3D PRINTING IN OCCUPATIONAL THERAPY:
INCREASING INTEGRATION INTO PRACTICE BY COUNTERING BARRIERS

A Thesis submitted to the faculty at Stanbridge University in partial fulfillment of the requirements for the degree of Master of Science in Occupational Therapy

by

Arren Bruland, Catharine Kim, Mathieu Woo, and Angel Yen

Thesis Advisor: Dennis Chen OTR/L, BCP, CPAM

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Certification of Approval

I certify that I have read 3D printing in occupational therapy: Increasing integration into practice by countering barriers by Arren Bruland, Catharine Kim, Mathieu Woo, and Angel Yen, and in my opinion, this work meets the criteria for approving a thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Occupational Therapy at Stanbridge University.

Dennis Chen OTR/L, BCP, CPAM

Instructor of Occupational Therapy

ACCEPTED

Vikas Sharma, OTD, OTR/L

Program Director, Master of Science in Occupational Therapy

Dedication

We dedicate this project to our family, fellow peers at Stanbridge University, and practicing occupational therapists around the world.

Acknowledgements

The authors would like to thank their thesis advisor, Dennis Chen, for his guidance, vision, and support. His knowledge and passion for the field inspired us to put our hearts into this project. We are extremely grateful towards the occupational therapists who shared their work, designs, and experiences with us. Their contributions as pioneers of 3D printing in occupational therapy enabled the completion of this project. Thank you Stanbridge for this opportunity of exploring 3D printing with occupational therapy practitioners and collaborating with research driven individuals. Additionally, we are very appreciative of Stanbridge University's MSOT program director Dr. Sharma, and the Learning Resource Center for guiding and assisting us throughout the project and keeping accordance to APA 6.

Abstract

3-Dimensional Printing (3DP) is a flagrantly under-explored resource in occupational therapy (OT). After a preliminary literature review identified four barriers (application, cost, time, and education) in integrating 3DP into OT, this study aimed to challenge those ideas. Six practicing occupational therapists (OTs) from diverse settings around the world were recruited to participate in interviews that would spotlight user perspectives and 3DP utilization in practice. The results showed that the four identified barriers were preconceptions that did not align with perspectives of therapists currently using 3DP in practice. Not only are there numerous applications, the results also reflect 3DP as a valuable tool that can be used in OT. It enables therapists to creatively address client needs while adhering to clinical practices. Despite initial expenditures of cost and time

when learning the skill, therapists found long-term benefits that outweighed startup investments. OTs were able to eliminate purchases of outsourced or catalogued merchandise and print items at their facilities or homes for clients. Customized 3DP items were designed from scratch or redesigned to fit client specific needs. OTs employed time saving strategies that enabled them to multitask and adapt to their available time frames. Because the majority of the participants were self-taught, many felt that educational courses should integrate 3DP courses into curricula for the potential of 3DP to be embraced by OTs across the globe. We supplemented our interview findings with additional literature drawn from relevant fields that supports the experiences of the OTs. Qualitative data demonstrates that OTs who have found applications of 3DP in their unique practice benefit from employing 3DP and are able to transform their delivery of services. By presenting the collective, lived experiences of overcoming challenges and encountering success, this study encourages non-users to try this new and revolutionary technology.

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3D Printing in Occupational Therapy: Increasing Integration into Practice by Countering Barriers

Whether fitting a patient for customized devices or providing education on the use of assistive equipment, occupational therapists (OTs) can use technology to provide creative solutions to address each client-specific issue. Three-dimensional printing (3DP) is a modern tool that can help OTs meet the unique goals of their clients. Its applications in the medical field as prosthetics, implants, medical devices, and sensory tools show the diverse opportunities of its use. Despite its promise in other medical fields like surgery and medicine, the prevalence of 3DP within occupational therapy (OT) is lacking.

Due to the lack of 3DP presence in research and practice, OTs may not be fully aware of the possible applications of this tool. Studies have shown that OTs have reservations about integrating 3DP into practice because they suppose it has no alignment to their work (Hofmann et al., 2019). Additionally, clinicians may believe they do not have the time available to fully learn and use 3DP and modeling services (McDonald et al. 2016). Lastly, literature suggests that high costs and training are also general challenges of 3DP (Lundsford, Grindle, Salatin, & Dicianno, 2016). From the literature, four barriers to 3DP utilization were identified: lack of application, perceived high cost, time consumption, and difficulty with learning. Helping practitioners recognize and overcome these barriers will unveil unexplored potential and enable growth within the field of OT. This is important because OT is an adaptive field that calls for its practitioners to be cognizant of technological advancements that could bolster quality of care.

This study interviewed the few OT practitioners who are currently using 3DP in practice. We also discuss the barriers identified towards its integration in the literature.

By addressing these barriers that individuals face and illuminating the feasibility of adopting 3DP into practice, we hope to demonstrate the pertinence and potential of 3DP in OT. Alongside the accounts from OTs at the forefront of 3DP's application in the field, relevant literature drawn from the rehabilitative sciences and related settings is compared to interview findings.

The target audience for our project are OT professionals (OTR/OTA) in all settings. Since OTs work to enable meaningful activities for their clients, 3DP is a customizable solution to help enable engagement in occupations. 3DP has effective implications in the manufacturing of assistive devices, sensory toys, and orthotics, as well as reducing long-term costs in the production of such devices. The research agenda of the American Occupational Therapy Association (AOTA) and the American Occupational Therapy Foundation (AOTF) were taken into account in our study (AOTA, 2017; AOTF, 2011). A major research goal in the AOTA and AOTF agenda is to examine extrinsic mechanisms (such as technology, social support, culture, and social policies) and how they support performance in daily life (AOTF, 2011). Countering the barriers and highlighting applications will bring awareness and recognition of this underexplored technology. It will also provide guidance towards approaching and navigating this modern technology. We hope our project illuminates the feasibility of integrating 3DP within OT practice and shares knowledge of the current ways it is being used to address society's occupational needs.

Statement of Purpose/ Hypothesis/ Research Question (PIO)

The purpose of this study is to recognize the application and feasibility of 3DP in OT by addressing the barriers confronted during integration into practice. How six OTs around the globe use 3DP was explored. Through semi-structured interviews, we explored how these OTs perceive the four barriers we identified through our literature review: lack of application, perceived high cost, time consumption, and difficulty in learning. The data collected through interviews provided a candid look into the process of integrating 3DP into diverse settings. Then, the literature on 3DP regarding applications, cost, difficulty, and time consumption was compared to interview findings to gain a comprehensive perspective of 3DP usage.

With our study we aimed to answer this research question: In OT, are the perceived barriers of 3DP utilization true challenges that contribute to the lack of integration into practice?

P: The target audience is anyone in the field of OT

I: The intervention considers perceived barriers of 3DP utilization

O: We hope to increase the prevalence of 3DP in OT practice

We hypothesize that these barriers in applications, cost, time, and learning are valid but can be addressed and overcome. As with learning any new skill, OT practitioners may encounter initial difficulties, but this tool does align with the needs of OT practice. When OT professionals recognize the feasibility and applications of 3DP, we believe that OTs and OTAs will become more active in pursuing utilization of this technology to advance our field.

Preliminary Literature Review

3DP is already being used in other fields like medicine, engineering, and education (Ganesan, Al-Jumaily, & Luximon, 2016). The potential applications of 3DP in OT related devices can significantly impact therapeutic practices in terms of material cost, adjustability, productivity, creativity, and aesthetic design (Ganesan et al., 2016). We delved into the reasons why OTs were not applying 3DP into their practice. A preliminary literature review identified the common preconceptions that deter individuals from integrating 3DP into practice.

