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Space Food Experiences: Designing Passenger's Eating Experiences for Future Space Travel Scenarios

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Given the increasing possibilities of short- and long-term space travel to the Moon and Mars, it is essential not only to design nutritious foods but also to make eating an enjoyable experience. To date, though, perhaps unsurprisingly, most research on space food design has emphasized the functional and nutritional aspects of food, and there are no systematic studies that focus on the human experience of eating in space. It is known, however, that food has a multi-dimensional and multi-sensorial role in societies and that sensory, hedonic, and social features of eating and food design should not be underestimated. Here, we present how research in the field of Human-Computer Interaction (HCI) can provide a user-centered design approach to co-create innovative ideas around the future of food and eating in space, balancing functional and experiential factors. Based on our research and inspired by advances in human-food interaction design, we have developed three design concepts that integrate and tackle the functional, sensorial, emotional, social, and environmental/atmospheric aspects of "eating experiences in space." We can particularly capitalize on recent technological advances around digital fabrication, 3D food printing technology, and virtual and augmented reality to enable the design and integration of multisensory eating experiences. We also highlight that in future space travel, the target users will diversify. In relation to such future users, we need to consider not only astronauts (current users, paid to do the job) but also paying customers (non-astronauts) who will be able to book a space holiday to the Moon or Mars. To create the right conditions for space travel and satisfy those users, we need to innovate beyond the initial excitement of designing an "eating like an astronaut" experience. To do so we carried out a three-stage research and design process: (1) first we collected data on users imaginary of eating in space through an online survey ($n = 215$) to conceptualize eating experiences for short- and long-term space flights (i.e., Moon, Mars); then (2) we iteratively created three design concepts, and finally (3) asked experts in the field for their feedback on our designs. We discuss our results in the context of the wider multisensory experience design and research space.

Keywords: food, food-interaction design, multisensory experiences, human-computer interaction, human space travel, eating experiences

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INTRODUCTION

In recent years, there has been increasing interest and greater global efforts in the development of commercial space flights. SpaceX, Blue Origin, and Virgin Galactic envisage space tourism that can bring "non-astronauts" into space. The ambition outlined by NASA is to send people to Mars in the 2030s and beyond (Wilson, 2016). Most recently, JAXA (Japan's space agency) announced their Space Food X initiative, a program to develop new food technologies and systems to solve the challenges of food production in space (see Space Food X, 2019). JAXA targets the future of life in space by encouraging researchers and practitioners alike to think about 2040 and the future of life on the moon, as equivalent for the NASA aspiration of life on Mars. Those and many more initiatives are making space exploration once again an exciting global endeavor for humanity.

Although there is still a long way to go to enable life on the Moon or Mars, we have now the opportunity to contribute to this future vision. Here we argue that the Human-Computer Interaction (HCI) community—embedded within the computer science community—now has the occasion to contribute a new perspective and knowledge on how to think about and design future interfaces in space, especially drawing upon the increased research efforts around food and food-interaction design within HCI (see Comber et al., 2014 for an overview) and related disciplines in psychology and sensory science. Technology has revolutionized how humans produce, distribute, and prepare food beyond local boundaries, and even how we eat (see the 2018 Manifesto on the Future of Food and Computing Obrist et al., 2018), and will continue do so when preparing humanity for life beyond Earth.

About a decade ago, Grimes and Harper (2008) coined the concept of celebratory technology, stressing the relevance of designing for the positive aspects of eating. The authors advocate Human-Food Interaction (HFI) design through technological augmentation rather than corrective technology design. In other words, we should not attempt to fix undesirable behaviors but rather design technologies around the richness of human experiences and practices related to food. Barden et al. (2012), for instance, demonstrated the implementation of such a technology, which enables remotely located guests to have a technologically enhanced dinner party. Khot et al. (2017) used food printing to positively encourage physical exercise, whereby people received a chocolate print based on their daily activities. Inspired by new fabrication technologies and manufacturing approaches to food, Wang et al. (2017) developed the concept of shape-changing, and programmable food that transforms during the cooking process. More recently, technological advancements in acoustic levitation have led to the design of a novel taste-delivery technology that transports and manipulates food morsels (solid and liquid food) in mid-air (Vi et al., 2017a). All these efforts are directed toward a new generation of interface design based on taste to augment human-computer interactions (e.g., Vi et al., 2017b, 2018; Velasco et al., 2018) but also help create new food and eating experiences.

These examples highlight that food not only serves a nutritional purpose but can also be thought of in different ways to ensure personal and emotional well-being. In the context of space exploration, researchers have highlighted the need to consider the psychological effects of food on space explorers as individuals and groups (Binsted et al., 2008). Moreover, prior research in sensory science supports the relevance of multisensory components of food experiences in their perception and enjoyment (Stroebele and De Castro, 2004). For example, different lighting (e.g., red) and sonic (e.g., high pitch tunes) conditions can modulate how people experience taste attributes (e.g., how sweet) and how much they like a given food or drink (Spence et al., 2014b). With the aforesaid ideas in mind, we see a great opportunity for HCI and HFI design (see also Velasco et al., 2017; Nijholt et al., 2018) to co-shape the future of eating experiences in space, especially accounting for the desires of both astronauts and non-astronauts. Designers can now start thinking about new ways of presenting and transforming foods, and then create completely new and playful interactions with food (as shown in prior works on programmable and shape-changing food Wang et al., 2017).

In this paper, we first provide an overview of what eating in space involves based on a systematic review of prior works in the context of space food design for the International Space Station (ISS) with an outlook on food system design for short- and long-transit flights and ultimately human settlements on lunar and planetary surfaces (see **Figure 1**). Based on this exploration, we present the opportunities for HCI researchers and designers in the context of food-interaction design. While there is an appreciation of the relevance of designing healthy and nutritious, but also enjoyable, social, and surprising eating experiences on Earth, we lack such research in the context of designing food experiences for outer space.

Following a user-experience-centered rather an astronaut-centered approach (given future space tourism), we designed and conducted the first survey to capture quantitative and qualitative data on desired eating experiences in future space travel by non-astronauts. Using a crowdsourcing approach, we proposed two hypothetical journeys that accounted for long- and short-term space flights, one to Mars and one to the Moon respectively, to inspire participants' imaginations. We collected data from 215 participants and identified five key factors (i.e., functional, sensorial, emotional, social, and environmental) through the analysis of participants' descriptions of imagined eating experiences on the way to Mars or the Moon. Based on these factors we then, in a second step, designed three design concepts illustrating the integration of the various factors in the envisaged eating experience. Finally, we asked experts in a governmental space agency and private space companies to comment on our work. We discuss the overall findings and conclude with a summary of remaining design challenges and future design opportunities.

In summary, the main contributions of this paper are (1) a conceptualization of eating experiences for future space travel based on five empirically identified factors, which we then used (2) to design three novel design concepts to augment and transform eating experiences for individuals and groups for future space travel. Taken together, we aim (3) to inspire HCI

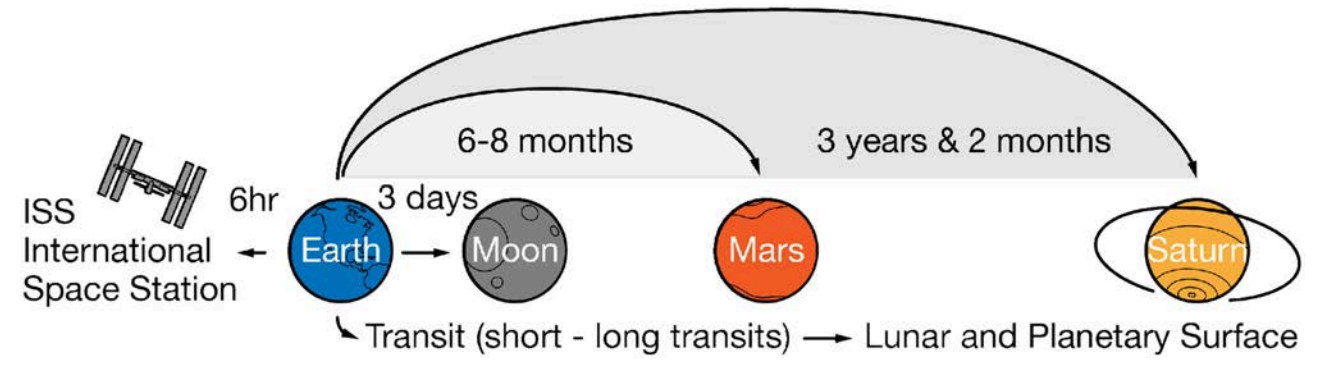

FIGURE 1 | Overview of the design opportunities beyond the International Space Station (ISS), accounting for transit flights (short- and long-spaceflights to the Moon and Mars) and ultimately human settlements on lunar and planetary surfaces. Note that the duration of the spaceflights presented is an approximation, as they can vary depending on several factors (e.g., orbits).

researchers and designers to further explore outer space as a new design space for innovation around food and food-interaction design and technological innovation.

