveness of any exercise countermeasure to combat the adverse effects of microgravity exposure. It only seeks to understand and find patterns of meaning relating to the sample's preference for the use and implementation of exercise countermeasure devices.

The aim of this qualitative work is to identify astronaut-reported operational considerations for the implementation of an exercise countermeasure device for use during spaceflight. The study also aims to determine if current NASA plans for the implementation of a single flywheel exercise countermeasure device may affect astronaut adherence to exercise prescriptions.

2. Method

2.1. Approach

A qualitative survey was used to explore astronaut operational considerations and preferences for the design and development of exercise countermeasures for use during spaceflight beyond low-Earth orbit, including the use of a single exercise countermeasure device (flywheel) for use on-board the Orion MPCV.

2.2. Participants

Three male astronauts (mean age = 57.7 ± 9.07 years) were recruited via purposive sampling [11] to take part in this survey. All participants were required to currently be taking part in, or have previously taken part in, human spaceflight. No additional demographic information was collected.

2.3. Materials

An open-ended, six question survey was designed by and implemented using the online survey platform Qualtrics [12]. The questions aimed to elicit the preferences and considerations that astronauts believe to be most important for the development and implementation of an exercise countermeasure during long-duration spaceflight, and consisted of the following questions:

1: What factors would you consider most important to you for the design of an exercise countermeasure device for use during spaceflight, and why?
2: Would you prefer to use multiple exercise devices during spaceflight or a single exercise device? Why is this the case?
3: Would you feel bored using only a single exercise countermeasure device? If so, how do you think this boredom might impact you?
4: Would you feel less likely to engage fully with an exercise prescription during spaceflight if there was only a single exercise device? Why is this the case?
5: Thinking about your health and wellbeing, would you feel confident using only a flywheel exercise countermeasure device for a mission of 30 days or less beyond low Earth orbit? Why is this the case?
6: Is there anything else that you would like to add?

2.4. Protocol and procedure for analysis

Ethical approval was received for this study from Northumbria University's Health and Life Sciences Ethics Committee. All data were collected through the online survey platform Qualtrics, where participants were provided with an information sheet so that they could provide informed consent to take part in the survey. After providing informed consent, participants then answered the six open-ended questions. Upon completion of the survey, participants were provided with a debrief sheet detailing the nature of the study. In total, the study was estimated to take between 5 and 10 min to complete.

To analyse the data, Braun and Clarke's 6-step process of reflexive thematic analysis was implemented [9,10]. A more inductive approach, in which coding and them development are driven by the content of the data, rather than by existing concepts of ideas [10], was used. It is worth highlighting that this does not exclude the influence of existing concepts and ideas. The separation between the orientational approaches to reflexive thematic analysis are not always fixed and exist as more of a continua [9]. In particular, the approach to the dataset incorporates semantic (coding and theme development reflect explicit content within the data set) and critical realist interpretations (focusing on reporting an 'assumed reality' evident within the dataset) [13]. NVivo qualitative data analysis software [14] was used to code and analyse the data (See Supplementary Material for the full transcript).

3. Results and discussion

The main finding of this study was the grouping of astronaut preferences for an exercise device during spaceflight into three common themes:

- Exercise device ease of access: this refers to codes relating to the accessibility of the exercise device, including the set-up, take-down, and ease of use.
- Motivational and behavioural considerations: these are concerned with psychological factors that affect the behaviour of the crew in relation to exercise, including enjoyment, boredom, and psychosocial considerations.
- Operational and technical considerations: these are concerned with the structure, function, and effectiveness (both physical and psychological) of exercise countermeasures, and how the mission profile (e.g. long, or short-term spaceflight, type of spacecraft) may affect exercise use.

These themes and the codes they relate to are displayed in Fig. 1.