Application

Hoffmann et al. (2019) found that OTs confessed reservations about integrating 3DP into practice because they saw no alignment between 3DP and their work. They felt unable to satisfy their responsibilities to the client when failing to make successful designs efficiently. Assessing user readiness, Chatzoglou and Michailidou (2019) conducted a survey of educated individuals who have no prior experience with 3D printers but could grasp this technology. The study showed that users anticipated 3DP would assist them in performing a task, but it would ultimately have no effect on their overall performance and productivity. These perceptions lead to a curtailment of trials in attempting to use and apply 3DP in practice. Currently, the lack of interest and inquiry into 3DP is evident from the limited literature regarding 3DP technology use in OT domains, including settings with students with special needs and assistive technology (Buehler, Comrie, Hofmann, Mcdonald, & Hurst, 2014; Lundsford et al., 2016). Ganesan et al. (2016) also identified that 3DP is not being applied in OT practice as is being done in other fields like education, medicine, and other industrial settings. While 3DP technology has been successfully utilized in other healthcare settings as customized medical devices and powered prosthetics, it has yet to fully be fully embraced in OT research and practice. With OT’s focus on evidence-based practice, a lack of literature propagates perceptions that there is a lack of application in the field.

Time

The perception of lack of time is another common issue that deters therapists from adopting 3DP into their practice. OTs face high demands on day-to-day workload that diminishes the time they have for activities outside of their practice (Gupta, Paterson, Lyasaght, & Zweck, 2012). Deviating from traditional treatment plans to trial and test a new technology can be time consuming. As Buehler, Comrie et al. (2014) found, one of the predominant barriers to 3D printed projects is lack of time for education and completion. Nemorin (2016) writes of the frustrations she experienced designing and producing a small 3D item, criticizing the number of days spent designing, as well as the number of failed attempts before the item was correct. Nemorin (2016) added on that the five lessons she received from a middle school teacher did not suffice as she still spent considerable time bringing the idea to life. McDonald et al. (2016) noted that clinicians are not only apprehensive about learning, but also about completing a print with the time they have available. Navigating and becoming proficient with 3DP demands additional time dedicated to education, and numerous participants struggled with making that time. Moreover, design and print success are unlikely upon the first attempt, entailing a trial and error process before the product of this technology is ready for application (Buehler, Comrie et al., 2014; McDonald, 2016; Nemorin, 2016). The initial experience appears cumbersome as this emergent technology will ask already busy therapists to spend extra time to learn on top of their existing workloads, ultimately deterring exploration of the potential of 3DP.

Cost

The perceived barrier of high cost associated with 3DP is yet another deterrence that discourages OTs from adopting 3DP technology. Hurst & Tobias (2011) mention that high costs of 3D printers have made 3DP exclusive to organizations and manufacturing companies in years past. Fused Deposition Modeling printers are a common type of 3D printer used to create 3D prints. These printers can print a larger variety of materials but are priced commercially in a range up to $5,000 (Silva et al., 2015). The high costs associated with 3DP are due to the running costs of paying for Computer Aided Design (CAD) software, maintenance of the machines, and relevant training needed to utilize 3D printers in practice (Lunsford et al., 2016). CAD software which is used to design 3DP designs is expensive and has not decreased in price over time (Lunsford et al., 2016). In addition, extraneous expenditures of 3DP include electricity and filament. Zheng et al. (2019) writes that printing materials needed to make items such as orthoses accumulates. Although 3DP can be cost efficient, the expenses associated with setting up the printer and the overall production process can add up (Ten Kate, Smit, & Breedveld, 2017). Based on the literature, the price of running a 3DP system can be costly and is an inevitable aspect of adoption. However, with continuous, rapid advancements being made in technology, reductions in 3D printer and material costs are expected (Zheng et al., 2019).

Education

Learning how to construct designs and utilize software tools in 3DP is often an arduous task, especially for those without extensive technological skills (Buehler, Hurst, & Hofmann, 2014). Unfamiliarity and lack of confidence with technology is understandably part of the reason why novice adult users feel more effort is required to learn these 3DP modeling programs. A qualitative study by McDonald et al. (2016) claimed that numerous student participants exhibited frustration while learning 3DP modeling software. Working on one's own caused McDonald et al.'s participant to throw the computer in exasperation, but also to realize that working in groups encouraged more success. Despite frustrations with the learning process, of the 65 physical therapy students in the study, 70% still wanted to further their education and skills. Traditionally, OT programs do not incorporate 3DP as a mandatory class. In relation to student education, introducing 3DP to students still in school would initiate the educational starting point earlier and allow individuals to develop their skills as a part of the curriculum (McDonald et al., 2016). Current literature climate seldom discusses educational resources and classes. Knowing difficulties in acquiring the knowledge and ability to manipulate this technology emphasizes how more educational resources are needed to help overcome learning challenges.

Theoretical Framework

Adoption of this new technology can be predicted on a bell curve according to the Diffusion of Innovation Theory. Although this theoretical concept is non-OT based, it is highly relevant when introducing 3DP to OT. This theoretical framework brings to light how innovatively feasible it is to blend the concept of 3DP into OT practice on a wider scale. The Diffusion of Innovation Theory consists of five categories that assist in guiding the implementation of 3DP technology into OT practice: relative advantage, compatibility, complexity, trialability, and observability.

The theorist E. M. Rogers first asserted that an innovation be evaluated by the Relative Advantage category (LaMorte, 2019). Relative Advantage is the scale to which the innovation in question is capable of successfully filling the position of, or even outperforming, the devices originally used for the same purpose. This category can be clearly identified in terms of 3DP as a new tool for creating OT implements for client treatment, rather than the practitioners relying upon mass produced prostheses or other developmental and therapy-based devices (LaMorte, 2019). Secondly, Compatibility gauges the accordance of the innovation with potential adopters' values, experiences, and other demands (LaMorte, 2019). Complexity entails how arduous and potentially problematic the incorporation of an innovation could be, while Trialability is defined as how safe it is for the target adopters to experiment with or examine the product with the aim being as risk-free of a test as possible (LaMorte, 2019). Both of these concepts relate to the integration of 3DP in OT because the complexity of this technology is self-evident in how some might perceive it to be difficult to learn, while the trialability of 3DP in OT would be the level of safe experimentation required to test it out in the field. Rogers' final factor of the theory, Observability, indicates the level to which the innovation demonstrates a reliable outcome (LaMorte, 2019). Because we are in the early stages of integrating this technology, future OT research must explore and record outcomes.

Rogers' Diffusion of Innovation Theory categorizes the different population groups when adopting an innovation: Innovators, Early Adopters, Early Majority, Late Majority, and Laggards (LaMorte, 2019). The Innovators are those who are leading the novel idea, who invent the initial concept of the innovation, and who trailblaze the scene for its earliest followers. The subsequent followers are known as Early Adopters. Then, the Early Majority are those who first become a part of the larger number of users. Following them are the Late Majority users. Finally, the Laggards make up the remaining 16% of those who eventually adopt and then transition to the initial innovation proposed by the Innovator group (LaMorte, 2019). When looking at the hopeful integration of 3DP as a widespread technological innovation in the OT field, this thesis project would be considered a part of the Early Adopters stage. As such, the goal of this project is to collectively call attention to the concept of 3DP technology as a reachable and contributable resource for inventing augmented treatment interventions in OT.

