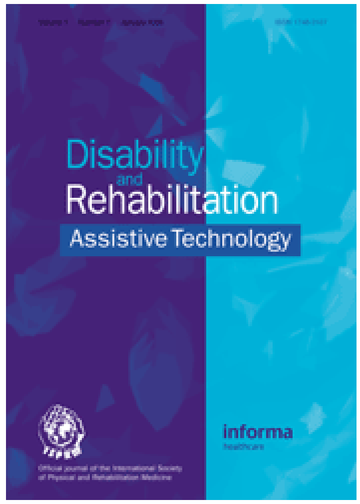

Views on the Usability, Design, and Future Possibilities of a 3D Food Printer for People with Dysphagia: Outcomes of an Immersive Experience

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Implications for Rehabilitation

- 3D food printers potentially have a role as an assistive technology in the preparation of texture-modified foods for people with disability and dysphagia.
- To increase feasibility, 3D food printers should be co-designed with people with disability and their supporters and health professionals working in the field of dysphagia and rehabilitation.
- Experts struggled to be able to print 3D pureed shapes owing to relatively low usability of the 3D food printer tested with problems using the interface and resolving problems in the print.
- 3D food printing is a fun and novel activity and may help to engage people with disability and dysphagia in making choices around the shape of the food to be printed.

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Abstract

Purpose. Although 3D food printing is expected to enable the creation of visually appealing pureed food for people with disability and dysphagia, little is known about the user experience in engaging with 3D food printing or the feasibility of use with populations who need texture-modified foods. The aim of this study was to explore the feasibility and usability of using domestic-scale 3D food printer as an assistive technology to print pureed food into attractive food shapes for people with dysphagia.

Materials and Methods. In total, 16 participants engaged in the unfamiliar, novel process of using a domestic-scale 3D food printer (choosing, printing, tasting), designed for printing pureed food, and discussed their impressions in focus group or individual interviews.

Results and Conclusions. Overall, results demonstrated that informed experts who were novice users perceived the 3D food printing process to be fun but time consuming, and that 3D food printers might not yet be suitable for people with dysphagia or their supporters. Slow response time, lack of user feedback, scant detail on the appropriate recipes for the pureed food to create a successful print, and small font on the user panel interface were perceived as barriers to accessibility for people with disability and older people. Participants expected more interactive elements and feedback from the device, particularly in relation to resolving printer or user errors. This study will inform future usability trials and food safety research into 3D printed foods for people with disability and dysphagia.

Keywords: 3D food printing; dysphagia; swallowing; usability; assistive food technology

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Swallowing Disability and Food Shaping Technologies

People who have dysphagia (swallowing difficulty) make up an estimated 8% of the world's population (Cichero et al., 2017) and many require texture-modified food (e.g., of a soft and bite sized, minced-moist, or pureed texture) to promote safe swallowing and reduce the risk of choking or respiratory illness (Groher & Crary 2020, Steele et al. 2015). The transformation of food from its regular texture (e.g., slow roasted meat) into a pureed or minced and moist texture often requires the use of food processor technologies, which for people with disability could be considered a form of assistive technology – enabling them ready access to texture-modified foods of the correct consistency. With little scholarly exploration of food processors or food shaping methods in the disability or indeed health literature, food processing technologies could be considered a *taken for granted* technology, potentially due to a ubiquitous presence of these items in households and residential settings. For example, food processing technologies may be funded as reasonable and necessary supports for people with disability within the National Disability Insurance Scheme (NDIS) in Australia as "assistive products and accessories relating to participating in household tasks" (NDIS, 2022).

Potential benefits to food shaping and quality of life

A person with disability and dysphagia (e.g., associated with cerebral palsy, intellectual disability, stroke, Parkinson's disease, motor neurone disease) who requires pureed or minced and moist food may be severely restricted in terms of the food items that they can include in their diet, and may also have unsightly or indistinguishable food items, which have a negative impact on their quality of life (Smith et al., 2022). Minced or pureed foods can be visually unappealing on the plate, particularly if it is not possible to identify the food, thereby reducing mealtime enjoyment and appetite (Smith et al., 2022; Smith et al., in press a). Over the past decade, 3D food printing technologies have been proposed as a technology-driven solution for providing visually appealing texture-modified foods to people with dysphagia (Hemsley et al. 2019; Smith et al., in press), with potential to out-perform traditional food shaping methods for pureed foods (e.g., using a scoop or spoon, food moulds, or piping bags) (Godoi, Prakash & Bhandari 2016). There are several as-yet untested claims, including from manufacturers of these devices, that the use of 3D food printers as an assistive technology could assist people with dysphagia to increase their oral intake, improve their nutrition and quality of life, and reduce human errors in food production such as inconsistencies in the texture produced by residential care staff or support workers (see Hemsley et al., 2019). However, to date, research on the development and implementation of 3D food printing has not been inclusive of people with dysphagia, their support workers or family members, or other key stakeholders such as speech-language therapists or dietitians,who hold training and experience in the provision of texture-modified foods (Hemsley et al. 2019). When asked about the feasibility of 3D food printing for people with dysphagia, allied health professionals exposed to a video of its operation in printing pureed foods queried its feasibility and whether it would provide any use-case benefit over and above existing food shaping methods (Smith et al., in press b).