When asked what factors were most important for the design of an exercise countermeasure, ease of access requirements were common across all the astronauts, who suggested that "ease of use" (Participant

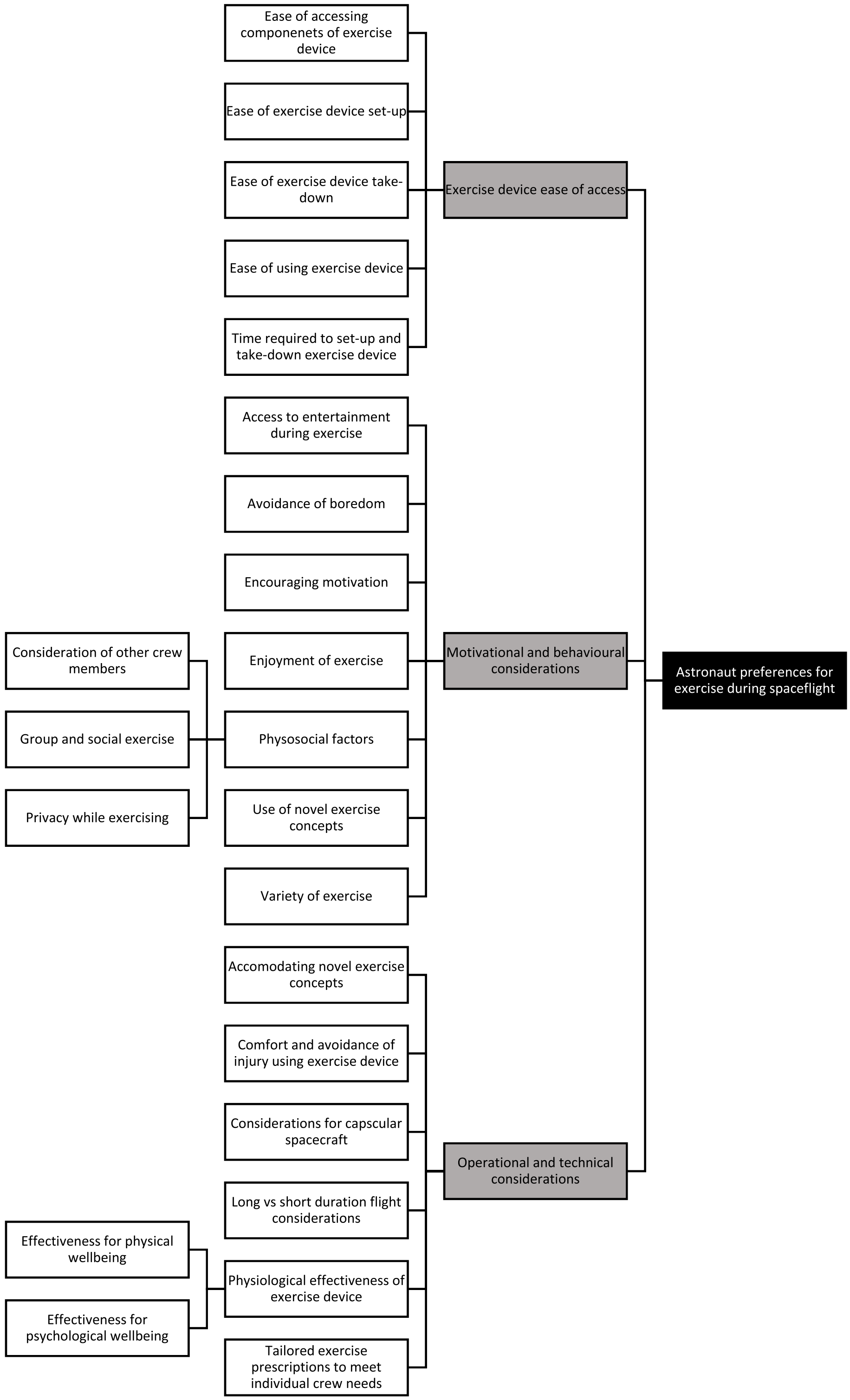

Fig. 1. Thematic map displaying codes and common themes related to astronaut preferences for exercise device considerations during spaceflight.

1), "ease of set-up" (Participant 2), and ease of setup and takedown" (Participant 3) were among the most important design considerations to them for the use of an exercise countermeasure during spaceflight. Participant 3 further suggested that ease of setup should be considered "in terms of time spent searching for parts", indicating that astronauts may prefer to have an exercise device that is either easy to assemble and disassemble, or remains fully assembled and in place. Participant 3 suggested that ease of access and use of the exercise device may be as or more important than the number of exercise devices chosen: "one device is fine, especially if it means that device can remain assembled in place, so it is easy to use", reflecting a common preference for the exercise device to be easily accessed and easy to use.