Methodology

Data Collection

Interviews. Through stratified and convenience sampling, six licensed OTs (three male and three female) were recruited. Recruitment platforms included the AOTA, Facebook, Thingiverse, OT references, and email invitations. The OTs varied in years of licensure (2-38 years). They had at least one year of experience with 3DP and all but one was based in the United States, the exception being based in Japan. Each participant worked in different settings (acute care, schools, outpatient with hand therapy, outpatient pediatrics, geriatrics, and regional home health). Consent forms and interview questions were sent to the participants ahead of time to ensure full understanding and to allow for comprehensively formulated responses. With consent, all data was audio and video recorded. Photos of created devices were provided by the participants. Following preparatory tasks, participants then took part in virtual, semi-structured interviews that permitted questions to be revisited in a conversational format. Open-ended questions were written regarding the four barriers and the overarching experiences these OTs have had with 3DP. Additionally, inquiries regarding pros, cons, and advice for novices were made. Interview times varied between 30 minutes to an hour.

Secondary Literature Review. After the preliminary review, we continued to conduct additional article retrievals from databases including, but not limited to, PubMed (National Center for Biotechnology Information), EBSCO, Cochrane, and Google Scholar to find evidence contradictory to barriers. Due to minimal OT research in this topic, non-traditional OT but related health science resources were used. Searches included the following key terms: 3D printing, 3-dimensional printing, 3DP, occupational therapy, OT, rehabilitation, applications, cost, time, and education. Secondary terms included: experience, perceptions, use, device, splints, adaptive equipment, consumption, and benefits. Several articles were sourced through the reference section from articles found via databases. Articles were organized into levels in accordance with the Oxford Centre for Evidence-based Medicine. Inclusive criteria consisted of the articles being related to OT, addressing at least one of the four predetermined barriers, and having been published within the last decade. Articles were excluded if 3DP was used for surgical procedures, lower body, non-rehab related uses, or a level 5 on the Oxford Centre for Evidence-Based Medicine scale. Reviewed and selected articles were then categorized into the appropriate sections of application, time, cost, and education. A total of 18 articles were used.

Storage

All participant files were stored in a private institution assigned drive. After receiving written consent and verbal confirmation, participants' photographed works were credited to them or the original designer. Extracted quotations from participant responses were kept confidential using pseudonyms of Participant 1, Participant 2, and so on. Only the research team and the thesis advisor had access to the data and recordings for the entirety of the study. Journal articles for the secondary literature review were stored in a drive shared only with the researchers and advisor of this study.

Data Analysis

Audio files were manually transcribed, coded, and analyzed. We organized the quotations within the four central barriers. Using thematic content analysis methods, we identified common codes within each barrier and created themes of the participant accounts on benefits and challenges of the 3DP process. Direct quotations pertaining to the study were extracted and presented in the results. No standardized evaluation instruments were used.

Ethical and Legal Considerations

This study was executed in accordance with the Standards of Conduct values of beneficence and nonmaleficence. Participants were provided information on how to contact Stanbridge University if they were dissatisfied with the manner in which this study was conducted. This research was largely observational and descriptive in nature. There was minimal to no risk to the physical and psychological well-being of the participants. An important ethical consideration taken into account for this study was the risk of a participant bias for 3DP since the majority interviewed were avid enthusiasts. An additional consideration for this study was the potential implicit biases while conducting and analyzing data. This study’s thesis advisor teaches 3DP and utilizes it in his OT practice, and we are advocates for the use of 3DP in OT. To mitigate incorrect crediting, measures were taken to clarify if the photos of designs provided by the practitioners were modified or originally designed. Additionally, we reviewed and noted interview recordings for information on where the designs were collected.

Results

Participant Overview

- Participant 1 has been in practice for 19 years in California, working in the acute setting at the Burn Unit of the ICU.
- Participant 2 has worked for four years primarily as a school-based OT in Arizona.
- Participant 3, a certified hand therapist, has spent a majority of her career working in hands and orthotics. She has been working in the hospital system for 27 years in Florida, currently in an outpatient rehab center treating many patients of different ages and diagnoses.
- Participant 4 has worked as an outpatient pediatric OT in California, focusing on orthopedics and neurology, for the past 13 years. He has been commissioned by various institutions to present and teach 3DP to OT students and practitioners.
- Participant 5 has worked with mostly the geriatric population in home health for two years in California. She also holds an educator position at a graduate level academic setting.
- Participant 6 has been practicing as an OT in Japan for almost 24 years. She works at a regional rehabilitation center and provides OT services at client homes.

Application

During our interviews, OT participants shared the various items they designed and printed using 3DP technology to meet the occupational needs of their unique patients.

Some OTs used 3DP to fix and modify traditionally manufactured items, making them a better fit for their client. Others applied 3DP to create items that were never actualized.

Hospital Setting. Two of our participants in hospital facilities shared the role of 3DP and how it enabled improved quality of care. Participant 1 integrated a 3D printed ball and socket joint onto an airplane splint to increase comfort for his burn patients (see Figure 1). He stated:

> The thing is this is a really complicated splint and it's rigid so it doesn't move, so what the problem I was having is that when you put it on a person, if you change the dressing or any kind of change, it wouldn't really fit anymore because it was rigid. So what I did is I printed out a ball-and-socket joint . . . basically you can put it in any direction and it doesn't matter what kind of dressings you have. With a mobile joint it doesn't matter if they have swelling because the arm, the torso, you can adjust everything on it.

Being able to make a 3DP splint granted him the ability to create customizable solutions for a complicated problem. Aside from splint making, Participant 1 shared his 3DP capabilities with the hospital's rehabilitation therapists and nursing staff by creating bundles of ear saver straps for masks (see Figure 2). He expressed other potential applications of 3DP joints for foot splints and other tools in an acute setting. These tools included adapters and ties for a hanging post, extension attachments for wheelchair breaks, and adaptive sticks for various controls.

In outpatient rehab, Participant 3 found many 3DP applications in the therapy center: "We make medical models for patient education, adaptive aids, finger orthotics and parts for larger orthoses, a spinning toy used by ST for voice therapy, and other devices or toys for use in our therapy clinic." When 3DP finger orthotics, specifically the widely used oval 8 splints, this technology granted her the ability to pair a client with a perfectly fitted splint, customize it with different colors, and create it on demand (see Figure 3). Participant 3 also mentioned the added convenience of eliminating inessential storage space. "I can measure it for you at an exact size. I don't have a bunch of shelves, (with splints) sitting there taking up space and maybe not being used. And I make sure we're able to do different colors." This participant also used 3DP to create adaptive equipment, including a toothbrush grip aid for individuals that may need a wider grip or extra weight for independent usage (see Figure 4).

