Novice User Views and Experiences of a 3D Food Printing Immersion Experience: Usability, Design, and Future Possibilities for People With Dysphagia

Abstract

Although 3D food printing is expected to enable the creation of visually appealing pureed food for people with dysphagia (swallowing difficulty), little is known about the user experience in engaging with 3D food printing. The aims of this study were to determine the views and experiences of key stakeholders from a range of disciplines on the feasibility of using a domestic-scale 3D food printer for creating safe and enjoyable pureed food for people with dysphagia. Five user immersion experiences were undertaken, where participants engaged in the 3D food printing process, to stimulate evaluative discussions in focus groups or small group interviews. These included participants across multiple disciplines expected to influence the future of 3D food printing for people with dysphagia. Participants were provided the opportunity to engage in the design, 3D printing, and tasting of 3D printed puree food. In the focus groups and interviews, participants discussed their impressions of pre-processing the puree food, 3D printer usability, implications for people with dysphagia and their supporters, potential future applications, and ideas for advancing the design of 3D food printers for this group. This study will inform future usability trials and food safety research into 3D printed foods for people with dysphagia.

Key Words: 3D Food Printing, Dysphagia, Swallowing difficulty, Pureed food, Food design

1. Introduction

People who have dysphagia (swallowing difficulty), who make up an estimated 8% of the world's population (Cichero et al., 2017) often require texture-modified food of a minced-moist or pureed texture (Groher & Crary 2020, Steele et al. 2015). However, minced or pureed foods can be unappealing on the plate, particularly if indistinguishable, reducing mealtime enjoyment and quality of life for people with dysphagia. 3D food printing technologies is often proposed as a technological solution to problem of providing visually appealing texture-modified foods to people with dysphagia (Hemsley et al. 2019) potentially out-performing traditional methods for creating or shaping pureed foods (e.g., using a scoop or spoon, food moulds, or piping bags) (Godoi, Prakash & Bhandari 2016). However, research on the development and implementation of 3D food printing has not yet included people with dysphagia, their support workers or family members, and key stakeholders in the provision of texture-modified foods (Hemsley et al. 2019).

In a recent systematic review of the literature on 3D printed foods for people with dysphagia, Hemsley et al. (2019) postulated that research to date primarily addresses the constructive problems of 3D printing food (e.g., ways to expand the range of nutritious foods that could be printed, including grains, meat, vegetable and fruit), with little attention to empirical or conceptual questions about human interactions with 3D food printers or people's views and experiences of consuming 3D printed foods. Research on the development of appropriate business models for implementing 3D printing as a solution, the associated costs along the value chain, and the safety for users who eat the foods is needed. Although human computer interaction is an integral part of 3D food printing (Hemsley et al. 2019), no studies have examined (a) the usability of 3D food printers, especially by older people or people with swallowing difficulties or their supporters; (b) how 3D food printers would be used by the people who are expected to benefit the most; nor (c) the safety of 3D printed food for this vulnerable group.

Pilot research on 3D food printing for people with dysphagia (Kouzani et al. 2016; Kouzani et al. 2017) involved 3D printing of a pavlova (the first 3D printing of egg white); and of a tuna fish, a nutritious protein, fruit and vegetable dish designed to form the shape of a tuna. Both the pavlova in the shape of Australia and the tuna fish were edible and tasted like their substrate foods. The results of these pilot studies highlight the interdisciplinary nature of the design process when connecting 3D food engineering with speech pathology to create 3D printed foods for people with dysphagia.

1.1 Food design for people who need texture modified foods.

The process of 3D food printing inherently involves food design aiming to improve the visual appeal of the foods. Food design refers to any design decision made during food production (Zampollo 2016). This may include modifying the visual appeal of the food by changing the shape, colour or how it is eaten (e.g. finger food compared to food eaten with a knife and fork). For people with swallowing difficulty, pureed foods are often plated using an ice cream scoop to keep each food item separate on the plate, negatively impacting on the way food is accepted (Balandin et al. 2009). Plating pureed foods this way reflects a functional approach, in that it meets the function of rapidly plating several meals for residents in supported accommodation or aged care settings. Other than making sure the scoops of puree are separated so that they do not mix, there is little to no consideration of visual design in this method (Milte et al. 2017). Indeed, support workers and others often stir to mix the scooped foods together, further reducing the visual appeal, prior to offering a spoonful of food to the person eating the meal.