RELATED WORK

Here we present an overview of prior research on food-interaction design and food system design relevant for space food experience design.

Food-Interaction Design: The Role of Technological Augmentation

Eating is a basic human need. There has been a growing interest within HCI in promoting healthier food practices and behaviors through persuasive technology (see Comber et al., 2014 for an overview). Often, food and eating habits involve challenges to which technology can provide a solution. Grimes and Harper (2008) advocate for a specific view on food and human-food interactions, introducing the concept of celebratory technology which emphasizes the positive aspects of eating in everyday life. The authors encourage researchers to think about the positive relationship between humans and food that should be augmented through technology, rather than just focusing on corrective technology that focuses only on the negative practices in humans' relationship with food. Hence, they argue for embracing the positive, and multilevel factors influencing eating, including cooking, social environments, and social practices. Barden et al. (2012) demonstrated the implementation of such a celebratory technology through a telematics dinner party staged between remotely located guests. Their pilot study showed an opportunity to create playful experiences and a sense of togetherness through the use of a tabletop video projection.

Exploiting the particularities of the relationship between humans and food, Khot et al. (2015) presented the idea of TastyBeats. This system provides users with personalized sports drinks, where the quantity, and flavor are based on the amount of exercise a user has done in a day. In a similar vein, EdiPulse (Khot et al., 2017) was introduced as a system that creates activity treats (chocolate creations) using a food printer. The prints were based on the person's physical activities on that day and allowed for personal and shared reflections at the end of the day. The motivation here was to augment the experiences rather than correcting a potentially unhealthy lifestyle.

Inspired by new fabrication technologies and manufacturing approaches to food, Wang et al. (2017) developed the concept of shape-changing and programmable food that transforms during the cooking process. Through a material-based interaction design approach, the authors demonstrated the transformation of 2D into 3D food (i.e., pasta). They considered these transformations for new dining experiences that can surprise users and be customized for various contexts, including outer space. A key practical advantage that comes with this idea is the saving of actual storage space on a spaceship (i.e., payload), as flat packaging allows for more food to be taken on long-term space flights. Similarly, Zoran (2018) introduced the idea of programmable edible taste structures and taste patterns that can enrich a user's interaction with and preparation of food. The authors argue that their fabrication approach, combining modular (silicone) mold and a generic mold-arrangement algorithm, allows for faster productions and more varied tastes (shape-forming) than 3D printing techniques. This work is based on given recipes and is further enriched by efforts that analyze recipes to extract cooking instructions (Chang et al., 2018).

More recently, technological advancements in acoustic levitation have led to the design of a novel taste-delivery system, i.e., TastyFloats, which transports and manipulates food morsels (solid and liquid food) in mid-air (Vi et al., 2017a). This contactless food delivery system has the potential to transform future eating experiences on Earth, resembling astronauts' eating experiences in microgravity (e.g., floating food at ISS). Initial research has shown that the use of acoustic levitation affects users' taste perception, with sweet becoming sweeter and bitter being less aversive. This hedonic modulation allows chefs to experiment in the context of molecular gastronomy, but can also be a game-changer in food-interaction design for children (e.g., make eating vegetables more enjoyable).

In addition to research efforts in HCI and HFI research, we can build upon rich knowledge in food and sensory science research to promote the relevance of multisensory food and flavor perception (Prescott, 2015). This research indicates that both the sensory properties (e.g., colors, shapes, textures) of foods and drinks and their associated elements (e.g., containers, eating utensils, etc.), and environments (e.g., social, physical, temporal, etc.) are critical when it comes to food expectations and experiences (Spence, 2015). This, in turn, opens up various questions in relation to eating experiences in space.

Food in the Context of Space Exploration

Designing human-food interactions in space is not a trivial task. Indeed, before astronauts eat in space, they need to undergo dedicated training on Earth, and multiple challenges associated with nutrition, production, conservation, and transportation, among others, have to be considered (see Perchonok and Bourland, 2002, for an overview on the past, present, and future of food and food systems in space, including research efforts linked to the ISS, requirements for transit food systems, and lunar surface settlements). Below, we summarize the key research on food design for space since its beginnings in the 1960s with the first manned spaceflights.

The design of space food has been driven by the need to not only improve the ingestion of required nutrients but also build morale and enhance mission productivity (e.g., Bourland, 1993; Buckley et al., 2011; Cooper et al., 2012; Salas et al., 2015). When astronauts are selected for a mission, for example, to the ISS, their training takes several years, including training in how to eat in microgravity, types of food packages, preparation procedures for foods, and the food environment on board (e.g., food gallery, trays, utensils). Eating itself follows a pre-defined menu/schedule for breakfast, lunch, and dinner. Everything is designed to be efficient. Astronauts select the package(s) from the pre-designed menu, follow its corresponding preparation instructions on the package (e.g., heat, rehydrate), then cut it open and use a spoon to eat it. Mixing is not an easy task in microgravity due to the fact that multiple packages and pieces are floating around, as is the person. When the meal is finished, the cutlery is cleaned and strapped back on to the food gallery and tray, and the waste is collected in a dedicated container (Perchonok and Bourland, 2002). Astronauts sometimes compare their eating experience with camping: *"if you are okay with camping, you are okay with eating in space"* (Kerwin and Seddon, 2002), where everything is pre-packaged for the time away from home, from grocery stores, and from any other luxuries of everyday life, including cooking facilities in a kitchen.

Food design has developed significantly since the 1960s and some of the effects of microgravity on food/chemosensory perception have been documented, though these are still not fully clear. Olabi et al. (2002) provided a systematic overview of the various, sometimes contradictory, findings on the effect of microgravity on the chemical senses. Some studies report an alteration, while others indicate a reduction, in taste perception (Olabi et al., 2002). This may be due to the different experimental techniques used in different studies, as well as in the small sample size of astronauts tested "in a real microgravity situation" rather than in a simulation of weightlessness. However, astronauts' subjective reports, summarized by Kerwin and Seddon (2002), seem to indicate a modified flavor (which involves both taste and olfactory components) experience in space: *"Some foods were disappointing on orbit. Whether taste changed because of nasal stuffiness due to body fluid redistribution on orbit or because iodine was used to purify the Orbiter potable water, many people experienced a dislike for certain things.* [...] *Food flavourful on the ground sometimes tasted bland in space"* (Kerwin and Seddon, 2002).

Although it might be hard to experimentally isolate the effect of eating in space, relative to other atmospheres, given all research on atmospheric influences on food perception (Piqueras-Fiszman et al., 2013), we believe that eating in space could be a distinctive experience, at least, for short space travels. For longer space travels, the specific atmosphere can be thought of as a design space for novel eating experiences that contribute to tackle fundamental challenges of individuals and groups in space (De La Torre et al., 2012). Indeed, recent research and public efforts hint at a change in perspective when it comes to the design of space food. Space agencies have started engaging with chefs like Heston Blumenthal[1] to design personalized foods for crew members to support their personal and emotional well-being over longer periods in space (6–12 months).

While we will witness multiple improvements associated with the development of foods and drinks for space in the years to come, there is a repertoire of them available to those who, for example, go to the ISS (Johnson, 2009). With this in mind, in this paper we suggest that it is time to reflect about what it means (and will mean) to eat in space both for astronauts and non-astronauts. Perchonok and Bourland (2002) highlighted the main challenges in relation to the design of transit food systems that refer to food design in two steps (1) short- and long-term space flights and (2) settlements on lunar/planetary surfaces. **Figure 1** summarizes the design space for food-interaction design beyond the ISS. Our research focuses on the first step, including short- and long-term space travel to the Moon and Mars.