Figure 1. Ball and socket joint for an airplane splint. Designed by David Chung, OTR/L

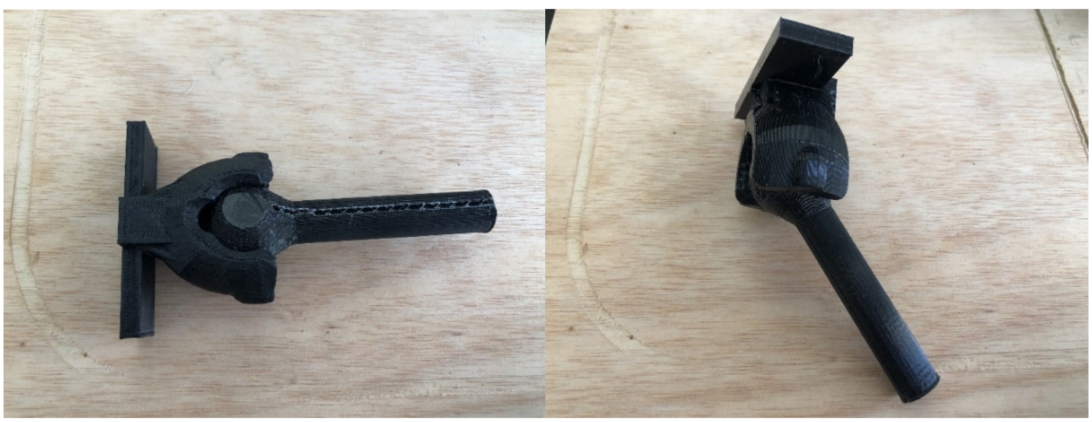


Figure 2. Face mask ear savers. Designed by David Chung, OTR/L

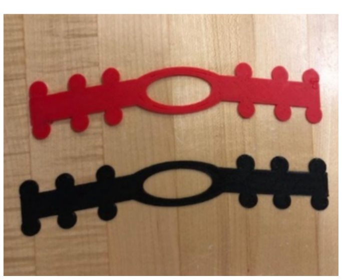


Figure 3. Oval 8 splint. Printed by Sandra Salinas OTR/ CHT. Original design by Bisquit.

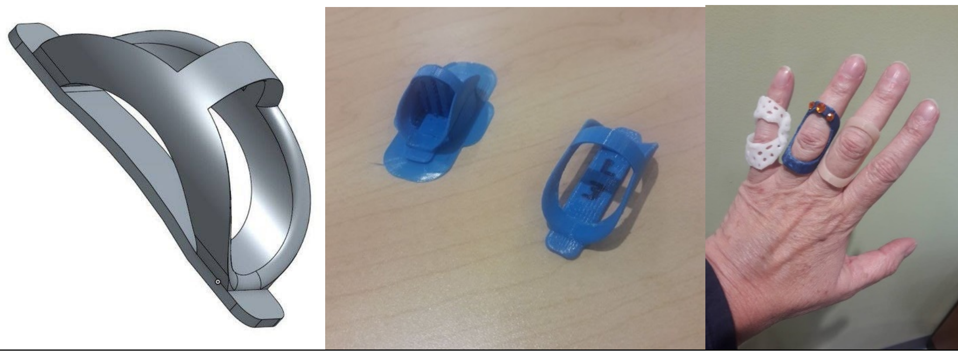


Figure 4. Toothbrush grip aide. Printed by Sandra Salinas OTR/ CHT. Modified by Joe Sharaya OTD, OTR/L.

Pediatrics. Two OTs in the pediatric settings elaborated on applications useful for their patient population. Participant 2, a school-based OT, found 3DP useful in creating solutions for his client population. For visually impaired children, he created tactile books that include 3-dimensionalized drawings to provide sensory output of the students' creations. When working with visually impaired students, this participant shared hearing about a school scanning student faces and printing them so that the students could feel the face of their friends. As a result, he decided to transfer handmade drawings done by students into 3D printed models: “Basically take your drawing and print it so then it gives that kind of--in a sense that texture, tactileness to it.” To address the occupation of play, he made a special print of a twenty-sided die with braille to allow the children with visual impairments to play a game of *Dungeons and Dragons* without requiring someone else to be present and tell the players what they rolled. This attention to detail and compassion for the experiences of his students was achieved through 3DP. To accommodate students lacking grip strength, this OT also made 3D printed modifications to glue sticks that provided leverage for independent usage in arts and crafts activities. The OT also presented 3D printed tong-like tools for hand strengthening and coordination building exercises. Supplementary to his physical creations and given the nature of the accident-prone population, he mentioned the added benefit of how easily repeatable and replaceable these tools were.

An outpatient pediatric OT, Participant 4, was also able to find ample applications of 3DP when working with children with disabilities. In his setting, 3DP allowed for easy adaptive equipment modifications including spoon holders and bike pedals (see Figure 5 and Figure 6). Participant 4 also applied the benefits of 3DP with visually impaired children by using this technology to create braille bricks for play on a Lego board (see Figure 7). The OT also used 3DP’s replicability feature to create easily misplaced or broken objects for stereognosis or motor skills assessment tools. Having them is necessary in delivering accurate testing in commonly used assessments such as the Peabody Developmental Motor Scales. Of the participant’s many productions, one particularly intricate project was a 3D printed prosthetic for a patient with a specific occupational need:

> It was for one of my patients that had a below elbow amputee, congenital amputee. He wanted to learn the violin so a lot of times insurance will pay for a body part prosthesis, or if you're lucky, myoelectric. But they don't really ever customize it for any type of activity. In this case it was for a kid who wanted to learn the violin.

After several trials, a customized 3D printed prosthetic that allowed violin playing (see Figure 8) was successfully made. This 3D printed prosthetic also had the added benefits of being able to withstand heat and that the design can be repeated. Participant 4 shared:

> I initially integrated thermoplastic splinting material with plastic hinges and 3D printed hinges and as I progressed, I turned it into all 3D printed because I found that that 3D printed material has a better heat tolerance than thermoplastic. Thermoplastic will start to melt and get soft about 150-180 degrees. Whereas PLA is about 200-225. And so the first prosthetic actually melted in their car . . . Then I just designed a new one from scratch all 3D printed and it's been working ever since. And he has broken parts of it . . . He plays a lot in concerts and things like that so luckily it's really easy to just push print again and then you just tell me what part he needs and I just print it.

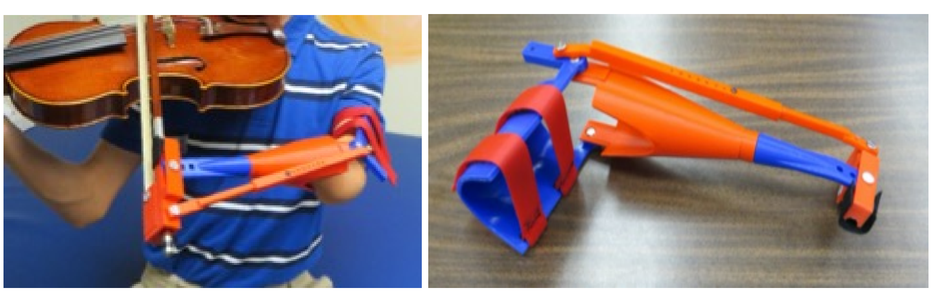
In pediatrics, the OTs interviewed have utilized 3DP to create specific and durable items for their clients.

Figure 5. Spoon Holder. Designed by Dennis Chen OTR/L.

Figure 6. Bike Pedal. Design modified by Dennis Chen OTR/L

Figure 7. Braille Bricks. Design modified by Dennis Chen, OTR/L.

Figure 8. Violin prosthetic. Designed by Dennis Chen, OTR/L.



Home Health. Two OTs from different nations, the United States and Japan, demonstrated the implications for 3DP when servicing clients in the home setting. Participant 5, a home health OT, found 3DP useful in creating adaptive equipment and modifications to tools for her geriatric clients. One example she shared was a 3D printed larger button to an electric toothbrush for a client with limited grip strength (see Figure 9). Other simple applications she found were in the creation of clasps and hooks for cables such as tubing from a sleep apnea machine. These clasps promoted increased safety and decreased risk of falls for senior clients transferring out of the bed.