A lack of usability research that is inclusive of end-users

In a recent systematic review of the literature on 3D printed foods for people with dysphagia, Hemsley et al. (2019) postulated that the research primarily addressed constructive problems, such as ways to expand the range of nutritious foods that could be printed (e.g., grains, meat, vegetable and fruit) with less attention given to questions about human interactions with 3D food printers or people's views and experiences of consuming 3D printed foods. In the period since, research has continued to focus on the engineering of 3D food printers, particularly to solve the persistent problem of printing meat safely. More recently, Human-Computer Interaction (HCI) researchers have begun to engage with Human-Food Interaction (HFI) (Bertran et al. 2019; Khot & Mueller 2019). Usability, a core concept within HCI, will be important in ensuring that 3D food printers are designed to be easy to use and meet the users' needs (Hemsley et al. 2019). The user experience can be defied as the product meeting all the user's needs including the design, marketing, and production of a product that is a pleasure to use and own (Nielsen, 2012). However, to date, there is little exploration in the literature on (a) the views of people with dysphagia or experts in a range of fields related to swallowing and mealtimes on their experiences of 3D food printing or potential application in dysphagia management; or (b) the usability of and user experience with 3D food printers, especially by people with disability and dysphagia or their supporters or other key stakeholders involved in prescribing assistive technologies. It is not yet known if 3D food printers designed to print texture-modified foods would meet the needs of people with dysphagia and their supporters and be enjoyable to use.

Prior research on 3D food printing for people with dysphagia has included the use of an industrial scale bioplotter (a printer that is suitable for printing biomaterials for insertion into the body, but not dedicated to printing food) repurposed for the first 3D printing of egg white as a protein, in a pavlova (Kouzani et al., 2016); and of tuna fish, a nutritious protein, fruit, and vegetable dish designed in the shape of a tuna fish (Kouzani et al. 2017). Both the pavlova and the tuna fish tasted like their substrate foods. These pilot studies connected 3D food engineering with the discipline of speech-language therapy highlighting the interdisciplinary nature of the design process. However, the research and use of a bioplotter in particular cannot directly translate to the real world settings, since a chef, cook, or resident would need access to either an industrial scale or domestic scale dedicated 3D food printer to produce 3D printed food.

Food Design for People who Need Texture-Modified Foods

While the shape of meals for people with disability and dysphagia has received little attention in the literature (Smith et al., in press a, in press b), and a common intervention to improve safety and food intake for people with dysphagia is to modify food textures, there is almost no reference to the need for improved food design or food shaping in the extant literature on dysphagia and its management. Food design refers to any design decision made during food production and consumption, including modifying the visual appeal of the food by changing the shape, colour, or how it is eaten (Zampollo 2016). The International Dysphagia Diet Standardisation Initiative (2019a) outlines a framework for the description and testing of texture-modified foods and fluids according to their texture and viscosity, in 8 levels including Level 5 Minced & Moist food and Level 4 Pureed food. Limited consideration to the visual design of plating texture-modified food may make food appear less appetising (Milte et al. 2017); mixing scooped foods together further reduces the visual appeal of modified meals.

Research on the provision of texture-modified foods for people with dysphagia has focused predominantly on compliance with food or fluid texture recommendations to reduce the risk of choking (Hemsley et al., 2019). There is a small body of research on whether the appearance of the texture-modified foods influences person's oral intake. Reilly et al. (2013) explored whether techniques such as the use of food moulds, piping bags, gelification, and emulsification methods could improve the sensory appeal of pureed foods for people without swallowing difficulty and found that participants liked the food and rated it highly (Reilly et al. 2013). Germain, Dufresne and Gray-Donald (2006) reported that participants who ate moulded pureed food gained weight and had increased energy and nutrient intake. Furthermore, Higashiguchi (2013) reported that people with dysphagia who were given moulded pureed foods were more satisfied with the appearance of the food. Indeed, using food moulds helped younger people with dysphagia to identify the foods they were eating (Lepore, Sims, Gal and Dahl, 2014). These studies indicate that the physical structure of the pureed food is an important element of food design that has positive outcomes for the consumer. However, two studies indicated that some people with swallowing difficulty preferred traditionally prepared pureed food, and did not find moulded food as easy to eat (Stahlman et al. 2001; Stahlman et al. 2000).