Research on the provision of texture-modified foods to people with dysphagia often focuses on compliance with or adherence to recommendations regarding the food or fluid texture in order to reduce the risk of coughing or choking (Hemsley et al. 2019). In community settings, non-adherance to food texture recommendations might relate at least in part to the lack of visual appeal of the texture-modified foods. Current attempts to improve the visual appeal of pureed meals include the use of food molds, piping bags, gelification and emulsification methods (Hemsley et al. 2019). Food molds have been examined as a method to improve the visual appeal of pureed meals for people with swallowing difficulty, with mixed results. Early research on using food molds to serve pureed peaches as peach slices demonstrated that people with swallowing difficulty liked these foods less than traditionally prepared pureed food scooped into a bowl, and furthermore did not find them as easy to eat (Stahlman et al. 2001, Stahlman et al. 2000). More recently, Lepore, Sims, Gal and Dahl (2014) reported that using food molds to present pureed food more attractively helped younger people with dysphagia to successfully identify the foods they were eating. Higashiguchi (2013) also reported that people with dysphagia who were given molded pureed foods were more satisfied with the appearance of the food. Focusing on nutrition, Germain, Dufresne and Gray-Donald (2006) reported that participants who had molded pureed food gained weight and had increased energy and nutrient intake. These mixed results highlight the importance of considering food design in relation to texture-modified foods, and that there is a good deal of variability in the effectiveness of food molds across different populations.

Other methods using food design elements tested to improve the visual appeal of food include the use of piping bags, gelification, spherification and emulsification (Reilly et al. 2013). Reilly et al. (2013) explored whether these techniques could improve the sensory appeal of pureed foods for people without swallowing difficulty. Participants rated the taste of the pureed foods prepared using these experimental methods on a Likert scale of 1 (did not like at all) to 3 (neutral) to 5 (much liked). Overall, the experimental foods received ratings between 3 and 5 (Reilly et al. 2013), but the number within that reporting a 'neutral' response were not reported, suggesting modest results.

Two recent reviews of evidence relating to 3D printed foods and their potential use in providing texture-modified foods (Dick, Bhandari and Prakash, 2019; Hemsley et al., 2019). Dick et al., reviewed studies focusing on the expanding range of foods suitable for printing, noting that there was yet little evidence of the printing of fibrous meats particularly beef. While suggesting that offcuts of beef might be useful for printing purposes, the authors identified 3D printing of the meat as a potential food safety issue and highlighted a need to maintain a safe temperature of meats throughout the pre-processing and printing (Dick et al. 2019).

Hemsley et al. (2019) reviewed sixteen papers related to 3D food printing and dysphagia, finding no research examining the usability or feasibility of 3D printed foods as a food shaping method for people with dysphagia. Furthermore, there was little evidence to suggest that the 3D printing of pureed meals improved the nutritional value of meals for people with dysphagia and nutritional disorders. In order to determine the usability features and potential applications of a domestic-scale 3D food printer for people with dysphagia in more detail, the first author of this paper sought and gained funding from the National Health and Medical Research Council to purchase a domestic-scale 3D food printer, the Foodini made by Natural Machines. At the time in 2018, this was a new technology with which most people, including the researchers, were not familiar. As a domestic scale device, it provided an important and accessible opportunity for usability testing, enabling multidisciplinary socio-technical research to examine how 3D food printers could be designed and used to improve mealtimes for people with dysphagia.

The aims of this study were to (a) obtain the views of experts from multiple disciplines, including speech pathology, engineering, marketing, dietetics, public health and social work, law, food services, and consumers, on the use of a domestic-scale 3D food printer for people with dysphagia; (b) identify any usability issues with the device, particularly in relation to its domestic use by people with dysphagia and their support workers or family members; and (c) consider future directions in relation to the further design of 3D food printers for people with dysphagia.

2. Materials & Method

Ethical approval for this research was provided by the University (de-identified).

2.1 Materials:

The 3D Food Printer used in this study, the 'Foodini' by Natural Machines, is powered by Android and features computer aided design (CAD) capabilities (Natural Machines 2019). In this study, the device was housed at the University in a 3D printing laboratory. The Foodini is an extrusion-based printer with five stainless steel capsules that the user fills with pre-processed puree food. In this study, pureed foods were either purchased ready-made or made in a domestic kitchen from raw vegetables, meat or fruit and pureeing the foods using a food processor. The range of pre-made puree textured food substrates (e.g. packaged icing mix, mashed potato, guacamole or hummus dip) were used as these were ingredients on the food menu of the Foodini printer. Each puree food substrate used in the study was first tested to ensure it was of a smooth puree consistency meeting the standards of the International Dysphagia Diet Standardization Initiative (IDDSI) fork and spoon tilt tests (see https://iddsi.org).