Participant 6 has been practicing OT for almost 24 years in Japan. She provides services for patients in her assigned region at their homes. To meet the occupational needs of her various clients she uses 3DP to create assistive devices, including mop grips, drink holders, one handed nail cutters, and other kitchen aids (see Figures 11, 12, 13, and 14). She shared the advantages of applying 3DP into OT practice:

> We can share the data over the internet. We can share and if we already know the data, we might not need instruments from scratch. We can remix (modify) the data that depends on our client's abilities or condition . . . Most of OT's using 3DP are having personal printers in their house.

With 3DP's virtual nature, OTs from different physical locations can learn from creations of others and find applications for their own clients. She also shared:

> In my opinion, [the] biggest advantage of 3DP, [is that] we can include them (the clients) into the making process. In the rapid prototyping. We can make instantly. Our clients can try immediately. And we can discuss the future designs with each other. It's a very important process.

With 3DP, Participant 6 was also able to discuss the exact designs of each item with her client. Each design was made in consultation with the client, and so involving them in their treatment plan.

Figure 9. Toothbrush depressor in designing application. Designed by Claire Uke, OTR/L, CAPS.

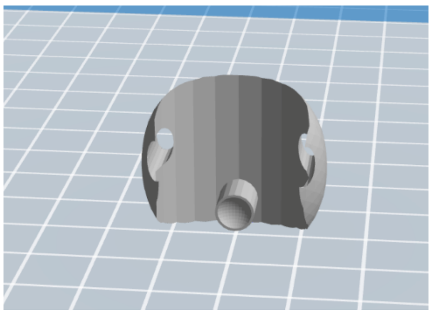


Figure 10. Mop Grip. Designed by Sonoko Hayashi OT.

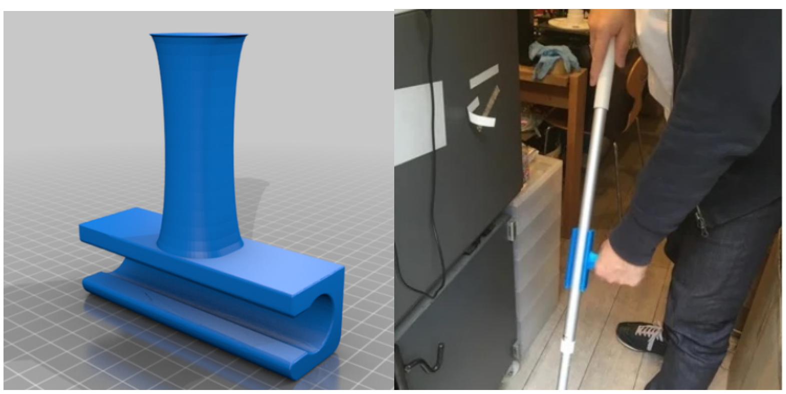


Figure 11. Drink Holder. Designed by Sonoko Hayashi OT.

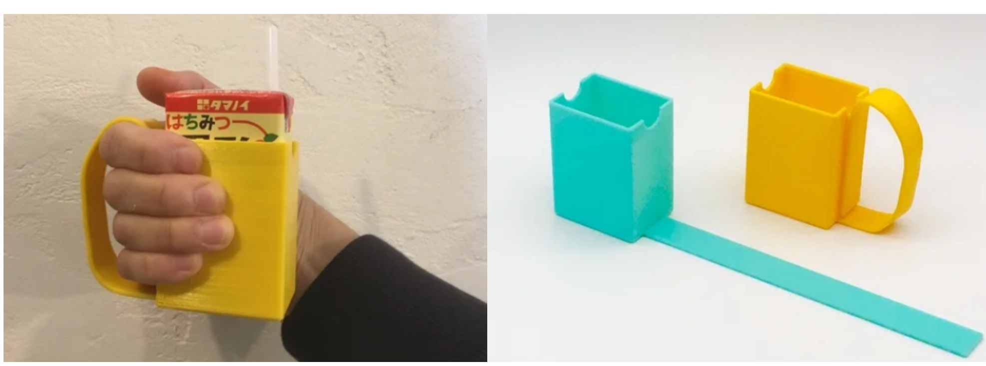


Figure 12. Drink Holder 2. Designed by Sonoko Hayashi OT.

Figure 13. One Handed Nail Cutter. Designed by Sonoko Hayashi OT.

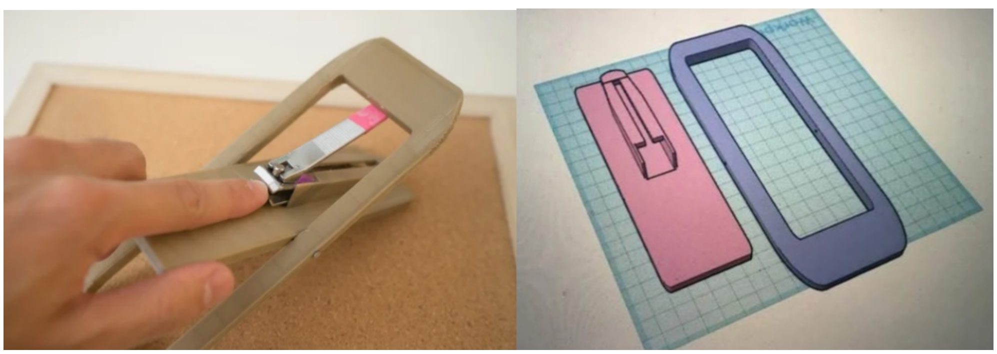
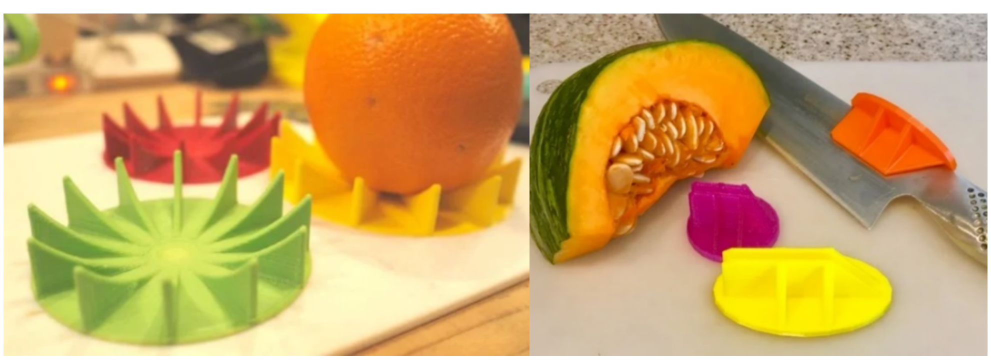


Figure 14. Knife Aids. Design modified by Sonoko Hayashi OT.



Time

Invested in Learning. OTs measured the length of time needed to feel comfortable with 3DP between a range of 2 months to 1 year, except for one therapist who referred to the learning process as continuous. Attitudes towards the process were mixed between feeling it was quick and complicated, but altogether eased with repetition. Therapists also unanimously agreed on a learning curve. Participant 1 suggested that with proper research and usage of a printer company with good customer support, the learning process is not considerably difficult. Participant 5 referred to 3DP as a "labor of love." Despite the initial time investment needed to learn 3DP, all the therapists have found 3DP valuable within their practices.