Ease of access for the exercise countermeasure was not the only factor considered among the most important to the astronauts. Several motivational and behavioural factors, and operational and technical factors were also identified. In terms of operational and technical considerations, the astronauts highlighted the need for the exercise countermeasure to be effective for relevant outcome measures. Participant 1 suggested that the exercise device should cover “a broad range of exercises”, be “practical”, and “appeal to a broad range of possible activities (both in terms of offering a full body workout and different types of exercise e. g HIT vs endurance) and crewmember preferences”, and that the device should be “contributing to both physical and mental wellbeing”. This indicates that one of the primary concerns for the astronauts is that the exercise countermeasure is effective for protecting relevant health outcomes, including both musculoskeletal and cardiovascular deconditioning, and psychological wellbeing during spaceflight. This sentiment was echoed by participant 2 who, in response to being asked what their most important considerations for the design of an exercise device was, said “replication of terrestrial loading, so as to avoid musculoskeletal deterioration during flight” and, when asked if they would prefer multiple exercise devices or a single exercise countermeasure, that the exercise countermeasure should include “multiple exercises for variety and to assure total body exercise”. This both highlights the importance of the exercise countermeasure being effective for relevant health outcomes, and that a single exercise device may be suitable for use so long as it provides multiple exercises and variety.

The desire for “multiple exercises for variety” (participant 2) in the exercise prescription was a common outcome discussed by all three astronauts. For example, participant 1, echoing earlier statements from participant 2, suggested that if this variety in exercise is achieved it would potentially overcome the need to use multiple exercise devices:

“Multiple devices currently offer a variety of different exercises and the ability for multiple crewmembers to train at the same time. However, this is not high on my priority list. If a new, single, device could offer a similar variety of exercises then a single device would suffice.”

Participant 3 appeared more conflicted about the use of a single or multiple exercise countermeasures to achieve variety, as when they were asked if they would prefer to use multiple exercise devices or a single device they responded “multiple. Otherwise the exercise time can be tedious”. However, when asked if they would fully engage with an exercise prescription using only a single exercise countermeasure, they suggested that “one device is fine, especially if it means that device can remain assembled in place, so it is easy to use. However, the routine should vary”, echoing the calls of the other astronauts for a varied routine in their exercise prescriptions.

While the desire for variety could be seen as an operational and technical outcome to be achieved by using an exercise device with a varied exercise prescription, the underlying reason for this preference may be related to motivational and behavioural factors, particularly enjoyment of exercise and the reduction of boredom. For example, participant one argued that “exercise in space needs to be an activity that crew will enjoy, contributing to both physical and mental wellbeing. To that end, the device needs to appeal to a broad range of possible activities”, suggesting an initial link between exercise and enjoyment. This sentiment was supported by participant 2 who, when asked if they would feel bored using only a single exercise countermeasure, replied “yes, most definitely” and that “boredom” would be partially responsible for failing to engage fully with an exercise prescription. Participant 3 also suggested that a “varied routines to reduce boredom” was among their most important considerations for exercise countermeasure design. These statements are reflected in terrestrial studies, in which boredom has been linked to lower performance and adherence to exercise prescriptions, for example through reducing motivation to exercise [15,16].

Maintaining variety may overcome the challenge of using only a single exercise device, as participant 1 suggested that “if it is well designed it will offer something for everyone and enough range of possible exercises to allow sufficient variety for a week-long exercise programme” and, when asked if they would feel bored using a single exercise countermeasure, they went on to say “no - not if it offered a good variety and range of possible exercises”, highlighting both the preference for variety to reduce boredom and echoing concerns about maintaining the effectiveness of the exercise countermeasure. Participant 2 held similar preferences, suggesting that “short duration, for which 30 days is at the upper limit, would probably be OK with a simple flywheel device. There are clever adaptations with a flywheel that could make exercise less boring, however (and more effective for total body resistance training)”, further highlighting the preference to make exercise less boring while maintaining the effectiveness of exercise countermeasures.

The astronauts also suggested that other measures to reduce boredom that were not specific to the exercise device itself could be implemented, such as avoiding “boredom through VR/AR augmentation and/or Peloton-type motivation with virtual instructors” (participant 2). This was also highlighted in greater detail by participant 1:

“Crew enjoyment during exercise often comes from listening to music/podcasts, watching TV etc. I enjoyed running and biking using a tablet app ‘Run Social’, which enabled me to immerse myself in an almost virtual environment (Swiss/Scottish mountains etc). I think entertainment during exercise is an extremely important element to consider for integration or at least compatibility with future countermeasure devices.”