2.2 Participants:

Participants were members of multiple disciplines who had volunteered to join the Expert Reference Groups of two programs of research on the use of 3D food printers for people with dysphagia. These experts represented consumers and the disciplines of speech pathology, dietetics, business, hospitality, food services, marketing, computer science, engineering, aged care, consumers with disability, and computer sciences. See Table 1 for a full list of participants with their discipline, experience with 3D printing, and experience in working with people with dysphagia.

Insert table 1 about here

2.3 Method:

Data Collection. In total, sixteen participants took part in one of five immersion experiences in the 3D printing laboratory that involved supported use of the 3D food printer. During and after each immersive experience, participants were asked about their impressions of the device. They took part in focus groups or small group interviews methodology, either in person (n = 13) or, during COVID-19 restrictions on social distancing in 2020, in online videoconference using Zoom (n = 3). The immersions were designed to give participants the experience of 3D food printing to inform their discussions on usability and feasibility for people with dysphagia. Immersions conducted online using Zoom provided a similar virtual experience and involved the researcher setting up a streaming camera and following the instructions given by the participant as to the foods to use, the shapes to choose, and then printing the food, plating it, and tasting it.

In the immersion, whether conducted in person or online using Zoom, participants were invited to make choices about what would be printed and food/shape combinations that they wanted to see printed. At all times on Zoom, the participants could see the interface of the device, the action of the printer and the engagement or interaction of the research assistant with the device in real time and gave instruction to the researcher operating the device to observe the human-computer interaction and feel some sense of control over the food selected, the shape selected and the ultimate creation being discussed.

Both in-person and on Zoom participants gave instructions and feedback during the observations and also asked questions of the researcher about the device as it was being used. Participants who attended in person at UTS were able to directly operate the machine themselves, with guidance and support from the researcher, and also to taste the food printed. The foods printed by the participants were the standard food shapes available within the pre-set 'recipes' provided in the printer software. A selection of the foods printed showing some of the outcomes of the prints made by participants is shown in Figure 1. Immersion experiences, in which at least five food shapes were printed with three different ingredients, were timed to suit the convenience of participants and give them 1-2 hours of exposure to the device, the printing procedure and discussion about their experiences. Discussions between participants and the investigators during their immersion experience were audio recorded. Following their immersive experience, participants were asked to reflect on their experience and take part in a focus group discussion. Recordings were then transcribed, de-identified, and analysed for content themes (Patton 2014).

2.4 Data Analysis

A content thematic analysis of the transcribed discussion was conducted (Patton 2014). This involved the first three authors read and re-reading the texts, coding the themes in NVIVO and discussing the content themes to arrive at a consensus view on the most categories of meaning, forming and connecting common themes and sub-themes present in the data. This was discussed with all authors as a group to ensure cross-disciplinary input to the interpretation of participant quotes, provided to increase the plausibility and confirmability of the findings (Patton 2014).

3. Results

Results are presented in terms of the content themes identified across all five group discussions and transcripts of the immersion experiences. Overall, there were six themes and twelve sub-themes identified in the data. Table 2 provides a table of themes with example illustrative quotes for each of the themes discussed below.

Insert Table 2 about here.

3.1 A First Impression and Experiences of 3D Food Printing

Fun to do, but insubstantial and not meeting expectations. The group discussions reflected some enthusiasm for finding a suitable useful purpose for the 3D food printer and agreed that the food shapes created were generally aesthetically pleasing (with the exception of the meat, which separated on printing). G2P10 said "If I was a person eating mush every day, the same thing, I'd go, oh that's [3D printed shape] cool.' However, having seen the machine in operation and immersed as users in making choices in the design process (i.e., mixing colours for colour, taste, and choosing shapes), most participants were still not clear who would find the machine useful in practice. Many participants came with the expectation that the 3D food printer was able print to a full meal on the basis of the materials provided on website promotional materials. G1P1 stated 'when you look at the picture … there's a meal.' By the end of their printing experience many of the participants doubted that people with dysphagia or their support workers would be able to use the device and several questioned who the intended user might be. At the end of the hands-on experience with the device, G1P1 stated that the experience was 'very disappointing and of course now makes me wonder, what was actually happening in the last 3D food printing demonstration I saw.' Although the printer did not meet expectations, each group discussion remarked on the novelty and 'fun' experience of being involved in the printing process. G5P5 commented that 'Some of them (the shapes) are very juvenile aren't they, dinosaurs' which other participants felt might appeal to children who were 'fussy eaters'. ERG1 participants did not always know how the prints would turn out and that it was an unfamiliar experience, as one said 'I thought it was quite fun because we had not done it before' (G1P1). Although a print may be a surprise, it was seen as desirable that there be some predictability and reliability of the print, as G1P1 said '[people could be] frustrated because they wouldn't see what they were expecting'.