OPPORTUNITY FOR DESIGNING EATING EXPERIENCES

The ambition of NASA is to send people to Mars in the 2030s (Wilson, 2016). Hence, if we now start to systematically think about how HCI can make a difference in the design of experiences for future space travelers, we have the opportunity to co-shape and co-create the future of space exploration. Thinking about future target users, we need to look at astronauts (current users, paid to do the job) but also beyond and consider paying customers (non-astronauts) who will be able to book a space holiday to ISS, the Moon, or Mars.

To create the right conditions for space travel and satisfy those users, we need to innovate beyond the initial excitement

[1] *Heston, We Have a Problem... the Top Chef Cooks for Tim Peake | Life and Style | The Guardian*. Available: online at: https://www.theguardian.com/lifeandstyle/2016/mar/05/heston-blumenthal-chef-cooks-astronaut-tim-peake (accessed May 1, 2019).

of designing an "eating like an astronaut" experience (Schmitt, 1999). To do so, we can draw upon prior HCI research in HFI (see previous section) and build on insights from food science and multisensory research, particularly research that has shown that the environments in which we eat and drink and their multisensory components can be crucial for an enjoyable food experience (Stroebele and De Castro, 2004). For instance, different lighting (e.g., red) and sonic (e.g., high pitch tunes) conditions can modulate how people experience (e.g., how sweet) and enjoy a given food or drink (Spence et al., 2014a). What is more, recently, there have been many initiatives to develop specific environments in virtual reality (VR) which modulate people's food perception, enjoyment, and behaviors[2].

In addition, there is relevant work on the theory of empirical aesthetics that inspires design ideas that consider, for instance, elements of surprise, semantic instability, ambiguity as pointed out in prior work (see Carbon, 2011; Belke et al., 2015). By experimenting with those elements it is possible to elicit "aha" moments that influence the attractiveness and innovativeness of the experiences (Carbon and Leder, 2005; Carbon, 2015). Recent work has reported on such aesthetic emotional experiences in the context of space travel by emphasizing the opportunity to recreate such awe-inspiring experiences with technologies such as virtual reality (Stepanova et al., 2019). The authors refer to the overview effect (i.e., the fact that seeing the Earth from a unique perspective—from space, leaves them with a unique feeling of awe, which could lead to deep changes in their perspective about the world) that was reported by many space travelers. While this work is not directly linked to eating experiences, it demonstrates the potential of "space" as design area that can create and inspire new experiences that are aesthetically and emotionally powerful.

In the following sections, we systematically investigate this newly emerging field opportunity for HCI research and practice. We first conducted an online study on the general public's imagery and desires for food and eating experiences in space, whilst considering two hypothetical scenarios for short- and long-term space travel (the Moon and Mars, respectively). Based on the findings, we then ideate a series of design concepts that illustrate the future design space.

STEP 1: CONCEPTUALIZING EATING IN SPACE

To the best of our knowledge, there is no empirical data on non-astronauts' imagery about eating experiences in space. Hence, we designed a survey that aimed to stimulate users to think beyond their familiar eating experiences and imagine going on a short- and long-term space flight (6 days vs. 15 months, round trip to the Moon vs. Mars respectively). Please note that the duration of the spaceflights presented is an approximation, as they can vary depending on several factors (e.g., orbits). We collected quantitative and qualitative data to establish an understanding of the relevant factors that define a desired food and eating experience in space. Using a crowdsourcing approach enabled us to reach a large sample size.

Methods and Materials

A total of 215 participants (Females = 149) from the United Kingdom, between the ages 18 and 70 years (M = 37.75 years, SD = 12.31), were recruited on Prolific Academic (http://prolific.ac/) to take part in the study in exchange for £1. The experiment was designed and conducted on Qualtrics and lasted for approximately 10 min.

All participants completed a survey that included several sections: (1) General description of the study, (2) Consent form, (3) Questions about the participants' food experiences on Earth, (4) Questions about the key elements of eating experiences the participants considered important for a trip to the Moon, (5) and a trip to Mars, and finally, (6) General questions on knowledge about space food, interest in food, age, and gender. All the different elements of the survey were presented in sequential order but sections 4 and 5 were randomized.

The purpose of section 3 (food experience on Earth) was to put participants into the appropriate mind-set for eating and food experiences (following the approach used by Desmet and Schifferstein, 2008). First, participants were asked to think about what they had been eating during the last 24 h and to write 5–10 food items they ate during that time. After that, they were asked to describe the single eating experience they had most thoroughly enjoyed (max 750 characters) and to give it a title. In the final question, they were asked to list the 5–10 most important elements in their reported eating experience; indicate if anyone was present during the situation and if yes, who; and how long ago the experience took place (for all responses we followed prior approaches for word association tasks, reporting words associated with the given situation Piqueras-Fiszman et al., 2013).

Before moving on to sections 4–5 (depending on random order), the participants were encouraged to think about a future where humans leave Earth and go on space trips to the Moon and Mars. On this transition page in the survey, participants were told that, as space tourism and long- and short-term space flights may become part of our everyday life in the future, we need to consider what and how we eat on such trips. Based on this framework the participants were told that, in the following sections of the survey, they would be asked to consider a long and short space trip. We aimed to capture participants' intuitive responses as a main reference point for conceptualizing the desired eating experiences in space.

Sections 4 and 5 of the survey were almost identical, differing only in that one of them considered a trip to the Moon (up to 6 days' return trip) and another a trip to Mars (up to 14 months' return trip). In both cases the indicated time encompasses a fly-by scenario rather than a landing on the planet scenario which would come with different challenges. These sections included two main parts, allowing a quantitative and qualitative analysis of participants' responses. In the first part of each section, the participants were asked to think about 5–10 most important things in relation to eating (e.g., could be everything related to what they may eat and/or what may accompany their eating

[2]One example is project Nourished, a Gastronomical VR Experience. http://www.projectnourished.com/.

experiences) that they desire and would not want to miss on their space trip (word association task). In the second part, they were given the option to write any comments that may help for understanding their word choices.

In the remaining section, section 6, participants were asked to report their age and gender, and to answer two questions: *Please indicate how much you know about space food?* And *Do you consider yourself a "foodie" (a person with a particular interest in food)?* using 100-point visual analog scales. Ethics approval for this research was obtained from the University's Science & Technology Ethics Committee at the University of Sussex (ER/MO273/7). All participants provided written informed consent to participate in this study.

Results

Most of the participants reported that they did not have much knowledge about space food ($M = 16.99$, $SD = 19.88$), though most of them considered themselves "foodies" ($M = 61.10$, $SD = 26.53$).

Quantitative Analysis

The quantitative analysis of the results focused on the word association task involving the questions on the participants' memorable eating experience on Earth and their expectations about the most important elements they would not want to miss on trips to the Moon and Mars. The analyses were performed in R statistical software. **Figure 2** (A-Earth, B-Moon, C-Mars) presents a summary of the 50 words most frequently selected for each of the different scenarios presented to the participants. The size of the words represents their relative frequency, with larger words being more frequent than smaller words. Words such as "atmosphere," "family," "service," and "company," are more often selected when describing the elements of a memorable experience on Earth. However, when people think about key elements of possible food experiences in trips to the Moon and Mars, most of the words are associated with sensory, hedonic, and functional aspects of eating (e.g., "texture," "fresh," "flavor," "chocolate").

Correspondence analysis, as implemented in the R package FactoMineR (Lê et al., 2008), was performed on the scenario (i.e., Earth, Moon, Mars) and words frequencies. The results revealed a significant difference in the distribution of words across scenarios, $\chi^2 = 2{,}708.46$, $p < 0.001$. Two main dimensions appeared to explain the variance in the data, with 71.02 and 28.98% explained, respectively (see **Figure 3**). Based on the highest frequency words in each dimension, one might argue that Dimension 1 refers to "socio-emotional" elements associated with eating experiences and Dimension 2 to "sensory" aspects of such experiences (see **Figure 3**). Most differences take place along Dimension 1 in the x-axis. In other words, it appears that, whilst there is a small difference between the words reported in relation to the trip to Mars and the trip to the Moon, the difference between these two and the words in relationship to the experience on Earth is more salient. In **Figure 3**, we present the top 10 words that contributed more to Dimension 1 and Dimension 2, respectively, in the correspondence analysis. Visual inspection of **Figures 3A,B** reveals that the words that contribute more to the variation in Dimension 1 are associated with sensory attributes of foods and drinks, but involve additional elements which might also be associated with the experience of eating, the feelings that arise from such experience, and the people involved in the experience.