Dick et al. (2019) reviewed studies focusing on the expanding range of foods suitable for 3D food printing, noting that there was limited evidence of the printing of fibrous meats, as to date 3D meat printing has not been embraced by the food industry. 3D printed foods have the potential to be easy to eat for people on soft diets, resulting in less spillage of food from poor chewing or inadequate lip closure, or coughing out food, and therefore more of a meal being consumed, particularly if looked appealing and appetising. Nevertheless, to date there is no research demonstrating that the 3D printing of pureed meals improves the food intake or nutrition of people with dysphagia who often have nutritional disorders (Hemsley et al. 2019). Given that there is still scant research on 3D food printing for people with dysphagia, the aims of this study were to (a) obtain the views of experts from multiple disciplines and a person with disability and dysphagia on the use of a domestic-scale 3D food printer for people with dysphagia as a form of assistive technology; and (b) examine the usability of a 3D food printer and identify any usability issues, that might guide its further user-centred design in relation to its potential domestic use by people with disability and dysphagia and their support workers or family members.

Methods

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

Materials

The 3D food printer

The 3D Food Printer used in this study, the Foodini by Natural Machines, is powered by Android and features computer aided design capabilities (Natural Machines 2019). The Foodini (Natural Machines, 2019) was selected as the only domestic-scale 3D food printer available at the time for producing pureed food items from natural food ingredients (i.e., without food thickeners or additives), claiming also to benefit people with dysphagia. It was selected to provide a stimulus for reflection and discussion about the possibilities of 3D food printers in the future, and to commence an exploration of user experiences. The printer belonged to the University and could only be used under supervision of trained university staff in a laboratory setting, to maintain hygiene and monitor safety in terms of the device function.

The Foodini is an extrusion-based printer (i.e., where food is pushed through a cylindrical metal cartridge (canister) through a nozzle onto a printing plate) with five stainless steel canisters that the user fills with pre-processed pureed food. The Foodini ships with five canisters, and extra capsules can be purchased. The canisters each have a screw-on nozzle and a 'top' cap which seals the top of the canister for setting into the printer which then, during operation, pushes the top down into the canister to extrude the pureed food through the nozzle, while moving so as to make the 3D shape, layer upon layer. Thus, the user must manipulate the canister, the nozzle, and the cap in order to prepare the printer; and then must use a touch-screen interface on the front of the device to control the print, choosing the food shape to be printed, adjusting its size, and adjusting the temperature of the cartridges (room temperature or warm).

The Foodini is pitched as an easy to use, Internet of Things (IoT) device with both onscreen and WiFi connectivity for controlling printing. Other 3D food printers on the market at the time of this project were specific-purpose devices, not designed to produce texture-modified foods and often not in 3D shapes. For example, the PancakeBot 2.0 (PancakeBot, 2022) had a specific narrow function of printing and cooking pancake dough, as did Primera's cookie printer, which prints edible printed images onto cookies (Primera, 2022). Other 3D food printers have an industrial focus such as Beehix's production line equipment, for printing items for baking after the print (e.g., biscuits) or printing decorations onto baked goods (Beehix, n.d). The Foodini provided a potential opportunity for usability testing, enabling multidisciplinary research to examine how 3D food printers could be used to improve mealtime experiences for people with dysphagia. Natural Machines have used 3D food printing for texture-modified food outcomes as part of their advertising campaigns for the Foodini device (e.g., Natural Machines, 2020). Retailing for (at the time of purchase) $4000USD, and at the time of writing revised to $6000USD outright or under subscription almost $4000USD for two years of usage), research to question and validate these claims in a controlled environment was important to assess if the printer could meet the needs of people with disability and dysphagia, their family members, and disability service providers and provided value for money as an assistive technology.

The food being printed

Unlike the inkjet printers with premade cartridges, or 3D extrusion printers with rolls of filament, the Foodini requires the user to fill cartridges (referred to in this study as canisters) for each print. In this study, pureed foods used for printing the food shapes were either made in a domestic kitchen from vegetables, meat, or fruit that had been pureed using a food processor or purchased as the pre-made puree textured food substrates (e.g. packaged icing mix, mashed potato, guacamole or hummus dip) as described on the food recipe 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 IDDSI fork and spoon tilt tests (IDDSI, 2019b). In this study, the device was housed at the University in a 3D printing laboratory.