Spent Designing. When it came to designing the devices, therapists alternated between starting from scratch and reshaping a premade file from the web. If working from a blank canvas, applications like Tinkercad and Sketchup were repeatedly described as user friendly. Fusion360 was also a designing software mentioned multiple times but very complicated to use. If items were likely to have been designed already, therapists sought already finished files on online communities such as Thingiverse and Yeggi. For example, Participant 5 downloaded a shoehorn file, reformed it with a hook, and turned it into a customized dressing stick for a client. However, Participant 3 did mention finding a desired print online could become time consuming. Yet, this remixing process was mentioned by five of six participants and emphasized as a time saving alternative. It was also the more familiar, preferred way of starting a project. Therapists added on that reusing designs they had made in the past sped up their processes. The consistent repeatability available through 3DP helped to reduce future time expenditure. As done by

Participants 1 to 4, 3DP designs were saved, stored, and brought back at a moment's notice for client specific needs or related future projects. Participant 4 reflected on the convenience of reprinting as he was able to quickly reproduce broken custom-made parts of a 3DP prosthetic made to help a child play violin. Participants 1 and 3 elaborated on the convenience of saving files by praising the ease of sharing with other therapists. Time spent on designing can vary per therapist, item, and method used. However, results show that online communities and the ability to save files contribute to reducing the time needed to design each device.

Printing. Overall attitudes towards the printing process were similar between participants. Common themes were found regarding the time needed for printing consisting of trial and error, passive print time, and ways that sped up the process. Two therapists mentioned frustrations during their trial and error phases. One noted the time associated with attempting print after print, therapists expressed it as a necessary process. Another common theme evident from therapist responses pointed towards their utilization of passive time. When the machine was printing, Participants 1 to 4 set it aside and used that time to treat other patients or do other activities. Participant 3 detailed spending only 5-10 minutes actively attending to the printer. While the printer was making a finger orthotic the following hour, the participant attended to other patients and tasks. Printing time was also heavily contingent on what item was being made. According to Participant 5, a solid, dense doorstop took roughly 5-6 hours to print. Participant 6 printed a mop assist in 4 hours and Participant 4 a water bottle holder in 3 hours. However, once again, the majority was passive time, and only 10 minutes were considered active time. Participant 1 added that, "printers are getting better and better so I think we will see this more often and the speed will just increase." A couple of participants raised our attention to the importance of planning ahead. By doing so, Participant 2 was able to send students home with helpful devices before the COVID shutdown. Participant 3 commended the benefits of print-on-demand at her facility and how she could have an item available for the client before their next visit. While many initially discussed printing time as a con and visibly showed hesitation, they countered this barrier with the time-saving strategies discussed below.

Time-Saving Strategies. All therapists noted strategies that reduced overall time spent on 3DP. Aside from the already mentioned strategies of pulling from premade designs or reusing personal designs, technical recommendations were made as well. Participant 6 specified how choosing the appropriate nozzle size and orientation of the object on the print bed could be used as shortcuts. The same participant highlighted that keeping the item small and simple was important. Therapists also distinguished how 3DP saved them time compared to traditional methods. Participant 3 said, "compare this to looking through a catalogue, placing our order to our buyer, the buyer contacting the company, our receiving department taking in the order, sending someone to deliver it to our department. This is more time overall." Participant 3 also shared valuable insight on how she would use the 3D printed item as a therapeutic means by having the patient remove supports and sand the device. Having the patient be a part of the process of picking a design and helping complete it captured patient interest and added therapeutic value. Each of our participants developed time management skills that helped them integrate 3DP into their practice. There were recurrent themes of drawing from online communities, reusing designs, multitasking, and making technical changes. Each attest to time saving strategies that reduce overall time expenditure.

Cost

Cost Savings. Throughout the discussions with therapists, many OTs mentioned that 3DP was used in their practice because it saved them money in some form. When identifying the benefits of 3DP, most therapists highlight the term “cost savings” when utilizing 3DP into their work. Four of the six OTs mentioned that in their practice, cost savings would save them money because 3DP is a cheaper and a more affordable option to get products to clients. According to Participant 3, “I am told that 3D printing is expensive. Cost savings were significant while providing items for use by our clients they otherwise wouldn’t have.” She also mentioned, “So you might not be making money with a 3D printer, but you’re going to save them money.” Depending on setting, management may favor 3DP because of its ability to save money for the facility. When speaking about the hospital system, Participant 3 mentioned that it is common for hospitals to purchase expensive equipment for their hospitals for the benefit of their clients. She mentioned that hospitals are comfortable with spending money on high priced facility equipment like exercise bikes and gym equipment, which is very expensive. But 3D printers are significantly cheaper than gym equipment, and this technology would ultimately save the facility money. OTs often purchase products out of their own pocket to benefit their clients. Participant 2 mentioned that 3DP saved him a lot of money, savings that he would then typically spend on his own clients. Utilizing 3DP can also save money for therapists significantly when working in a pediatric setting. Working in pediatrics, it is common for children to outgrow custom fitted devices. As mentioned earlier, one participant created an assistive device to help his client play the violin. The therapist mentioned that when his client grew older, he was able to print replacement parts whenever his client outgrew the assistive device. Therefore, having the ability to print items on the demand at low cost would ultimately be a cost-effective solution for therapists in this field.

Cheaper Alternatives. When comparing the production cost of 3DP objects to the traditionally purchased alternatives, nearly all OTs mentioned the cost benefit of 3DP. In our interviews, all but one occupational therapist reported using 3DP because it is an economic alternative to create assistive devices and tools for their clients. Participant 6 mentioned that most 3DP products were cheaper in price than the traditionally purchased products. More specifically, Participant 6 stated, "Most of our products made from 3DP are made at a cheaper price. The price of filament is very cheap compared to assistive devices. We can make assistive devices for 1/8th the price of common materials." Due to the economic benefits of 3DP, many therapists can provide a wide array of assistive devices for their clients without causing a financial burden to the therapist. Participant 2 said that with 3DP technology, he was able to provide his clients with products that they can take home, without ever having to worry about losing items that could cost him money. When creating 3DP products, Participant 3 felt more comfortable giving her clients assistive devices because it would only cost her cents to make. She gave an example that finger orthoses are typically on the market for $20, but she can create a custom finger orthosis for 18 cents with 3DP. Participant 5 remarked that when working in low income areas, it is difficult to have clients purchase items for therapy. She shared:

> I have a lot of Medicare patients so I have the ability to, you know, make something instead of buy it. They probably don't have the income, they're very low income in general. So they probably don't have the income in order to afford to buy something. Even just off the shelf. So if I can just print it up. I mean that's like $20 for you know 1 kg of filament, it's like nothing.

As 3D printed objects are cheap to produce, using 3DP can ultimately enable therapists to produce adaptive equipment for clients with financial limitations.

Material Price. When discussing the running costs of 3DP, all therapists reported that running a 3DP system is not too expensive. Participant 4 mentioned that as technology has gotten better with 3DP, costs have dropped significantly, meaning that decent 3D printers are now affordable. He also mentioned that, with the current state of technology, decent entry-level 3D printers can be purchased for between $200-$300. The bulk cost of a 3DP setup would be the printer itself, while the running material cost would become affordable over time. Participant 1 mentioned that after purchasing the initial printer, he believed that it was not expensive to maintain a 3DP system because the only outgoing costs would be the electricity and filament. He stated that a large roll of filament could be purchased for around $20. When asking participant 3 about what can be printed with a 1 Kg roll of filament, she mentioned that she would be able to print 30 to 40 facemasks. Participant 5 stated that filament can last a long time if users only print smaller objects.

Reimbursement. When discussing the topic of reimbursement with OTs, no therapists were directly reimbursed by their work of 3DP. Participant 2 stated that he currently pursues 3DP on his own, but at this point of time, he does not get reimbursed.