Qualitative Analysis

We also analyzed the justifications provided by the participants about their word choices in the two outer space travel scenarios. We received a total of 118 responses for the Moon and 122 for the Mars scenario (out of the overall 215 participants). Four main themes that also crystalized themselves in the quantitative analysis guided the analysis of the qualitative data: (1) functional, (2) sensorial, (3) emotional, and (4) social aspects of desired eating experiences in space (note that this relates to fundamental human psychological and biological needs that have been described, and which need to be considered, in the context of space flight Szocik et al., 2018). The main author coded the dataset in two rounds using NVivo11[3], a qualitative data analysis program, which revealed an additional fifth theme categorized as (5): environment.

(1) *Functional*: contains references to nutrition, health, balanced diet, vitamins, food that fills the belly, being easy to eat.
(2) *Sensorial*: contains references to food texture, smell, tastes, flavors, freshness, food choices/variations, hot-cold foods, sweet-savory, drinks.
(3) *Emotional*: contains references to comfort food, reminder of home, Earth-favorites, treats one does not want to miss.
(4) *Social*: contains references to the social context, sharing a meal with a loved one, making it a communal experience.
(5) *Environment*: contains references to the atmosphere and temporal differences between the Moon and Mars (food is secondary on a short trip, but should still be enjoyable), the availability of a comfortable chair and dining table, cutlery, napkins.

Out of a total of 121 references in the Moon scenario, the functional/nutritious (∼29% of references) elements of eating are equally important as the emotional comfort of eating in space (∼28% of references). Sensorial factors such as textures, freshness, or smell are considered relevant as well (20% of references). Those are followed by environmental (14%) and social references (9%).

Out of the 248 references in the Mars scenario, there is a shift, relative to the Moon scenario, toward the sensorial aspects (31.5% of references) in comparison to the functional/nutritious (22.5% of references) characteristics of eating in space, with the emotional comfort (30% of references) aspects being the second most important element. Social aspects, although considered relevant by participants, only comprised 7% and the environment ∼9% of the references. **Figure 4** provides an illustration of the different distribution of the various themes across the two hypothetical scenarios.

[3]NVivo, M. (2019). *NVivo 11 for Windows | QSR International.* [Online]. Available online at: http://www.qsrinternational.com/nvivo-product/nvivo11-for-windows (accessed September 17, 2017).

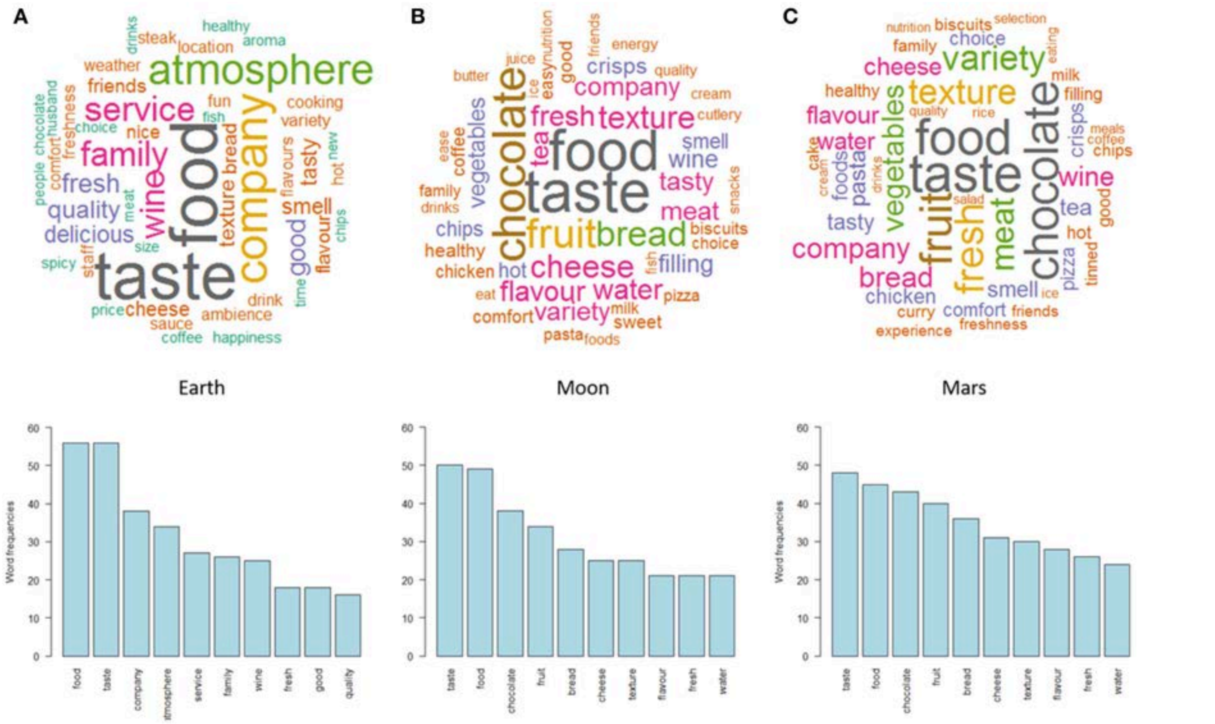

FIGURE 2 | Word clouds (upper panel) representing the most frequently selected words and corresponding 10 most frequent words (lower panel) for Earth **(A)**, The Moon **(B)**, and Mars **(C)**.

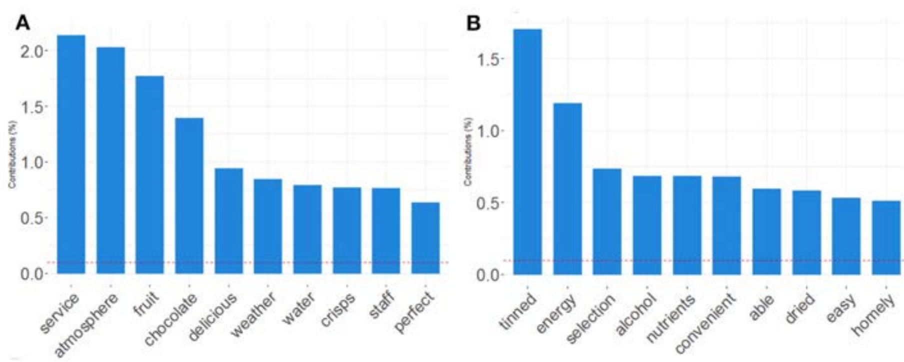

FIGURE 3 | Contribution of words to Dimension 1 **(A)** and 2 **(B)** in the correspondence analysis. The red line represents the expected average contribution of the words.

STEP 2: DESIGN IDEATION FOR EATING IN SPACE

Based on both our literature review and the quantitative/qualitative analysis of the online survey, we developed ***three design concepts*** based on the *functional, sensorial, emotional,* and *social aspects* of eating experiences embedded into the *environment* of future space travel.

Design Concept 1: Spice Bomb Mixing

This idea takes inspiration from the concept of an "emotional" cleanser, where people are put into an appropriate mood before eating to enhance the experience and make it enjoyable (Spence, 2017). From our literature review, we also know that astronauts report diminished flavor perception in space due to stuffiness in the nose (Olabi et al., 2002). Thus, the experience of food is described as less strong and sometimes bland, which makes astronauts desire flavor-enhancing condiments and spicy sauces (Kerwin and Seddon, 2002). Moreover, the results from our survey highlight peoples' desire for a variety of tastes and flavors during space travel. The *Spice Bomb Mixing* concept addresses this challenge and provides an opportunity to improve the sensory aspects of eating in space.

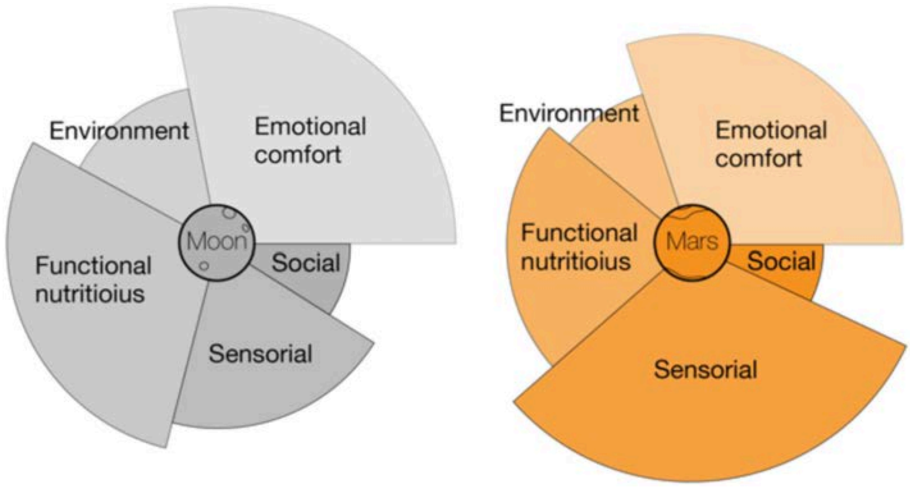

FIGURE 4 | Illustration of the importance of the various themes that emerged from the qualitative analysis for short- (Moon) vs. long-term (Mars) space travel (the size of the circle reflects the number of coded references for each theme; details on percentages reported in the main text).