Participants

Participants were drawn from multiple discipline areas who agreed to form members of an Expert Reference Group on the use of 3D food printers for people with dysphagia. See Table 1 for a full list of participants with their lived experience, discipline, experience with 3D printing, and experience in working with people with dysphagia.

Insert table 1 about here

Data Collection.

The 16 participants were invited to attend the university 3D food printing space (within a 3D printing laboratory) at a time convenient to them. Those who could not attend at the group time were welcomed to attend in individual appointments. The 2 hour visits were designed to enable participants to take part in an interactive immersion experiences with the 3D food printer, and give their impressions of the device while using and afterwards reflecting on their immersive experience and the usability of the device. Due to COVID-19 social distancing restrictions, three of the 16 participants completed their immersive experience online videoconference using Zoom, guiding the choices in the process and viewing all steps but not being able to taste the food that was printed. The immersive experiences were designed to give participants the experience of all stages in the process of 3D food printing to inform their discussions on usability and feasibility for people with dysphagia. Whether attending in person or online using

Zoom, participants were invited to make choices about what food to print and the food/shape combinations that they wanted printed. In the 3D printing lab, participants directly engaged in the different steps of the 3D printing process: selecting food, filling print canisters, using the Foodini interface, observing printing, plating, and tasting the final print product.

In Zoom, the virtual experience involved the researchers setting up the Zoom laptop camera view to see both the researcher and the 3D food printer and its interface directly in front of the participant who was online; with the researcher following the instructions given by the participant on the foods to use, the shapes to choose, printing the food, plating it, and describing the taste. 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 researcher (the first author) with the device in real time. Participants were able to give instructions to the researcher operating the device. This gave online participants several opportunities to observe the researcher using the device and have control over the food selected, the shape selected. There was also opportunity to have an informed discussion about the ultimate creation. All participants were encouraged to give instructions and feedback during the observations and ask questions about the device as it was being used. The foods printed were the standard food shapes available within the pre-set 'recipes' (in that the food content was named as 'mashed potato' or 'hummus') provided by the Foodini printer software. A selection of the foods printed showing some of the outcomes of the prints made by participants is shown in Figure 1.

[INSERT FIGURE 1 here]

The immersive experiences gave participants a good deal of exposure to the 3D food printing process and usability of the device. In the time provided, participants considered that they had seen all that the device could do, even if not printing all of the various food shapes possible. All 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).

Data Analysis

A content thematic analysis of the transcribed discussion (Patton 2014) involved five authors reading and re-reading the texts, coding the emergent themes in NVIVO and discussing the content themes. The final categories of meaning were reached through consensus. From these, the main themes and any clusters or categories of meaning within these were identified, and discussed with all authors for cross-disciplinary input to the interpretation of participant quotes and to increase the plausibility and confirmability of the interpretation of the data (Patton 2014).

Results

Results are presented as the content themes identified across all group and individual discussions with quotes from the transcripts provided to help illustrate the immersive experiences. For the purposes of this paper, we are presenting three major categories of themes in the results, based on prior research and our data: expectations and impressions of a 3D food printer; usability of a 3D food printer in practice; and implications for the management of dysphagia and future possibilities for 3D printed food printers in an emergent field.

Expectations and First Impressions of the 3D Food Printer in Action

Participant expectations for the 3D printer were high, in part due to marketing material from Natural Machines, and in part due to the expectation of the printer output within the device menus and recipes. Participants expected to be able to print to a full meal on the basis of the information provided on the website promotional materials. G1P1 stated ‘when you look at the picture … there’s a meal.’ Group discussions reflected initial positive reactions to the concept and use of 3D printed food as a means for delivering quality of life in texture modified foods. Enthusiasm was expressed for 3D food printing fitting into an aesthetically pleasing meal arrangement. 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, and consistent with prior concerns of Dick et al (2019), meat printing failed on the aesthetic due to separation on printing which introduced a new challenge for visual efficacy. A consistency test of the pureed meat showed it correct prior to the print, but it separated into liquid and puree layers during the printing process, providing a potentially unsafe and unappetising mix of consistencies (thin liquid with dry ground mince). Participants across the focus groups and interviews lacked certainty about the purpose of the device. Despite having experienced the machine in operation, both directly and vicariously whilst watching others and making design decisions in the process, most participants remained unclear about who would find benefit. On the basis of their experiences, and their own difficulties in filling the cartridges and using the device touch-screen interface, participants expressed doubt that people with dysphagia, or their support workers, would be able to use the device and identified a range of accessibility barriers to its use.

Usability of the 3D Food Printer in Practice

Core to the concerns of the expert reference group members was the mismatch between the promise of the device for simplicity or ease of use the reality of printer or user errors and resulting frustration. In relation to her in-person 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.' Three distinct problems affecting the user experience were identified in the results: loading the printer, the printer interface, and poor quality or inconsistency of printed outcomes.