3.2 Usability of the 3D Food Printer

Difficulty filling the capsules. Participants considered the device in terms of its usability for them and how it might be used within the disability community, in particular how the printer would be used by people with dysphagia or their supporters. In-person participants trialed several ways of filling the capsule, either from the top or the bottom or using a spoon or a piping bag. GP4 reflected the common view that 'It was very fiddly and time consuming'. Most participants viewed filling the capsules by hand as being time consuming and messy, particularly when using a spoon as outlined on the user instructions. Some participants found it easier to fill the capsule with a piping bag, and others suggested that a syringe might help to fill the capsules neatly and to reduce air bubbles in the mixture. Their difficulties in filling the capsules easily or neatly prompted much discussion about what might make it easier, but also the expectation that this should have been addressed in the design, as G4P13 stated: 'I'm surprised when you were doing it, it doesn't come with an attachment that's a spout. That would make sense.'

Capsule parts and cleaning. The capsule size being quite small at only 90mL prompted discussion about an increased preparation time having less reward with the food print resulting in a small shape for a lot of effort in filling and later cleaning of the capsules. As G1P7 commented: ‘The time component is huge and to put the food in the canister and print it and wash it all up, all the pieces – there’s a lot.’ Participants surmised that the capsules might not hold enough puree to print an entire meal or to make multiple servings of a specific food. The small size of the capsules could necessitate hand-cleaning between prints if creating one meal of different food items and cleaning of several parts might form a barrier to consumer satisfaction with the device. G1P8 thought it was like having to wash ‘a million dishes, having to wash those bits and pieces’ and G1P7 agreed ‘I hate washing up!’ However, some participants conceded that they would most likely wash the various parts in the same way as the parts for any other kitchen appliance, in the dishwasher.

Participants viewed that the shapes printed might make suitable snacks due to their modest size, rather than a full meal; and could entice ‘fussy’ eaters to have a taste of a new food to expand their food range, or for those who relied on tube feeds but took small tastes of pureed food for enjoyment. ERG1 members similarly observed that the small size of the printed foods and the novelty of the process might make 3D food printing an engaging cooking activity for people with cognitive impairments, particularly as high printing success rates were achieved with chocolate and icing. The limitations of the small size of the prints were also clear, as G1P2 stated ‘it looks more like a dessert, a chocolate sort of thing. It doesn’t look like you can create a meal’.

The printer interface. Participants agreed that the touch-screen user interface of the 3D Food Printer at times provided frustratingly slow response times in operating the functions of the device. They considered that the navigation of the software was not user friendly and would present challenges for consumers who were not used to this type of technology or had dysphagia associated with physical or intellectual disability. Icons and words on the screen were small, and the meaning somewhat opaque relying on users guessing meanings and using a 'trial and error' exploratory approach to using the device. The slow responsiveness of the system meant that users were not always sure if their touch had been registered or not, leading to errors in multiple pressings of the screen. Users made several comments and raised questions as to software design and usability of the interface and how far the novice user experience had been considered in the design.

There was consensus across the groups that people with disability, including those with visual or cognitive impairment, would struggle to use the device. As G2P10 said 'also an older person probably wouldn't be able to see this'. Participants' disappointment in the device interface related both to their expectation of responsiveness having been built up through several years of daily access to touch-screen devices with near instant responsiveness, combined with the expectation that this was a device 'for the future'; which should evidently build on prior technological developments in touch screen and interface technologies and not carry delays in responsiveness leading to frustration or errors in production.