Spice Bomb Mixing is a flavor-enhancing seasoning design concept. With the device shown in **Figure 6**, people can mix foods together to boost their flavors. Moreover, this concept is designed in a way that makes the preparation of food an interactive, social, and fun experience (illustrated in **Figure 7**).

We situated our design scenario in a microgravity context, although one might expect the development of artificial gravity in the future, especially on, say, a longer journey to Mars. In microgravity, it is hard to season food with solid ingredients, such as salt and pepper, as they would float, potentially impacting system functionalities if they became stuck in a device or maybe entering a space traveler's eyes. Thus, astronauts usually use liquid seasoning/sauces and mix the food by stirring it with a spoon[4]. While this is functional, food prepared thus lacks key dimensions that influence both the sensory and hedonic aspects of eating, such as crunchiness (Vickers, 1983).

Figures 5–7 illustrate the *Spice Bomb Mixing* design concept, highlighting first the various ingredients and then the container for mixing the various foods and flavors. The spice bomb involves a series of solid modular seasonings with different intensity variations (accounting for reduced flavor sensitivity in space). It will dissolve into food when the mixing pod, which can serve a group of people, is shaken.

This design considers the following main aspects:

- *Functional:* Convenient way of mixing and flavoring foods in microgravity by shaking the mixing pod. Combinations of flavors can be explored to ensure a variety of experiences over time, avoiding boredom.
- *Sensorial:* Using various, intensive spices (e.g., a curry mix and paprika) to enhance flavor perception.
- *Emotional:* Creating a playful and participatory process – diners can mix flavors together by passing the pod around, makes food preparation enjoyable.
- *Social:* Emulating the process of cooking using the pod. Our design enables the possibility of mixing ingredients in a fun and communal way (**Figure 7**).

Design Concept 2: Flavor Journey 3D Printer

We learnt from our study that people want unique food experiences, something that is often linked to people's "favorite" tastes. In the context of space travel, they considered the personal treats and foods they would not want to miss during the hypothetical space trips.

To provide people with their desired flavors, we developed the idea of a *Flavor Journey 3D Printer*. A person can either design or order the flavor profile of Earth foods from people such as family, friends, or chefs. The recipes can be directly sent to the printer instead of being delivered via a physical flight. Such a food printer can make the desired tastes and nutrients available on demand through reconstruction of the ingredients. For example, the food could be a "bar" that integrates several courses in one print and enables an individualized flavor journey (**Figure 8**). **Figure 9** shows the current conceptual design of the flavor journey and integrates the 3D printer (see **Figure 10**) that connects people in space with people (e.g., chefs or family members) on Earth[5].

Recent work on 3D food printing in space may help to customize nutrients and flavors (Hall, 2013). However, current space food printers are based on a continuous extrusion mechanism, and they cannot reach complete flexibility for voxel by voxel customizability. Lipson, et al. envisioned physical voxel fabrication through a printer that deposits multi-functional voxel

[4]Tasting Astronaut Food (Video) https://www.youtube.com/watch?v=6vVle67Tfjc&t=48s.

[5]Made in space: http://madeinspace.us/projects/amf.

FIGURE 5 | Demonstration of the spice bomb modules.

FIGURE 6 | Adding spice bomb modules into the mixing pod.

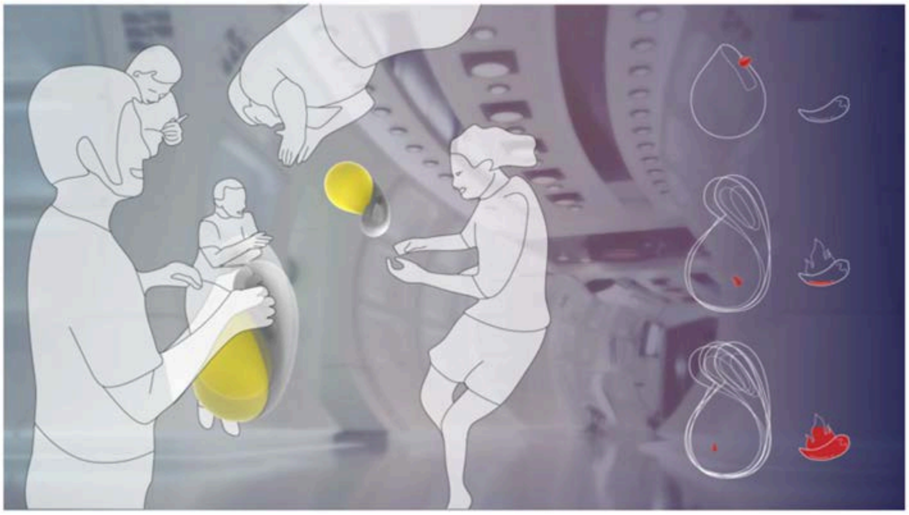

FIGURE 7 | Passengers mixing spice bombs and ingredients by shaking and throwing the mixing pod in microgravity. The longer they shake the pod, the stronger the food tastes.

spheres (Hiller and Lipson, 2009). Inspired by this framework, we propose combining culinary processes, specification, and voxel printing. Imagine a printer capable of making food composed of tens or even hundreds of small sphere voxels that are generated in real time. Some spheres could be hard, some soft. Some could be infused with a particular aroma, some with a particular taste. Multi-taste, multi-functional, and multi-textured food can be treated as digital material and assembled bit by bit to create a personalized eating experience in space.

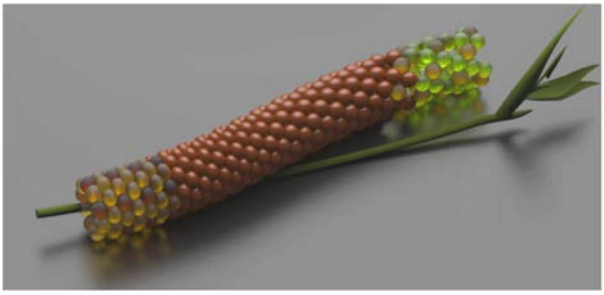

FIGURE 8 | Demonstration of the 3D printed bar, which includes three different courses in a single bar.

This design concept considered the following aspects:

- *Functional:* Combining multiple nutrients and flavors in one single food item through a hybrid food printing mechanism; the new printer mechanism allows full customizability of food in a 3D space.
- *Sensorial:* On-demand customizable flavors accounting for different flavor sensitivities in space, textures, and mouthfeel, enabling flavor variety in food.
- *Emotional:* Enjoying either one's own selection of desired foods/flavors or ordered surprise meals from people on Earth, such as relatives or a chef that creates exclusive dining experiences.
- *Social:* Shared cooking experience enabled through a space food 3D printer; collaborating with people on Earth—receiving real-time cooking instructions from either a chef or family members on Earth. With the possibility of communication (delay of 1.3 s to the Moon, 3–21 min to Mars[6]), food preparation can be a social and personally satisfying experience.

Design Concept 3: Earth Memory Bites

From the qualitative results of our study we know that people desire familiar Earth foods and flavors during their space travel, perhaps as a mechanism to cope with being homesick and to have a connection to home. The *Earth Memory Bites* concept proposes the design of small bites that contain distinct flavors representing different regions, cultures, or specific experiences concerning Earth food (such as established by Ahn et al., 2011). It also involves pre-defined options to provide comfort through familiar flavors and treats (see examples in **Figure 11**). Moreover, each of the bits of *Earth Memory Bites* is integrated and embedded in a specific dining environment (**Figure 12**). We envisage a projection mapping and VR solution that facilitates shared dining experiences (Salamon et al., 2018).