Design flaws in printer loading of food

When encouraged to complete all steps in the process, including the filling of the food canisters in readiness for printing, participants experienced a number of barriers to success. With no guidance (e.g., step by step instructions) from the user interface, participants followed the operating instructions and were given prompts by the researcher in their attempts at filling the canisters with pureed food (e.g., using a long handled teaspoon to fill from the top, or fill from the bottom). The user needed to ensure that there were no air bubbles in the canister as this would disrupt the print process; the canister needed to be filled such that, like a syringe, only the food material was extruded once placed in the device. This turned out to be more difficult than expected. Once food was placed into the canister, inserting the top cap and pushing it into position to seal the canister became a messy operation, and required wiping of the canister's surfaces (so that no food substrate came into contact with the internal parts of the 3D food printer) and a good deal of pureed food being left on the preparation mat. On observing one another in this process, participants who had used other food shaping tools, such as piping bags and spoons, perceived the 3D printer as inefficient. Most participants viewed filling the canisters by hand as 'fiddly' (GP4), messy (leading to food wastage) and time consuming. Difficulties in filling the canisters prompted 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 (for filling the canister). That would make sense."

The small size of the canister (90ml) was noted as a barrier for use, given the difficulty of filling it, and the small volume of output needed in the print. For the high effort of filling the canister, only a small printed item would result. Participants surmised that the canisters might not hold enough puree to print an entire meal or enough to make multiple servings of a specific food and would require cleaning during meal preparation. Referring to the multiple parts involved in the printing process, G1P8 likened it to having to wash "a million dishes, having to wash those bits and piece."

This prompted discussion about the disadvantages of the printer. 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 also identified an element of risk to food safety in having to manually prepare and insert the puree into the capsules, leaving room for error at critical points. They viewed this as a disadvantage when preparing puree for a person with dysphagia who requires a specific food consistency for safe swallowing. Participants questioned if there was an increased risk of contamination and spread of bacteria due to the increased level of food handling involved in the preparation of pureed foods, filling the capsules, and food being at or near room temperature while being printed.

Problems using the 3D food printer interface.

In practice, all participants agreed that the main graphical user interface touchscreen of the 3D Food Printer often provided frustratingly slow response times when operating the functions of the device. Latency issues with the touchscreen, along with a lack of user interface feedback (e.g., clicks or other sounds), created repeated situations where users were unsure if commands were received, followed, or if the machine was responding. They had expected the touch screen on the Foodini to behave with rapid responsiveness like a cell phone or tablet device. Between touching the screen and their selection being activated, even a small delay resulted in uncertainty that the selection had been recognised in the device. Most participants also had problems navigating the user interface, particularly with the small icons and low resolution on-screen text. As G2P10 said "also an older person probably wouldn't be able to see this (screen and writing size)." The user interface, pitched as intuitive, was perceived as ambiguous by participants who relied on trial and error exploratory approaches, and experienced challenges such as false starts and wasted prints. The participants included a range of educated, experienced, and sophisticated technology users, so concerns were raised about the challenges for consumers who were not used to advanced technologies or had physical or intellectual disability, or low literacy. The participant with disability and dysphagia, associated with cerebral palsy, was not able to operate the touch screen device, and directed her support worker in the steps of the process. Reflecting on this, she said: "I was wondering about the level of training needed (to use the device) it seemed like a lot." There was consensus across the groups that people with disability, including those with visual or cognitive impairment, would struggle to use the device and would need assistance from a support worker. The gap between the expectation of a kitchen-ready device, and the user experience of slow responsiveness that led to errors in production and extended food preparation time, resulted in a sense of frustration that the device was not meeting basic benchmarks for performance of a smart device.

Problematic outcomes: failure, error, and print problems

Participants discussed printer errors occurring mid-way through a print and the consequences this had on their user experience and the outcome of the print. Instead of error messages that are precise and supportive, the unhelpful error messages created confusion and frustration. For example, participants who were presented with an error message: 'unable to print ingredient' were unsure of what to do to resolve the difficulty. Participants' engagement with reasons for the errors reflected this lack of feedback on problems from the machine, as illustrated in the following exchange in ERG1:

> G1P7: what happened when we printed onto their mat and the nozzle dug into their mat
>
> G1P1: We printed onto that before and that didn't happen
>
> G1P7: Yeah that's what I mean. It was digging into it
>
> G1P1: I think that's a straight up error. I think it might've needed a reset
>
> G1P3: It was behaving weird when we had the problem with that [paper] plate

Participants in ERG1 considered the food prints variable with inconsistent performance of the device resulting in difficulty in replicating previous successful prints. This led to both user frustration and disappointment, and concern over the relatively large amount of food waste as failed print jobs rendered the partially-created pureed food shape unsuitable for use. Further, a failed print resulted in the Foodini requesting the print cartridges be refilled before restarting or continuing the print. Even with the participants' experience in technology, and expertise in preparing the pureed food, user experience was inconsistent and users were given limited feedback to determine differences between success and failure. As G1P4 stated "even if you 'know what you're doing … you might not 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 immersive experiences. Predictability and reliability of the printed food were seen as a key areas for improvement, as G1P1 said "[people could be] frustrated because they wouldn't see what they were expecting."