3.3 Printer safety, errors and the consequences

Participants discussed printer errors occurring mid-way through a print and their consequences on the user experience and the outcome of the print. For example, participants who were presented with an error message: 'unable to print ingredient' were unsure of what to do to resolve the difficulty. When successful, however, users expressed a sense of pride, as G2P9 said: 'I think it's fantastic. This one I'm very proud of this.' Participants in ERG1 considered the printer and the prints created were too variable, with inconsistent performance of the device meaning they could not recreate a print that had been done successfully, leading to frustration and disappointment. This also created a relatively large amount of food waste, as failed print jobs meant the puree shape partially created was not suitable for use and cartridges needed to be refilled. It also highlighted the level of expertise required in preparing the pureed food and using the printer to have a successful print, G1P4 stated if you 'know what you're doing [it determines] as to whether or not you might get a good result.' Uncertainty about what led to the errors and ways to respond to improve the print on subsequent attempts was common across the immersion experiences.

Participants also identified an element of risk being introduced by having to prepare the purees and manually insert them into the capsules, leaving too much room for 'human error'. This has the potential to be particularly detrimental when preparing puree for a person with dysphagia, who requires a specific consistency (e.g., smooth puree) for safe swallowing. Additionally, there is the increased risk of contamination and spread of bacteria due to the increased level of food handling involved in the preparation of pureed foods, filling of the capsules, and food being at room temperature while being printed.

3.4 Pre-processing of puree foods: Implications for using the 3D food printer

Easing the process of creating the puree texture. Much of the variability of the 3D printing process arose in the 'pre-processing' phase of the printing. In this phase, the puree for printing was either purchased or made at home using a food processor or blender, adding to the time demand. A great deal of variability in print success arose on home-made puree textures which had passed the IDDSI fork and spoon tilt tests and were smooth in mouth feel. It was not clear if the variability was due to the machine or the preparation of the puree, but G1P4 questioned the pre-processing step: 'If you had good results from the last time you tested it and this time you didn’t, I kind of go, well what was different in the prep.’ Pureed meat was tested at the correct consistency prior to the print, but separated into liquid and puree layers during the printing process, providing a potentially unsafe mix of consistencies (thin liquid with dry ground mince). Similarly, the pureed hummus met texture requirements of puree with IDDSI tests but did not print smoothly through the printer nozzle resulting in variations to the shape or blockage and stopping of the print. This impacted on several attempts in each of the immersion experiences. Pre-made shop bought puree textures such as mashed potato and icing printed more predictably and did not block the printer nozzles. The problem of using preferred home-made foods modified for the printer was of interest across the immersions with higher variability expected in the domestic kitchen. G1P1 explained ‘But you know if you cook something like pumpkin or mashed potatoes, depending how much water you use, how long you cook it, makes a lot of difference as to whether it’s watery or whether it’s firm’. G1P4 stated ‘it does seem to indicate that whatever preparation you do, you need to be very succinct and know what you’re doing as to whether or not you might get a good result’. Participants also noted that the print success depended largely on the quality or type of the ingredient, with G1P1 also stating that ‘some (foods) are smooth and buttery, some are kind of watery’. The 3D Food Printer itself lists the suggested food product (e.g. hummus) to be used for printing several of its pre-set shapes. However, it does not provide ingredient recipes for these food suggestions. As one participant explained ‘The machine only says hummus or guacamole - it doesn’t tell you the recipe’. This lack of specificity around the recipes suitable for printing created an additional level of complexity when trying to achieve consistent and successful 3D food prints. Ultimately, the use of shop-bought standardized puree texture foods (specifically mashed potato, specific brands of smoother hummus) yielded the most consistency in prints and the most predictable food printing experience, satisfying the print shape. Purchasing pre-filled cannisters rather than requiring the user to fill these was put forward as a solution to removing both the 'fiddly' component (and potentially the cleaning) previously mentioned, and the print errors related to variability in puree texture and a trial and error approach to printing the puree food.

3.5 Potential Applications of 3D Food Printing

Creating meals in residential care settings. Across the groups, views on the usefulness or potential application of 3D food printing within an aged care or disability group home setting differed. As G5P17 said: 'For morning tea I can see it working for the residents, cos there's five canisters you could fill all five up … and then they can come along and say what shape would you like for your morning tea today?'. Some participants viewed that the introduction of 3D food printing could increase efficiency in food preparation for residents with dysphagia in aged care. G1P4 stated '...how much of their time is taken up by food prep for the guys with swallowing disabilities, a huge amount. Take that away and suddenly that's a lot more valuable'. Others felt that the significant level of effort and time taken to prepare the pureed foods for 3D food printing would not be feasible. G2P10 stated 'I couldn't see a support worker in a care facility spending 20 minutes on this'. However, across the groups, participants also agreed that 3D food printing would be valuable for aged care settings and group homes if preparation time and the potential for food texture and human error in operating the device interface could be reduced.