In *Earth Memory Bites*, people can order a given combination of flavor profile and multisensory experience. They have two options: (1) order the desired flavor and dining environment together or (2) order the flavor and receive it along with a suggested dining environment. The latter could be generated through an automated algorithm that creates the perfect dining environment in VR, based on available research on atmospheric influences on eating experiences. The different flavors would be prepared as a 3D print recipe (building on the printing design introduced in our second concept) and sent to the person together with a carefully chosen multisensory environment. Then, the person can print the flavors of the bites and experience them in the immersive dining environment on the spaceship (either alone or together with others). All the bites would be self-contained and edible as one-size bites to avoid having different items moving around the spaceship. Each bite would contain the specific selected flavor and would be printed in the form and texture of the actual food item (e.g., a strawberry bite, a banana bite; see **Figure 11**).

This design considered the following main aspects:

- *Functional:* Develop bite-sized appetizers or snacks that do not crumble.
- *Sensorial:* Music, visual projections, atmospheric light, temperature, and humidity of the environment to match distinctive Earth atmospheres (e.g., familiar places), or new eating scenarios created to match the desired multisensorial experience of the bite series.
- *Emotional:* Recreating and eliciting a nostalgic and comfortable eating environment (e.g., a restaurant, bar, park) through an ambient projection (i.e., panoramic theater) that could be shared with others.
- *Social:* People can share their favorite flavors (bites from Earth) with others on the spaceship. This allows people to feel connected to home without becoming homesick and at the same time strengthens their social ties on board.

STEP 3: EXPERT FEEDBACK AND REACTIONS

In the final step, we contacted experts in the field of space research from governmental space agencies, private space companies, and experts in this field or a related one (e.g., expertise in microgravity environments). We received responses from three out of six contacted experts. All feedback was provided in written form and was based on four main questions. First, we asked for feedback on the four main factors (i.e., functional, sensorial, emotional, social) that we identified for the design of food-related experiences for future space travel. To provide experts with a short summary alongside the paper itself, we described each factor in one sentence. Next, we asked them to think about any factors that might be missing. We further aimed to learn their opinion on the key differences between astronauts and non-astronauts and receive specific feedback on the relevance of our three concept ideas for future space travel (short- and long/to the Moon and Mars). Below we summarize the key feedback and provide representative quotes to illustrate the received feedback. Please note that these comments define only a preliminary step and require further in-depth studies.

Across all three experts, the social factor around eating was emphasized as very important, especially when the travel time increases. A senior chief scientist from a governmental space agency wrote: *"I like the criteria (4 factors) that you*

[6]Space Academy, M. (2019). *Space Academy, "Communication Delay."* [Online]. Available online at: http://www.spaceacademy.net.au/spacelink/commdly.htm (accessed September 17, 2017).

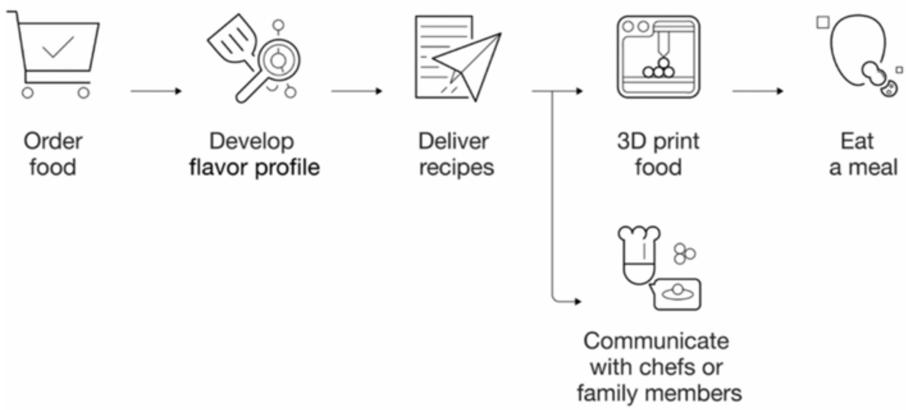

FIGURE 9 | The workflow of Flavor Journey 3D Printer.

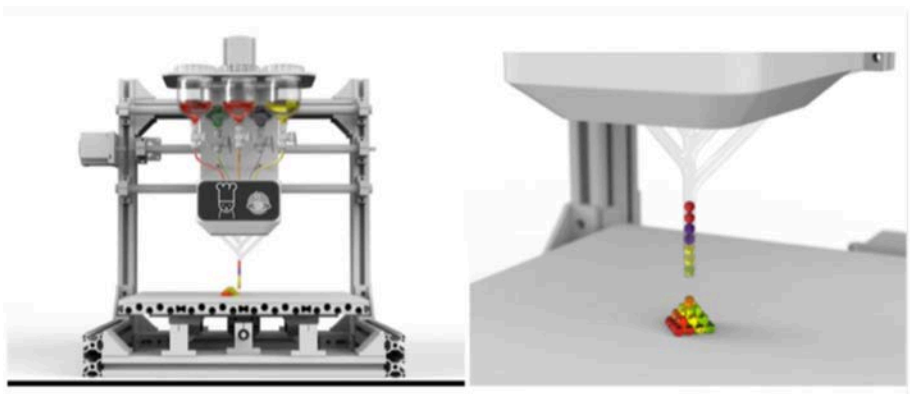

FIGURE 10 | The Flavor Journey 3D Printer.

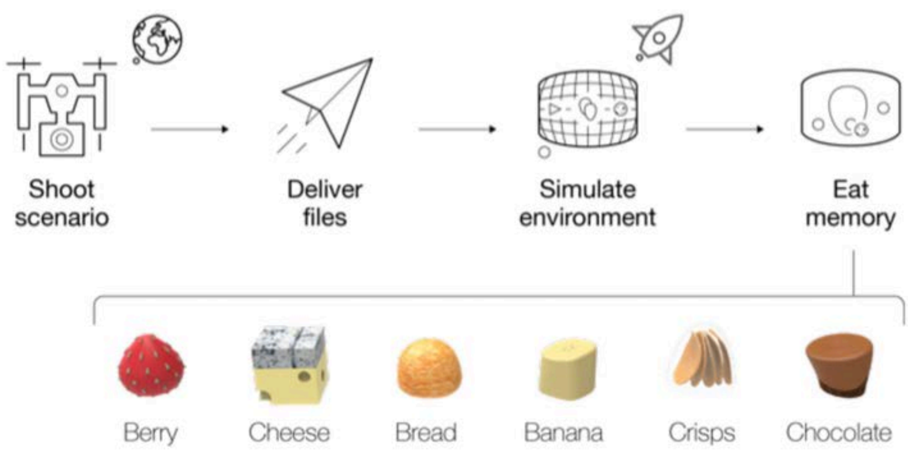

FIGURE 11 | From the preparation of foods and specific flavors to the presentation in a simulated dining environment.

chose. More specifically, the social one that should be combined with the time period of the trip and/or stay" [P1]. An expert representing a private space organization emphasized the social dimension: *"All [factors] are very important. Social is far too often overlooked"* [P2]. The third expert, who has professional expertise in microgravity environments wrote: *"Functional should be the*

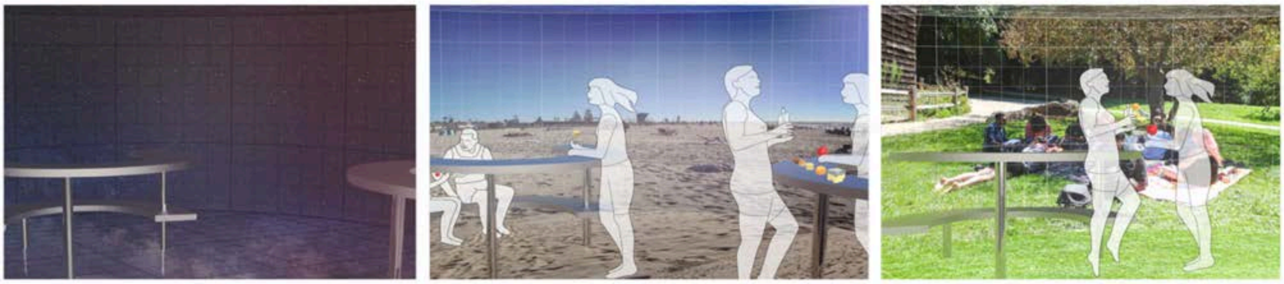

FIGURE 12 | The **(Left)** illustration is the deactivated state of the simulation environments; the **(Middle)** and **(Right)** illustrations are two examples of environmental dining simulations in space, including beach and park.

primary factor: in a context when the cost of payload decides whether a trip is doable or not, we will need light food with high protein content. On the other hand, life in space is a solitary experience... and this will be even truer for longer trips: any occasion to socialize and create a communal experience (potentially through play) would be welcome" [P3]. In addition, P2 wrote: *"I guess the big thing I would add is food for the sake of creativity and artistic outlet, which can help individuals to re-focus on something other than their primary work, and hence re-charge!"* Regarding other influencing factors, P3 added the packaging of food and recycling of water as factors that should be considered, suggesting for the latter, *"It is not difficult to imagine that even on a medium-sized spaceship it will be necessary to recycle water for [the] long term....and there is no humidity in space. So, drinks would be tasteless in [the] very short term. Maybe it would be interesting to add flavor to water. Or to have a way to create water from gasses"* [P3].