He shared that the topic of reimbursement is tricky within OT and 3DP because there are currently no direct billing codes that can help a therapist get reimbursed with his/her work with 3DP. Many OTs use this technology to create products for their clients with the understanding that they might not get reimbursed for it. Participant 4 stated, “Let me be honest. I can’t find a Medicare code where this will belong, so I don’t bill for it that way.” However, OTs can bill for other treatments—for example, sessions where the client uses their 3DP products. There are a few ways that therapists are able to bill treatment while using 3DP products with their clients. For instance, Participant 3 shared that she was able to bill for client education of adaptive equipment, while Participant 4 mentioned that he was able to bill for therapeutic activities like completing activities of daily living.

Education

Improved Learning with Experience. The data for this study revealed that the majority of our participants felt learning improved after trial and error and that they gained experience over time. Experiential learning is a leading factor in achieving the necessary success and knowledge for mastering this technology. Each individual’s approach was unique but nearly unanimous that one needed to develop experience in order to learn about all the various aspects of this technological tool, and then apply it into practice. Participant 5 stated, “There is a learning curve when it comes to 3D printing, and I have hit every single learning curve, dilemma, and difficulty that you could possibly imagine.” She then shared how despite those obstacles; she was able to persevere because ultimately, she had this passion for learning. “The next thing I knew, I was buying my own printers.” Participant 3 agrees, “I made errors and learned from my mistakes.” These responses demonstrate the participants' belief in enduring a learning process and reflecting on mistakes was a rite of passage in learning 3DP.

Self-taught Learning. The final common theme that consistently stood out in the interviewing process was the self-taught learning method. This theme appeared in all of the participants’ responses as one of the most common and successful ways of learning how to manipulate this technology and then adapt it to their own needs in their practices. While it showed to be a highly effective method to learn 3DP, responses also indicated the need for a genuine interest on the part of the therapist that wanted to teach themselves such a complex concept. Some, like Participant 1, had never heard of 3DP workshops, which is why he was self-reliant. The motivation behind each participant was reflected within key words uttered by the participants such as enthusiastic, share, imagination, opens, and awesome. Independent 3DP education is possible in overcoming the intimidating learning curve. More importantly, when discussing this method, the participants displayed a sense of pride and excitement, indicating the level of satisfaction from their self-taught success in consolidating and rehearsing the learned information. Participant 2 said, “To me, it was well worth the frustrations that I initially had.” The self-taught learning theme goes in tandem with the media-based learning theme since being self-taught often calls for finding public online resources. For example, participant 2 referred to, “My friend Google let me look it up and see who else has had that experience and what can I do to maybe address it, and not have that issue in the future.” The combination of individual motivation and ability to research information is how each participant in this study learned 3DP.

Media-based Learning. Media-based learning was another method of education our participants took advantage of when in search of techniques and solutions for issues. This method was used with media-based technology such as learning through video instruction or diagrams on technological devices like computers, learning through experience, 3DP learning resources or classes, and with self-taught techniques. According to Participant 2 and 4, internet searches and YouTube were their immediate go-to methods of learning. Participant 2 shared:

> I basically ended up having to refer to a lot of videos in terms of just how do you get the thing that you're trying to print to like stick to the bed of the 3D-printer, and like watching videos and looking at just kind of other people's experiences.

Participant 4 similarly said, "If I saw something that I was confused about, I would just either YouTube it or Google search it. So I kind of like pieced it all together." These two approaches were representative of most of the others interviewed. Participant 5 also had nothing but good things to say about learning 3DP skills from the media and videos:

> YouTube is great. [laughs]. Let me say. YouTube is very helpful. So, I mean there was a lot of Youtubing like I want to be able to do this, how do I want to do this. And then, I found out one Youtuber does things that really long way around and there's a faster way to do it in Tinkercad.

Several participants stated how invaluable this educational theme was to the entire process. It served them well in terms of how effectively they absorbed the information that was specific to their dilemmas as they arose in the learning process.

Formal Learning Resources. Another common theme was the concept that educational resources are available to those wanting to navigate 3DP. Every participant stated that formal, in person education courses were a part of their journey. While some had better experiences than others, due to what was available at their time of adoption, many provided a hopeful outlook on incorporating lessons into OT programs. Two participants are already teaching and sharing their knowledge of 3DP at OT programs. The courses were found useful because they focused on developing troubleshooting skills and overall comprehension of the technology. Participant 2 stated how he regretted not being able to learn in such a course, indicating how beneficial he believes this method of learning 3DP to be. A Makerbot workshop was one such course that Participant 3 underwent to learn how to handle the technology. Although the majority of the participants that mentioned such a course were in favor of it, Participant 3 stated that personally she found it to be frustrating while learning in that course, but Participant 5 expressed:

> I think it’s so valuable! Like to watch students come up with whatever their case study is and then create something based on that. It’s so amazing! You should see their eyes light up, like when they see it tangible, in their hands after they’ve designed it and it’s been printed.

This description of student reactions she personally experienced illuminated the immediate connection people have with 3DP. While every participant had an experience that ranged from frustrating to invaluable, therapists are picking up on the increasing interest and need for formal education.

Discussion

Application

OTs have found creative and effective uses for 3DP in various settings, ranging from hospitals to client homes, pediatrics to geriatrics. By utilizing the customizability, rapidness, and repeatability of 3DP in each of the settings, the OTs interviewed all stated they sought to maximize the potential of 3DP to increase each client's occupational engagement.

Hospital Setting. In a hospital setting, length of stay is generally limited, and discharge planning is prioritized. Within these constraints, OTs are tasked with creating quick, effective solutions for a large population with diverse situations. One of most recognized applications of 3DP technology is in the production of splints—a major domain of OT. As seen by three of the OT participants, 3DP proved to be a useful tool in creating highly specific splints with additional benefits. This technology not only provided simplification of splint making, it created one that was more accessible and had additional features. As Participant 1 stated, 3DP allows for 1 therapist to design the object and other therapists could download and print. Splints as difficult as the airplane splint are made available to non-designers. Similarly, a 2018 study explored customized neck splints for patients at risk for burn contractures as another area in which 3DP splints have been revolutionizing and elevating the medical field (Visscher et al., 2018). Participant 3 also demonstrated the benefits of 3DP oval 8 splints, commonly used for many finger conditions. Compared to traditionally manufactured oval 8 splints, those that were 3D printed were able to be customized to fit any finger for any client of all ages perfectly. Because of its immediate creation ability, it also had the added benefit for decreasing storage space that manufactured ones would take up in the workplace. Literature also attests to further benefits of 3DP splints. In one study, Day and Riley (2017) demonstrated the use of 3DP to design devices that allowed a patient with a fifth digit amputation to play the French horn. Paterson, Donnison, Bibb, and Campbell (2014) elaborated on the customizability of splints. They incorporated smart designs that could avoid abrasion and accommodate edema. Additional adaptations included printed hinges that allowed for easy donning and doffing. Lattice and curlicue designs were also integrated into the final product based on personal preference. These creations and modifications seen in the interviews and literature demonstrate benefits and accommodations only obtainable through 3DP.

Aside from splints, researchers and users applauded the flexibility and individualized abilities of 3DP. OTs who identified product or access gaps were able to manufacture designs to provide client centered care that was once considered unfeasible. Additionally, customized devices for clients increased device satisfaction and adherence to prescribed interventions (Schwartz et al., 2020). In a hospital setting, this modern tool has proven to address voids in consumer needs that standardized technology was unable to satisfy.