Implications of 3D Food Printing for the Management of Dysphagia

Variability in performance and outcomes

The 3D food printer's promise of automation, computerized control, and precision was undercut by the user experience of inaccuracy, inconsistency, and opaque error processing. In reflecting on their experiences overall, ERG 1 participants also agreed on the user default position being to blame themselves for errors, wanting the device to provide prompts:

G1P7: I feel like it surprises us every time we use it [others laugh]

G1P1: This is interesting – we all think it's us. We've not done the food right, not practised right, [others agree]. We haven't really said it must be the machine.

G1P3: I think it could be the machine that is not well designed. The machine should tell us it should be this it should be that [others agree] like try and add a bit of cream or whatever – give a solution.

The participants in this study identified key barriers in the printing process, and several expected benefits of the 3D printed process were not fulfilled. The barriers included the preparation required to use the printer, and the results of the printing process. The performance of the printer was inconsistent and lacked detailed information on the preparation requirements needed to meet specific texture required for printable food. Nevertheless, participants noted a role for printed foods as a novelty, special occurrence, and way to give consumers with disability increased food choices.

Variability in food prints of home-made puree textures which had passed the IDDSI fork and spoon tilt tests (IDDSI, 2019b) and were smooth in mouth feel were a problem. It was not always clear to the participants if the variability of print was due to the machine not printing the food consistently as expected or if there was some slight variation in the preparation of the puree prior to printing (e.g., not being completely smooth in texture). G1P4 noted that the pre-processing step might not always be precisely the same: "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?" However, with the opacity of error messages, and limited technical guidance for the machine standards, this introduced a level of randomness and risk to the texture shaping process. For example, pureed hummus which met texture requirements of puree with IDDSI tests did not print smoothly through the printer nozzle, resulting in blockages and failed print runs, and subsequent food wastage. The absence of guidance for the printer's required tolerances created a gap between the expertise in food preparation and the performance of the machine. The information on the recipe display in the 3D Food Printer software lists the suggested input product (hummus) without recommendation for 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.

Opportunities for a market in pre-filled canisters

Convenience as a facilitator for 3D food printing uptake and use. Participants 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." Using store bought mashed potato, standardized puree texture foods, and specific brands of smoother hummus yielded the most consistent and predictable food printing experience. This led to the view that pre-filled canisters would function as both a solution to removing the "fiddly" filling component and the print errors related to variability in puree texture. Several participants across groups discussed the concept of buying prefilled canisters of desired ingredients to reduce the preparation time required for printing. G4P1 stated "if the puree was premade that went into the canisters 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.

Saving time in standard food preparation. Participants considered pre filled canisters might be beneficial when support workers have less time or experience in preparing foods to be printed. Some participants suggested that the introduction of 3D food printing could increase efficiency in food preparation for residents with dysphagia, as G1P4 stated “...how much of their time is taken up by food prep for the guys (people) with swallowing disabilities, a huge amount. Take that away and suddenly that’s a lot more valuable.” Across the groups, participants also agreed that 3D food printing would be valuable for residential aged care and supported accommodation in the community if preparation time and the potential for food texture and human error in operating the device interface could be reduced.

Increasing choice and control. Group 5 also discussed the potential benefits of 3D food printing in providing people with dysphagia the opportunity to choose the shape to be printed, bringing an increasing sense of choice and control into their food selection. Participants also suggested that the device could be paired with a smart phone app, thus allowing easy access and ordering of the puree food substrates. Such technological improvements could lead to increased choice and independence, as G1P4 said: “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." Across the immersive experiences, the participants noted the tension between presenting 3D food printers as being easy to use, and the more exacting specifications of the food printing requirements. As 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."

Potential for nutritional benefit. Participants G4P1 and G4P2 discussed the issue of malnourishment of some people with dysphagia and suggested that the use of pre-filled canisters in the printer could provide a way to increase the quality and nutrition of the purees served. This could assist the preparation of texture-modified foods with additional levels of nutrients, visual appeal, and flavour. A pre-made puree (in pre-filled canisters) could potentially create a printed meal formulated to ensure adequate levels of nutrients and flavour; with the 3D food printing process transforming the puree into a visually appealing dish. G4P13, a dietitian, considered that to be useful, the printed shapes would need to be a standardised portion size for the ingredient type to improve nutrition.