When asked about the main differences between astronauts and non-astronauts (future space travelers), their opinions diverged. The most senior expert was very critical, stating that *"Non-astronauts cannot imagine what life in space means and actually is. In addition, half of them are sick and food must be adjusted*" [P1]. This is contrary to what the private space agency representative wrote: *"Non-astros may have more time to enjoy food, or at least [a] lesser workload, thereby making them feel more inclined to *take* the time to enjoy. They may also be more prone to boredom, and food can be a great source of entertainment, as well as education about the microgravity environment!"* [P2]. The third expert also emphasized the differences based on the expectations and training of the person. Astronauts know what to expect, as also stated by P1, and are trained for the journey. They often have a different attitude to challenges and are highly motivated and often technical people. Non-astronauts will have different backgrounds, and food could indeed become an important way to overcome boredom and nostalgia. This expert particularly emphasizes need for expectations to be managed for non-astronauts: *"Only recently movies have started to associate to 'space travel' the related difficulties. Until a few years ago the only words you could associate with 'space' were 'fun' and 'adventure'... so we will need to develop a culture for future travelers that also includes food*" [P3].

In the final part of the feedback, we asked the experts for feedback on the three design concepts we had developed and how relevant they consider them. Across all experts, the second concept, ***Flavor Journey 3D Printer,*** was considered the most interesting. P2 found this concept particularly interesting because of its social angle: *"I like the idea of family on Earth designing food! Great opportunity for creativity as well."* P3 remarked that this idea seems the most feasible of all three ideas because 3D printers already exist and could become functional in space. The first concept, ***Spice Bomb Mixing,*** was not considered very relevant, and the experts were unclear about how it worked. Meanwhile, the third idea, ***Earth Memory Bites,*** was considered interesting but *"doesn't provide as many benefits as #2"* [P2] and P3 wrote: *"Triggering memoirs is a two-edged sword: it may trigger nostalgia when there is no way back (you cannot just hop on/off a spaceship), but it can also help [with] fighting it"* [P3].

Overall, the second idea was considered most relevant, especially as it combines the feasibility of emerging technologies, such as food 3D printing, with the possibility of creating more enjoyable eating experiences when on longer space trips. In the present study and design concepts we focused on the general public's imagination of eating in space as they will be potential future users in the context of space travel. Future engagement with astronauts themselves will enrich this investigation and help us prepare humanity for a life beyond Earth.

DISCUSSION

There has been a plethora of innovations in food science and food system design over the last 60 years, much of it driven by the need to develop appropriate food for astronauts in the ISS. Now that we face journeys beyond the ISS, with the general public as potential target users, it is time to think, design, and innovate again. Below we discuss how our research is relevant in opening up a new design direction for HCI researchers and designers interested in novel human-food interactions and eating experiences in space, including opportunities for technological innovation around fabrication and shared virtual environments.

Beyond Food-Interaction Design on Earth

Our investigation into the design of eating experiences for future space travel is motivated by increased efforts within the field of HCI to design and develop technologies and new forms of food interactions. Notably, these human-food interactions not only emphasize the functional purpose of eating (to be and stay healthy) but also increasingly support the need to produce and consume food in a pleasurable way. Here, we have explored the design space around HFI from a functional but overall experiential perspective, including the sensorial, emotional, and social dimensions of eating. Each of the three design concepts we presented above aims to tackle the multiple needs and desires of future space travelers based on prior theoretical and empirical work.

The first design concept, *Spice Bomb Mixing,* touches on all the four aspects of a positive eating experience in space, but was initially inspired by the *functional* and *sensorial* challenges in space. The mixing pod not only makes food preparation easier and allows for flavor augmentation including textures and crunchiness (currently missing due to only liquid seasonings being available in space, Bourland (1993) but also facilitates the creation of positive food experiences through collaborative creations and interactions, emphasizing the *social* practices around the eating and preparation of food (Grimes and Harper, 2008). The concept is based on a simple "walk up and try" principle that does not require explanation. The mixing pod design fosters simplicity in packaging design and the relevance of multisensory food experiences (Schifferstein et al., 2013), accounting for the preparation process before eating and enabling a creative temporal-spatial journey. The design acts as a facilitator and pre-defines a journey for which the outcome (i.e., resulting flavors, seasonings, foods) could be a surprise and be changed over time through various choices of ingredients.

The second design concept, *Flavor Journey 3D Printer,* also touches on the different aspects of food experiences, but initially intended to foster the *emotional* and *sensorial* challenges that become even more relevant on longer spaceflights, such as the journey to Mars. Being away from home for a long time makes people crave the familiar and "occasional" comfort food to overcome homesickness. Hence, we invented a novel 3D food printing mechanism that enables the creation of new flavors and meals. Chefs on Earth can create new meals on demand and send them back to the spaceship to be printed. This adds a *social* component to the design as it allows others such as family members or friends on Earth to create new food experiences for their loved ones.

The third concept, *Earth Memory Bites,* integrates ideas from the previous two concepts. Notably, this concept has the ambition of fostering the *sensory*, *social,* and *emotional* aspects of eating experiences by accounting for the multisensory influences of the environment in which a person is eating. Multisensory ambience research and design (e.g., Stroebele and De Castro, 2004; Spence et al., 2014b), which studies the right combination of sensory cues (e.g., light, sound, smells) for foods and drinks, can help to determine the extent to which the food experience will be memorable. This is also supported by our survey findings, in which service/atmosphere were mentioned as key elements for a memorable food experience on Earth. Thus, in our last design we embedded the food in a specific environment, which would strengthen the *sensorial* aspects of eating.

Taken together, our design concepts hint at different opportunities for socio-emotional multisensory eating experiences and food design in future space travel. There is scope for design even beyond the experience of eating, for example, considering the complete cycle of food growth and waste recycling, as outlined in the challenges for transit food system designs (Perchonok and Bourland, 2002). For short- and long-term space flights, the main technical challenges are associated with packaging, enabling a longer shelf life of 3–5 years, and providing a crew with fresh food and more variety in the menu, including variations in texture and color of food (e.g., salad crops) (see more details in Perchonok and Bourland, 2002). Moreover, our concept designs can be further reflected against the theory of empirical aesthetics (Carbon, 2011). Elements of surprise, such as shown in our *Spice Bomb Mixing* design, can be further extended with novel elements of sematic instability, or ambiguity to elicit more memorable aha-moment around eating experiences in space, especially in the context of longer travels (e.g., to Mars) where variation of food experiences becomes more essential. There is also an opportunity to take further inspiration from crossmodal correspondence research such as some recent work on the exploration of typical and atypical colors in food (i.e., carrots Schifferstein et al., 2019) and their effect on users expectations and ultimate experiences. It has been shown that, although atypical colors produce culinary opportunities, commercial success may be limited until consumers integrate them in their everyday habits (Schifferstein et al., 2019). With respect to space travel, such work can not only bring variation in the food experience but also create suitable combinations of different sorts of food on long-term space flights.

In terms of the future ambition of creating human settlements on lunar and other planetary surfaces, new challenges involving crop processing and food preparation will emerge. While the first challenge of crop processing requires new technologies for growing food, cultivating agriculture in water scarcity, generating power, etc., the second challenge of food preparation is often under-emphasized. The human act of preparing food (i.e., cooking) is essential to our emotional and social well-being, and the social aspects of food preparation and meals have been shown to have a positive effect on team bonding and morale in long-duration missions in analog simulations (e.g., Binsted et al., 2008; Häuplik-Meusburger et al., 2017). Taking into account these food design challenges, interaction with food in space explorations has multiple "parts" that we the HCI community can design for, building on prior work on food production, sustainable practices (Choi and Blevis, 2010), and waste management (Ganglbauer et al., 2013).