Improving nutrition. Participants G4P1 and G4P2 discussed the issue of malnourishment of residents with dysphagia in aged care facilities or group homes and suggested that the use of pre-filled canisters in the printer could provide a means to increase the quality and nutrition of the purees served. This could make cooks or kitchen assistants within these facilities better equipped to manage the preparation of texture-modified foods whilst also maintaining adequate levels of nutrients, visual appeal, and flavour. A pre-made puree (in pre-filled cannisters) could potentially create a printed meal formulated to ensure adequate levels of nutrients and flavor; with the 3D food printing process transforming the puree into a visually appealing dish. G4P14, a dietitian, considered that to be useful in care facilities, the printed shapes would need to be a standardised portion size for the ingredient type to improve nutrition. Participants also highlighted that many of the pre-set food shapes and ingredients did not reflect a broad range of dietary requirements, such as dairy free or vegan meals.

Improving choice and control in a novel food activity. Although the usefulness of a 3D food printer for the preparation of full meals within aged facilities was thought to be limited by the time cost and relatively small size of the food shapes printed, participants did perceive value in the process of 3D food printing for people with dysphagia. Some participants viewed that printer might provide as a useful way to create visually appealing pureed foods for special occasions or treat foods. To illustrate, G4P1 stated ‘it would make a lovely little birthday cake for residents’. Members of ERG5 also discussed how the novelty of the process could be useful in care facilities to encourage people to engage in meal preparation by choosing the shape and flavour of their food. Group 5 also discussed the potential benefits of 3D food printing in providing residents the opportunity to choose the shape to be printed; increasing choice and control in the process. Sharing the food shape 3D files across devices across homes (using the ‘smart homes’ or ‘internet of things’ aspects of the device) with other people with dysphagia also provided a potential method to socialize around the process, for example by creating a recipe or a shape and then ‘sending to a friend’ (G2P10). G2P9 thought that this would be particularly beneficial for children and young adults who enjoyed making and sharing food recipes and photos, but also involve sharing ‘food shapes’.

Participants also suggested that facilities could use the 3D food printer to pre-prepare meals in a variety of different shapes and freeze them for future use. G4P1 stated ‘you'd freeze it as a choice - to give choice’. This led to a discussion on the potential for improved food intake of residents associated with increasing the visual appeal of the 3D printed foods.

3.6 Ideas for Improving the Usability and Benefit of 3D Food Printing

A wider range of pre-set food shapes that are realistic. Participants made several suggestions to improve the function of the 3D food printer and its usability. G1P1 considered that many of the designs were not real food shapes but were were ‘fun’ shapes (e.g. flowers or spirals). To expand on this, a wider variety of ‘proper food’ shapes (i.e., that resemble the shape of the food tasted) would be beneficial in enabling users to create a meal with a realistic appearance. Participants were curious as to whether the amount of the printed food eaten would differ depending on the realism of the shape (e.g., chicken printed in a star shape compared to chicken printed in the shape of a chicken leg). G4P1 wondered ‘what gets people to consume the meal? And so I think comparing things would be really interesting’. However, not all participants thought this might make a substantial difference across shapes. G1P1 said ‘whether you have your mashed potato in a spiral or whether you just have it as we would all have it, we would eat it - it's immaterial really’.

An expanded range and more cultural diversity in recipes and food shapes. ERG1 and ERG4 considered that the range of shapes should be expanded to include more cultural diversity across the foods featuring in the recipes and shapes. G1P1 stated ‘You'd think they'd have various sorts of dishes – tapas - not mashed potato and peas'. Similarly, G1P4 said: 'it's not very diverse food. Where is the fried rice or noodles?'

Increased printer capsule size. Participants across groups discussed the potential for the printer capsules to be larger in size, allowing for larger food shapes and multiple prints to be created from the one capsule. As G4P14 said: 'Even if there were two large [capsules] that hold more capacity so you print pull it out, then print the next one so from a production perspective a larger canister would be better than five different ones.' It was suggested that this would be more efficient for care settings needing to produce large numbers of pureed meals several times a day for residents with dysphagia. ERG4 suggested that larger capsules would be an important strategy to ensure the printed shape met the dietary guidelines and daily nutritional requirements for each component of a meal (e.g. protein). G4P1 explained 'I guess that's going to be important for certain proteins and things that you want to try and make at a certain portion size based on recommendations'.