Embracing the Novelty of 3D Food Printing as a Special Treat

Across the participants' immersive experiences, a common thread of willingness to explore the potential of the texture modified printed food emerged, with an emphasis on embracing the challenge of the process as a novelty, and the triumph of success as a distinct benefit. From the user experience side, it was an unfamiliar experience and G1P1 stated "I thought it was quite fun because we had not done it before." Having experienced the current state of play in printed food, participants could see potential areas of future research and new developments and opportunities for the process. Although frustrations arose with inconsistent outcomes in the current printer, participants recognized that 3D food printing is new in an underdeveloped market.

Participants suggested that printers might provide a useful way to create visually appealing pureed foods for special occasions. G4P1 stated “it would make a lovely little birthday cake for residents.” The perceived limited capacity of the 3D food printer for full meals was countered by the potential application for texture-modified snacks, using the small size of the food prints, and novelty of textures and printed shapes as a way to return a “fun” experience of being involved in the food creation printing process. Even when G5P5 commented on the shape as being “very juvenile”, this was embraced by other participants as a way to potentially appeal to children with autism who liked routine or predictable foods, and “fussy eaters”. Novelty shapes and a sense of “playfulness” present were seen as inducing a sense of celebration. G5P16 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?” Members of ERG5 also discussed how the novelty of the process could be useful in supported accommodation to encourage people to engage in meal preparation by choosing the shape and flavour of their food. Sharing the food shape 3D files across devices and across homes (using the ‘smart homes’ or ‘internet of things’ aspects of the device) and with other people with dysphagia also provided a potential method to socialize around the process (G2P10).

***Expanded options in the taste and shape of foods to come*.**

The participants remained supportive of the future potential of printed texture modified food, and proposed a number of areas of future development – both in industry research and development and academic research. These clustered into extended support for the end users through the development of a wider range of recipes, shapes, and input options.

Considering both the novelty and emergent nature of the 3D food printing process, participants stressed 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. G4P13 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, including vegan and gluten freed 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. Participants also highlighted that there was a need for further research into alternate binding or thickening agents for printing pureed foods.

Participants made several suggestions to improve the function of the 3D food printer and its usability. G1P1 suggested that a wider variety of print options that resemble the “proper food” shape would enable users to create realistic meal appearances. G4P1 wondered “what gets people to consume the meal? And so I think comparing things would be really interesting.” Extending the opportunity for users to develop diverse meal options, 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?”

Discussion

This research examined perceptions, experiences, and key stakeholder judgements on the usability of the Foodini 3D food printer for people with dysphagia.

Through the use of an immersive experience, the key stakeholders in the management of dysphagia were able to experience the texture modified food printing as novice users through their first engagement with the Foodini 3D food printing process. The study identified a number of challenges. In this study the team had access to only one printer, the Foodini 3 D which is the only printer available in Australia for domestic use specifically in relation to texture-modified foods. However, the issues raised by participants are applicable to any printer that targets the domestic market. First, it revealed the impact of poor usability on the user experience. Second, it highlighted the willingness of participants to try to find use-cases and usefulness for the device. And third, it identified several areas of potential development for the use of 3D printers as mechanisms for improving the visual appeal and safety of texture modified food for people with dysphagia. As with prior research on potential for 3D printed texture modified food (Reilly et al., 2013), quality of life improvements shaped the focus on recommended developments moving forward. By drawing on a range of stakeholders including a person with lived experience of dysphagia and experts across disciplines with a wide variety of background knowledge, it was clear that the present technology could be improved for greater uptake and use in the future. As all participants had a pre-existing interest in improving mealtime safety and enjoyment for people with dysphagia through improved food design, they formed an 'informed novice' in trialling and reflecting up the 3D food printer.

The immersive experience in this project led to both positive and negative responses, demonstrating the importance seeking a range of participants from different backgrounds. The experts agreed that engineering and designing a wider range of finished food products, including meat and a range of vegetables, was a critical future development. This is an area where further exploration is required to assess the viability of a secondary market to support a texture modified food printing through an eco-system similar to ink cartridges and filament roles in conventional printing. Similarly, challenges experienced in failed prints indicated that if printers are aimed at the domestic market it is important to focus development on food shapes (3D models) that can be printed successfully and consistently, without additional labour burdens of time, effort, or frustration. This is supported by prior work by Higashiguchi (2013) on the satisfaction experienced from moulded and shaped food. However, the present study found that satisfaction for those involved in the production process varied. Further research including people with dysphagia and their supporters could examine (a) how they might respond to challenges presented by the printer to create pureed foods that are visually appealing, and (b) what supports they need to enable recurring successful use (Hemsley et al., 2019).