This indicates both the potential to implement entertainment alongside the exercise device, and a potential desire for a more social aspect to exercise using virtual instructors. While the use of virtual instructors during short-duration spaceflight may be possible, it could become more difficult during longer-duration spaceflight (such as to Mars) where communication delays [17] or technical constraints such as a limited power supply [18] may prevent or reduce the effectiveness of such technologies. This could be overcome through pre-recorded video and audio exercise instructions, or more novel techniques could be implemented to generate power, as suggested by participant 3:

“Power needed for biofeedback is minimal– use a coin battery for example. Or use a fitbit or a cell phone with batteries. Or use a USB3 port on a laptop. If there is really no power, then use a hand generator (squeeze to turn a wheel that generates power) with a super capacitor and consider the power generation as part of the exercise routine (It’s quantifiable and you need hand strength for EVA!).”

Participant 3 further suggested more novel methods of increasing enjoyment during exercise that could increase enjoyment of exercise, reduce boredom, and add a social aspect to the exercise prescriptions:

“Exercise devices in flight have historically mimicked exercise devices on earth. There is a better way. [*Name and mission redacted for anonymity*] introduced to the crew some active exercises that were fun and engaging. For example, we pushed off a bulkhead with our feet, flew fast to the opposite bulkhead and pushed off that to return. At first, this is hard to do– you don’t fly straight. After just a few minutes, you improve a lot. After a while, everyone got really good and we were tumbling between the bulkheads and going very fast so that we got strength training, impact training to the long bones, coordination exercises, spatial orientation exercises, all at the same time, while having a lot of fun. We would go in pairs and eventually we could get four people going simultaneously, rushing past each other. We really learned to fly! We also played games for exercise. We played tag and king of the mountain. We played a form of Quidditch in an emptied supply module where we used a red rubber ball as the snitch and went after it, pushing and pulling each other all over the place. In the current ISS, you could do that in the airlock. I encourage you to find exercises that utilize the unique environment of spaceflight rather than just reproducing earth-based exercise devices.”

These novel exercises that utilize the space environment could provide an alternative to the traditional exercise countermeasure suite, while also accommodating many of the astronaut preferences, including removing the need to setup and takedown the device (ease of access), increasing enjoyment while reducing boredom (motivational and behavioural considerations), and meeting operational requirements (operational and technical considerations). The use of these novel space-environment exercise countermeasures, which would not need to use restraint systems to attach the astronaut to an exercise device, may also lead to the "avoidance of "hot spots" and overuse injuries as a result of restraint systems", a concern highlighted by participant 2. However, the feasibility of such a novel exercise countermeasure approach, particularly within the constraints of capsular spacecraft such as the Orion MPCV [4], and the impact these novel exercises may have on the spacecraft should be considered. For example, participant 3 recalled that during these novel exercises: "we did get a call from the ground during our high impact exercises that we were registering on the station accelerometers and to go look at the solar arrays which were indeed flapping". However, they also suggested solutions to limit the impact these exercises have upon the spacecraft, suggesting that "there are lots of ways around that issue, for example, install a springboard at the bulkhead that isolates the impact from the vehicle". This suggests that the spacecraft could potentially be modified to accommodate these novel exercises to overcome the impact they may have upon the vehicle. This would be similar to how many current ISS microgravity applications, including exercise countermeasures, are attached via a vibration isolation system [19]. Participant 3 also suggested that these novel exercises could still be implemented within the technical constraints of future capsular spacecraft, in which the volume of exercise space will be limited to an area of 5 m^2 [18]: "I think there are plenty of exercises that could be done utilizing weightlessness within 5 cubic meters. For example, two crewmembers could simultaneously dribble each other off the walls like basketballs (that would be a hoot and a half!)." While these novel exercises may also allow for group and social exercise, participant 1 also highlighted that considerations should be made for astronauts that do not wish to be disturbed by the exercise prescriptions ("crew will want to exercise without being disturbed or disturbing other crew where possible" (participant 1)), however, this may be difficult to accomplish within the confines of the limited volume requirements of capsular spacecraft where most mission tasks, including exercise, will likely occur in the same space.