An easier way to fill capsules and access to pre-filled capsules. As previously noted, participants' interactions with the device, specifically using the software interface and attempting to fill the printer cartridges with a smooth enough puree food for a successful print, was at times a source of frustration. Participants suggested that providing an easier way to fill the capsules or else to purchase pre-filled capsules would improve the usability of the printer for a wider range of users. G2P9 stated that the capsule filling process was 'not very convenient. You need to bag it before you put it in.' This inconvenience was mirrored by other ERG4 members who suggested a tool should be designed to ensure the capsules could be filled with reduced mess, food wastage and reduced risk of air bubbles. In comparison, ERG1 members discussed the concept of buying prefilled capsules of desired ingredients to reduce the preparation time required for printing. G4P1 stated ‘if the puree was premade that went into the capsules and then people would just print it straight away’. G2P9 also outlined various steps in the process with implications for the supply chain, in that the availability of

> ‘food that you buy as purees and put in the machine and press print, to mitigate the risk for the carer because they don’t have to do [make] a puree, the person can swallow it … it would help people to be something you’d buy and put it in the fridge and then your meals are ready … if you have limited mobility you put your canister in the thing and print it.’

Should pre-filled canisters be available, it was considered this might be beneficial in the community where support workers might have less time and experience in preparing foods to be printed. Participants also suggested that the device could be paired with a smart phone app allowing for easy access and ordering of the puree food substrates. Such technological improvements could lead to increased choice and independence, ‘the person with a disability or the family choosing, there’ll be an app or something – yes I’ll have that one, that one, I want to replace the pumpkin one with this’ (G1P4).

Cost of the 3D food printer. At the time of the study, the retail price of the Foodini 3D food printer ($4,000 US). Considering their own immersive experiences, participants conceded that potential buyers of the 3D food printers in the disability community may only invest in the new technology if there were a trial period, as there might be for other costly assistive technologies. Participants viewed this as potentially being important given some of the difficulties with usability that had been raised (e.g. capsule filling, print reliability) and the ‘trial period’ being a requirement in some funding models where individual funding packages rely on the person’s needs being met and ability to use the technology successfully.

Recipes for 3D food printing.' Considering both the novelty and emergent nature of the 3D food printing process, participants saw the need to develop tasty smooth puree textures suitable for the print, and to provide a book of recipes specifying techniques for preparing the food substrate and designing new food shapes for programming into the device. G4P14 suggested that a recipe book could provide: 'standardised images, and if you could sort images into meat or proteins, vegetables, desserts and they have really set sizes.' Participants' comments reflected that standardised and well-tested recipes might help to ease the pre-processing stage, improving time cost and benefit associated with 3D food printing, and the reliability and predictability of the 3D food shapes printed.

4. Discussion and Conclusion

This research focused on the user experience in relation to 3D food printing for people with dysphagia, by examining the impact of immersing novice users in the 3D food printing process. All who volunteered to participate had an interest in and motivation towards improving mealtime safety and enjoyment for people with dysphagia, through improved food design. As such, the study examined an empirical problem in the design of 3D printed foods (Oulasvirta & Hornbæk, 2016). In introducing novice users to the process through an immersion, more informed views could be obtained from potential consumers, health professionals, engineers, marketing and business personnel, and people involved in food production and quality control in disability and aged care settings. Thus, the research provides several insights on the usability and the feasibility of 3D food printing for people with dysphagia and their supporters, and ways that the present technology could be improved for greater uptake and use in the future.

The users' immersive experiences led to a number of emotional responses – both positive and negative - demonstrating the importance of setting user expectations and attending more closely to the printer functions; and not only aiming for foods that can be printed successfully, or the engineering of a wider range of finished food products, including meat and a wider range of vegetables. The results of this study suggest that even if a print is successful, if it comes with additional labour or burden of time or effort, even frustration, it may be discounted or abandoned early. Indeed, the delight or joy in the reward of printing food successfully will need to outweigh the time and effort invested in working against a slow or non-responsive user interface. Further research is needed to determine how far these results relate to the user experience of people with dysphagia who wish to invest in a 3D food printer for use at home; or to larger residential settings such as aged care homes. Research including people with dysphagia and their supporters should examine how they might respond to challenges presented by the printer to create pureed foods that are visually appealing and what supports are needed to enable successful use.