Overall, the results of this research suggest that 3D food printing for people with dysphagia is at an early or emergent stage of development. Also, the user experience requires improvement before these devices can be recommended for purchase as an assistive technology for people who might benefit from printed texture modified meals. Problems with the user interface, the usability of the device, and the consistency and success of food printed need to be resolved before 3D food printing can be offered as a viable alternative to standard methods of shaping food such as piping bags or food moulds. It would be important for future 3D food printers to provide constructive advice as to how the user could recover from printer or user errors (Cockton 2013; Nielsen 1994). Without attention to the user experience, even if the device produces 3D food that will keep its shape, any 3D food printer is likely to fall short of its full potential in substantially moving the field forward or finding a domestic market in people with dysphagia.

The user experiences in this study also indicated the need for the development of standards around 3D food printer design that take into account the context of the user experience. Usable technology allows users to complete tasks it is designed for, efficiently and effectively, as well as providing users with good guidance, and thus supporting learnability (Cockton 2013; Nielsen 1994). Our results indicated that additional supporting skills, resources, and assets were required before the printer could be used. This make the device impractical given that people with dysphagia often rely on different family members or support workers to access devices used in food design and production when preparing their meals. The experts in this study used a 3D food printing device that was new to them but they had the opportunity for practice, trial and error; and were motivated towards persisting when errors occurred, and finding out ways to improve usage. Support workers and family members may not have the time, motivation, or confidence to experiment with a device that is supposed to make food preparation easier. It may be important to incorporate user-centred supports into the 3D food printer design. These can provide for an interactive experience that includes sounds, signals, or speech from the device to provide feedback, cues or reminders of the required steps needed. It would be helpful if 3D food printers provided a way to ensure that the food substrate is suitable for the print in order to reduce the errors associated with blocked nozzles

Limitations

This was a small study with one make of printer so the results must be interpreted with caution. Nonetheless, the problems are noteworthy to avoid and potential benefits and applications important to consider in future printer design. The participants were experts in their field but novices in the field of 3D food printing, enabling examination of their first impressions and, with a diverse group, potentially reflecting the user experience of early adopters should people purchase 3D food printers as an assistive technology for people with disability who need texture-modified food. Further research may find it valuable to bring expert users of 3D printing (food and non-food) to explore a fuller use of the printer's affordances. Second, by affordance of market circumstances, only one model of commercially available 3D food printer was used. The Foodini had met the relevant Australian safety standards, and was positioned on the market as a consumer device that was 'kitchen ready'. The final limitation emerged within the study due to COVID-19 restrictions on face to face data collection. This affected some participant data, primarily in relation to the direct nature of the user touching the interface themselves, and in tasting the food.

Conclusion

Further research is needed on the human computer interaction elements of 3D food printers to support wider use by parties interested to adopt this emerging technology, so as to improve the printer interface, usability, sharing of recipes and personalization of taste to individual needs (Gayler et al. 2019). The positive elements of user experience outlined in this study, including the device being fun to use and the creative elements of designing novel food shapes, may serve to encourage the design and development of domestic-scale 3D food printers that users will perceive 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 involving people with dysphagia, their supporters, and health professionals in the development and testing of 3D food printers for the domestic market that includes people with dysphagia. As a potential future assistive technology, greater design effort and attention should be directed towards improving the accessibility of the 3D food printers, and the cost-benefit of funding 3D food printers is needed.

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Table 1. Participant Discipline, Prior Exposure to 3D Food Printing, and Experience in Dysphagia Management

Participant code	Discipline	Group Number	Prior Exposure to 3D Food Printing Y/N	Experience in Dysphagia Mealtime Management Y/N
G1P1	Speech pathologist and family member of a person with dysphagia	ERG 1	Y	Y
G1P2	Electrical and data engineering	ERG 1	N	N
G1P3	Adult with lifelong disability and dysphagia/lawyer	ERG 1	N	Y
G1P4	Manager of a large disability service providing meals for people with dysphagia	ERG 1	N	Y
G1P5	Social marketing and family member of a person with dysphagia	ERG 1	Y	N
G1P6	Disability support worker of G1P3	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
G3P11	Computer scientist	ERG 3	N	N
G4P12	Consultant chef for aged care	ERG 4	N	Y
G4P13	Dietitian	ERG 4	N	Y
G5P14	Chef and Catering company manager	ERG 5	N	Y
G5P15	Chef for aged care service provider	ERG 5	N	Y
G5P16	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.