As NASA intends to implement a single exercise countermeasure, the flywheel exercise device, on-board the Orion spacecraft [5], the findings should also be considered within this context. All three astronauts indicated that they would feel bored using only a single exercise countermeasure, risking the possibility that "it would make me less likely to do the exercise and also less likely to do it well" (participant 3), unless it "offered a good variety and range of possible exercises" (participant 1), or boredom could be avoided "through VR/AR augmentation and/or Peloton-type motivation with virtual instructors" (participant 2). As it has been evidenced that moderate effects of muscle deterioration become apparent by seven days of simulated microgravity exposure [20] and that this deconditioning may affect crew performance and safety [2], it is vital that astronauts fully engage with the exercise countermeasures available. As suggested by the astronauts surveyed here, this may be achieved through variety in the exercise prescription, as well as implementing additional forms of entertainment, including virtual reality or augmented reality augmentation (participant 2), or access to music, podcasts, or television (participant 1). The astronauts also suggested concern that the use of only a flywheel exercise device may not be suitable for missions of longer than 30 days. For example, when asked if they would feel confident using only a flywheel exercise countermeasure for a mission of 30 days or less, participant 1 said "yes. For a mission of such short duration then a flywheel, although perhaps not able to fulfil the points raised above, would suffice", while participant 2 said "short duration, for which 30 days is at the upper limit, would probably be OK with a simple flywheel device. There are clever adaptations with a flywheel that could make exercise less boring, however (and more effective for total body resistance training)," and participant 3 suggested that "for 30 days or less, a simple flywheel is fine. It's not about the device, it is about the routine". This suggests that, so long as missions remain short in duration (less than 30 days) and there is enough variety in the flywheel exercise prescription to prevent boredom, then its use on-board the Orion MPCV may be acceptable to astronauts. Participant 2 reaffirmed the possibility for a varied exercise prescription with a flywheel exercise device by suggesting that "different modes of resistance and endurance training can easily be envisioned with a flywheel - so don't treat it as a single exercise device. Think about other adapters for different exercise modalities," echoing the statement from participant 3 that "it's not about the device, it is about the routine".

The analysis presents common preferences across three male astronauts and represent the views of only a small sample of the overall astronaut population. The lack of diversity within this preliminary sample, including gender, astronauts of different abilities, age groups, and ethnicity, is a major limitation of the data set and as such caution should be taken in any attempt to generalise these results to the wider astronaut population. While the three male astronauts surveyed here present several useful suggestions regarding their own preferences for the use and implementation of exercise countermeasures, a more diverse sample is needed before attempting to make any general recommendations for an "ideal" exercise device. It would also be beneficial to consider additional characteristics of astronauts, beyond the currently listed demographic information, that may affect astronaut preferences for the use and implementation of an exercise countermeasure device during spaceflight. Specifically, it would be useful to note: do the astronauts have experience using a flywheel exercise device (including using the device in preparation/practice or during spaceflight)? and, are the astronauts aware of empirical data relating to the effectiveness of the exercise devices as a countermeasure to microgravity exposure? The data reported in this study should be used alongside additional considerations of astronaut preferences to supplement, not entirely inform, the development and use of future exercise countermeasures. Following the guidance from participant 1 that "the device needs to appeal to a broad range of possible activities … and crewmember preferences", it may be beneficial if the crewmembers chosen for future spaceflights are asked for their own preferences for exercise device development and usage so that their preferences can be augmented into their own individual, tailored exercise prescriptions.

In conclusion, the preferences of three male astronauts for the use of an exercise device during spaceflight may be categorised into three broad themes: exercise device ease of access (e.g. ease of setting up and using the device), motivational and behavioural considerations (e.g. enjoyment and boredom while exercising), and operational and technical considerations (e.g. effectiveness of the device for relevant health outcomes). The data presented here suggest that astronauts may consider a flywheel-based exercise device suitable as the sole exercise countermeasure on-board the Orion MPCV, and similar capsular spacecraft, so long as it engages astronauts in a varied exercise prescription that meet the physiological expectations required of exercise countermeasures for spaceflight deconditioning, is enjoyable and that measures are put in place to reduce boredom (achieved primarily through variety in exercise prescription), is easy to access in terms of both use and setup/takedown, and is used only as the sole exercise countermeasure for missions of 30 days or less. Individual crewmember preferences should be taken into consideration following crew selection to ensure the greatest adherence to the exercise programme.

Funding

This work received funding from the University of Northumbria at Newcastle and the Luxembourg Institute of Research in Orthopedics, Sports Medicine and Science (LIROMS).

Declaration of competing interest

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actaastro.2022.09.012.

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