Overall, the results of this research suggest that 3D food printing for people with dysphagia is an early or emergent stage of development. Also, much can be done yet to improve the user experience before these devices can be recommended for purchase as an assistive technology used to improve the safety and enjoyment of texture-modified meals. Problems with the user interface, the usability of the device, and the consistency and success of food printed will need to be resolved for 3D food printing to offer a viable alternative to standard methods of shaping food such as piping bags or food molds. Without attention to the user experience, even if the device produces 3D food that will keep its shape, it is more likely to fall short of its full potential in substantially moving the field forward or being taken up across populations with dysphagia.

The user experiences in this study also indicate the need for development of standards around 3D food printer design that take into account the user experience, particularly for use in the domestic situation of people with dysphagia who often have a range of other impairments, including physical and/or cognitive disability, and rely on family members or support workers for access to devices used in food design and production. The experts in this study were using a 3D food printing device that was new to them had the opportunity for practice, trial and error; and were motivated towards persisting when errors occurred, and finding out ways to improve usage. It is important to design user-centred supports into the 3D food printer, that provide an interactive experience that includes feedback, cues or reminders of the required steps being completed. 3D food printers need to become more immediately responsive to the user, such as through providing a way to test the food substrate is suitable for the print (e.g., to reduce the errors associated with blocked nozzles), and usage feedback systems (e.g., sounds associated with device steps).

There are three main limitations to this study and its results should be interpreted with caution. Firstly, although participants in this study were naïve and novice 3D food printer users, and as such the study provides important insights into early consumers' first impressions, it might have been limited by this lack of experience and the extent to which users could make full use of the printer's affordances. Had the participants included experts with knowledge of using a range of 3D food printers, further insights could have been obtained on how this particular printer compared operationally or in terms of food design elements and interaction design features in an emergent field. Secondly, the research was also limited the team only having access to one commercially available 3D food printer, and one which met Australian standards, at a time when few if any were known to be in use for people with dysphagia, either nationally or internationally. It is therefore not possible to say whether any of the features of use in the device in this study might apply to other 3D food printers on the domestic market internationally or if users would have different views or experiences. The third limitation is considered to have had a lesser impact on the results, and this relates to the immersion experience being online only, due to COVID-19 restrictions on face to face data collection at the time. This only affected some participant data, and primarily in relation to the direct nature of the user touching the interface themselves, and in tasting of the food, which ultimately tasted the same as its substrate foods as in prior research (Kouzani et al 2016, 2017).

Further research is needed on the Human Computer Interaction elements of 3D food printers to enable wider use by parties interested to adopt this emerging technology; to improve the printer interface, usability, sharing of recipes and personalization to individual needs (Gayler et al. 2019). Considering the positive elements of user experience outlined in this study, including the device being fun to use, recognizing the creative elements of designing novel food shapes should serve to encourage the design and development of domestic-scale 3D food printers that users view add to their quality of life, choices and participation and inclusion in food design. The field of 3D food printing engineering and design would benefit by continued interdisciplinary efforts that include consumers with dysphagia, their supporters and health professionals, including speech pathologists, dietitians, and occupational therapists. These parties should be engaged in the process of developing and user-testing 3D food printers as assistive technologies for improving the safety and enjoyment of meals for people with dysphagia. Recognising 3D food printers as a potential assistive technology would also indicate a need for further research on the accessibility of the devices, and the cost-benefit of funding 3D food printers for people with disability, in the event that these devices are shown to improve access to participation in safe and enjoyable meals.

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Table 1

Participant Demographics

Participant	Discipline	Group Number	Prior Exposure to 3D Food Printing Y/N	Experience in Dysphagia Mealtime Management Y/N
G1P1	Speech pathologist	ERG 1	Y	Y
G1P2	Electrical and data engineering	ERG 1	N	N
G1P3	Person with disability and dysphagia/lawyer	ERG 1	N	Y
G1P4	Manager of a disability Service	ERG 1	N	Y
G1P5	Social marketing	ERG 1	Y	N
G1P6	Disability support worker	ERG 1	N	Y
G1P7	Speech pathologist	ERG 1	Y	Y
G1P8	Public health/social work	ERG 1	N	N
G2P9	Business management	ERG 2	N	N
G2P10	Business management	ERG 2	N	N
G3P12	Computer scientist	ERG 3	N	N
G4P13	Consultant chef for aged care	ERG 4	N	Y
G4P14	Dietitian	ERG 4	N	Y
G5P15	Chef and Catering company manager	ERG 5	N	Y
G5P16	Chef for aged care service provider	ERG 5	N	Y
G5P17	Chef and catering company quality and safety officer	ERG 5	N	Y

Figure 1

Examples of puree 3D food shapes printed by participants during immersion experiences in using the 3D food printer.