Opportunities for Technological Innovation

Alongside specific design opportunities around HFI design, future space travel provides an opportunity for technological innovation. In our designs, we touched upon two technologies that are at the heart of recent developments in HCI: (1) 3D printing/digital fabrication technologies, and (2) ambient projection and VR technologies.

In a recent issue on digital fabrication for HCI, Mueller and Peek wrote, "*NASA is financing research to feed astronauts in space using 3-D printing; food will be transformed from a powdered form, which has a shelf life of 30 years, into customized and nutritious meals*" (Mueller and Peek, 2016). Alongside advanced manufacturing methods in food printing, combined with material science, our 3D food printer enriches this vision of computerized on-demand printing. We introduced the additional twist of connecting outer space with Earth, allowing chefs to engage in the creation of a remote dining experience and react to new requests within the limits of available food materials on a spaceship. In addition, the vision of ubiquitous computing (Weiser, 1999) can now be rethought and extended into space, innovating toward new technological solutions to enable the creation of realistic ambient atmospheres for enjoyable and personalized dining experiences (building on prior work in projected augmented reality, e.g., Pejsa et al., 2016). While projections as envisaged in our third design would allow the recreation of desired and congruent dining environments, more work is needed for distant experiences (Mok and Oehlberg, 2017), also going beyond single person experiences in VR (e.g., Project Nourished). Recent efforts in enabling shared VR viewing experiences (Gunkel et al., 2017) could make such experiences more social and allow for shared experiences with others, including loved ones, back on Earth.

Finally, most recent efforts enable users to experience environmental conditions such as ambient temperature and wind in VR, which could sensorially augment single or shared dining experiences (Ranasinghe et al., 2017). Future work can use those technological innovations to not only explore the possibilities in the context of space exploration but for designing eating and food experiences in other environments on Earth, from camping trips to extreme contexts such as long-term missions to Antarctica or in submarines, and intense military training camps. Several of those latter examples face similar challenges as in space (e.g., consumables, isolation, and redundancy). Astronauts (similar as we know it from artic expeditions or submarine travelers) are restricted with respect to consumables, particularly food, water, and air. Despite the fact that the space stations are not too far from Earth, considering space travel to Mars, a return journey does not require hours or days, but months, and is thus a key challenging factor with respect to isolation. Finally, we face the challenge of redundancy in space explorations. Space as physical space is precious and does not leave many options for backup systems. Each item must be carefully selected according to its absolute need. HCI has the unique possibility, McCandless (2011) concludes, to support solving these challenges through the implementation of computers and the development of effective interfaces, such as—proposed in this paper—multisensory interfaces for improved eating experiences.

Unsolved Challenges and Limitations

Despite great enthusiasm and the variety of HCI design opportunities, we have to acknowledge that there are still other challenges to be solved with respect to future space travel. For example, there is a need for solutions to protect humans from radiation effects or create artificial gravity for longer spaceflights to reduce the negative impact of gravity on human physiology. In light of these fundamental health and life-threatening challenges, food experiences have not been the highest priority for space agencies. However, considering the technological advances and the critical role played by food and its related aspects in human lives (e.g., how specific basic tastes influence people's decision-making, such as sour taste influences human risk-taking behavior Vi et al., 2018), we believe that it is time to start thinking about food experiences that are functional, but also more sensorially appealing, pleasurable, and social, during space travel.

Moreover, we would also like to acknowledge that asking non-astronauts about their imagined and desired eating experiences in space has its limitations especially due to participants (general population) unfamiliarity with that context. Prior research (Carbon, 2015) has pointed out the challenges of asking people about very innovative issues, such as future space travel in our case, as they tend to orient their answers to what they experience and know from everyday life experience. Whilst it is true that asking users directly challenging questions, as we did in our survey, may not provide the full complexity of food experiences in space, people's imagination and expectations about space travels may well be considered when designing experiences. In the end, when users are confronted with the reality/possibility of space travels they will have key expectations that will be either confirmed or disconfirmed, which is key to develop a smooth experience. Importantly, although our concepts consider people's imagery about food in space travels, we also acknowledge other challenges and inform the concepts with different perspectives in the literature. We operated on the assumption that what you consider important today should be accounted for in the design of eating experiences in space. We may not know all the changing variables today, but we consider our work as an initial reference point for the increased efforts around experience-centered food interaction design (e.g., Comber et al., 2014; Velasco et al., 2017; Nijholt et al., 2018).

Finally, in our work we only focused on space as study context and we didn't explore other related contexts (e.g., Antarctica, as discussed in Section Opportunities for technological innovation) for possible data collection and evaluation of our design concepts. Hence, future extensions of our work can take inspiration, and can be informed, by other user groups and comparable set ups such as crews in submarines, artic missions, and soldiers in expeditions/missions. We believe our work provides a first stepping stone for future work, that can be further linked to research efforts around the physical and psychological risks associated with such living environments (Suedfeld and Steel, 2000). Moreover, while there are still many challenges to overcome before we can safely send humans to space and long-term space travels, initial steps can be taking by promoting experiments for near Earth orbit flights, using also parabolic flight setups that create zero gravity environments (Wollseiffen et al., 2019). Such settings could provide the opportunity to explore the ludic and experiential potential of levitating food and provide an interesting route of exploration both for future space travel and terrestrial eating experiences.

CONCLUSIONS

In this paper, the aim was to envision a future of space travel that complies with nutrition requirements (Enrico, 2016) and at the same time strengthens efforts to consider food not only as a means for survival and health (Nestle et al., 2009) but also as a source of enjoyment. Food and eating experiences are part of our basic needs and pleasures as illustrated by the following excerpt from the communication transcript 1965 (National Aeronautics and Space Administration Manned Spacecraft Center, 1965) between Gus Grissom (Commander) and John Young (Pilot), on the first NASA crewed Gemini mission launch: C: *"What is it?"* P: *"Corn beef sandwich."* C: *"Where did that come from?"* P: *"I brought it with me. Let's see how it tastes. Smells, doesn't it?"* Young had smuggled a corn beef sandwich on board, which was seen by some as a sign of humor, but others critiqued him for endangering a million-dollar mission; crumbles can cause serious damage to people and equipment in space. This example, as controversial as it may be, highlights the human desire for familiar foods and the need to think beyond the functional purpose of food in the context of space exploration.

We used two hypothetical journeys, one to the Moon and one to Mars, accounting for long- and short-term space flights, to inspire the general public's imagination about eating in space. We used a crowdsourcing approach to collect quantitative and qualitative data. Based on prior work and the results of the study, we proposed three novel design concepts that account for the functional, sensory, emotional, social, and environmental factors of eating experiences in space. Although these designs are presented in the context of future space travel, we believe that the associated ideas can find meaningful applications in food-interaction design on Earth (e.g., remote dining experiences Barden et al., 2012). Moreover, people with sensory disorders associated with the sense of taste and smell (e.g., lower sensitivity Hummel et al., 2011) could benefit from innovations that aim to augment and strengthen flavor experiences that are often reported to be reduced in outer space. This is only the beginning of a new experiential lens on the design of human-food interaction beyond Earth.

In summary, we have seen a range of innovation around space food systems since the 1960s, especially as part of the Apollo programs (e.g., Smith et al., 1974; Perchonok and Bourland, 2002). For example, without Apollo, the microwave ovens many of us have in our kitchens or the ready meals millions consume every day, might never have been developed[7]. Despite immense progress, many challenges are still left to address in order to feed people in space—a challenge the Japanese space agency (JAXA) is supporting through a new initiative (i.e., Space Food X, 2019). We believe that our work will contribute to this line of innovation in research and development and strengthen the need for an experiential and multisensory approach in the design of future eating experiences in space.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Ethics approval for this research was obtained from the University's Science and Technology Ethics Committee at the University of Sussex (ER/MO273/7).

AUTHOR CONTRIBUTIONS

MO and CV designed the online survey, coordinated the data collection, and analysis. YT and LY iteratively designed the design concepts with additional input from MO and CV. MO collected and analyzed the expert feedback and wrote the main manuscript text with main input from CV. All the authors have contributed to and reviewed the manuscript.

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[7]BBC article *"Apollo in 50 numbers: Food"* by Richard Hollingham (28 June 2019). Retrieved from: http://www.bbc.com/future/story/20190627-apollo-in-50-numbers-food.

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