Pediatrics. 3DP also has strong implications when working with children. Adaptive tools and toys were created to provide an inclusive experience in everyday activities. Some of the OT participants were already aware of the literature regarding applications of 3DP toys for children with special needs. Like Participant 2, a study by Jo et al. (2016) demonstrated how 3DP technology could be used to depict 2D images for children with visual impairments. In this study, printed historical statues, artifacts, maps, and architecture allowed children with visual impairments to tactfully learn. This highly stimulating instruction method improved student understanding and teaching effectiveness.

As is the nature of the pediatric setting, OTs working with children require tools that are client specific, tolerant to damage, and easily replaceable. As children may be more prone to unpredictable behavior, items may become damaged or lost. Additionally, their rapidly developing bodies also require a specific but modifiable solution to their occupational demands. This is especially true when working with critical equipment like prosthetics. Similar to the experiences of OTs identified in the preliminary literature, Participant 4 also experienced initial failed renderings. However, unlike those presented in preliminary literature, the OT persisted with modifications and re-evaluations to create a successful prosthetic that fit the client perfectly and supported engagement in their occupations. Damaged or no longer fitting parts were able to be quickly reprinted using 3DP. Additionally, 3DP orthotics could be used to precisely fit the human body and provide stronger support than traditional thermoplastic orthosis (Zheng et al., 2019). Participant 4 also shared that the melting point of 3DP prosthetics were higher than that of traditional thermoplastic. With this, concerns about leaving the prosthetic in the car on a warm day can be avoided with a 3DP prosthetic.

Home Health. In OT practice, ensuring independence of clients also requires assessments of the home environment and equipment available that will help perform activities of daily living. Participants 5 and 6 used 3DP to create adaptive equipment like larger buttons for limited fine motor skills, shopping bag holders for those with limited grip strength, and bookmarks for one handed reading. These were only few of the creations made by OTs to help clients in their home environment. In the literature, aspiring OTs at Touro College successfully printed adaptive equipment like a key turner, sponge holder, straw stabilizer, toothpaste aide, and pants puller (Wagner et al., 2018). Additional creations by licensed OTs included mouth stick holders, bottle grip holders, and a tablet keyguard for hand tremors (Ganesan et al., 2016). These researchers highlighted how 3DP technology yielded better patient compliance to treatment, decreased use of clinic materials, and improved emotional responses. Our interview and literature findings indicated that there are many potential applications for 3D printed equipment.

Secondly, many of the OT participants highlighted the virtual nature and shareability of the 3DP designs. Often creating “remixes” of existing adaptive equipment, OTs were able to find applications of previously made designs towards their own cases. Participant 6 shared how in Japan most OTs have their own 3D printers. In Japan, OTs are assigned a region, and they manage their caseload of various diagnoses independently. With this technology, sharing adaptive equipment and design ideas has been made possible across geographical locations. This exemplifies literature finding that 3DP is being used as an adjustment medium. Rather than starting from ground zero, OTs are sourcing items that already exist on the market or online that they can then modify for their client’s needs. With this virtual tool, OTs in different physical locations were able to create modifications to allow for a perfect customization to widely used equipment. In a home health setting, this ability is especially beneficial because OTs are often independently responsible for a case. With the virtual capabilities of 3DP, OTs are now able to remain connected to other OTs by ideas and tool sharing. Considering these applications and benefits of 3DP, many of the OT participants expressed their visionary outlook onto other shareable creations using 3DP.

Time

OT schedules are busy and demanding, therefore calling for extra hours committed to learning another skill can be perceived as an arduous task. Undoubtedly learning and getting accustomed to 3DP will require effort and motivation. Every participant in this study dedicated hours to 3DP, but ultimately found its benefits outweighed the costs. Their testaments, along with follow-up literature, support how exploration of this emergent technology is not time spent in vain and can be navigated with time saving strategies.

Invested in Learning. The revealed experiences in this study confirmed that with practice and patience, integrating 3DP into OT practice is not only obtainable for OTs but elevates their work. The reviewed literature did not reflect an exceptionally positive experience pertaining to the process of learning 3DP but did indicate hopeful attitudes towards grasping the technology and harnessing its many uses when OTs are given enough time (Buehler, Comrie et al., 2014). The participants were able to transform their ideas and skills into producing quality, customized items. Many of the OTs in this study spoke of a learning curve; however, with experience they were able to expedite the process and find time saving strategies (Hofmann et al., 2019). Unlike the literature, the OTs in this study quantified the length of time it took for them to learn 3DP. While the range varies between 2 months to a year, it is important to note that comfort and familiarity towards using the technology are subjective. Additionally, prior computer experience and personal interest can be influential factors in the speed of learning.

Spent Designing and Printing. Convenient designing and printing methods served to reduce overall time spent on a project. Designing from scratch, drawing from public databases, or even reusing old designs were all common approaches for participants and therapists (Hofmann et al., 2019, Buehler, Comrie et al., 2014, Hurst & Tobias, 2011). Because of these digital platforms, 3DP holds a unique ability for creations to be saved into files, ready to be opened and reused at any moment. This is a feature that sets it apart from conventional therapeutic inventions. Given the lack of literature and small population of users, it is no wonder practicing therapists overlook this technology. This save and reprint feature elevates the consistency and repeatability of delivering custom made devices to clients. On top of this commonly overlooked component, there is another often ignored asset of the 3DP process. Participants and literature stated they were able to use passive printing time productively (Paterson et al., 2014). While active attention focused on the printer is required during set-up, it is not required once the print starts. Participants were at liberty to attend to other responsibilities. Occasional check-ups on the machine could be a part of the process but are not necessary for extended lengths of time, especially after one is familiar with printing. After the trials and errors of the learning phase, 3DP becomes a fast and automatic process that enhances workplace productivity, multitasking capabilities, and client-centered care.

Time Saving Strategies. Results from our literature review and participants revealed time saving strategies. Almost all of the participants frequented Thingiverse in search of ideas and designs from which they could draw, augment, or even share their own creations. Buehler, Branham, et al. (2015) supported Thingiverse as a resourceful community for users. These open source communities have the power of connecting creative individuals with others, fostering collaborative interactions and exchanges, and simplifying the time it takes to design an item. Users can download existing designs, make small modifications, and print it without having to learn CAD software. Even between therapists and their patients we saw strong time management skills when participant 3 had a patient help break off supports and sand the item to complete the 3D design as a therapeutic intervention for improving fine motor and coordination skills. Patient collaboration with therapists in the making process has shown improved patient adherence to devices (Schwartz et al., 2020). This increased adherence leads to better patient outcomes and potentially reduces the overall length of treatment. Moreover, 3DP bypasses traditional wait times for a product by removing a step of the product-to-client chain. With a printer readily available, therapists are not only the therapy provider but also become the manufacturer. Traditional methods of ordering and testing therapeutic tools are eliminated with this immediate ability to customize and print. Additional similarities included reusing old designs and altering print specifications. A participant's advice on technical adjustments was also reflected in McAlister & Wood's (2014) study that found decreasing the number of layers, printing hollow parts rather than solid, optimizing orientation, and maximizing parts per print were all methods that increased speed.

The results of this study do not refute that the initial investment of learning 3DP is time consuming. However, time is well spent after this period. Therapists adapted their practice to multitask and pick up time saving techniques. They involved patients in the creating process, collaborated creatively with other therapists, and are among the first to disseminate the potential of 3DP into OT.

Cost

OTs often provide assistive devices, products, or tools that help their clients for therapy. These assistive devices are often costly which can become a barrier to opportunity for these clients. In recent years, OTs have realized the clear potential of adopting 3DP technology into their practice. The nature of 3DP technology allows therapists to save money, while producing cheaper alternatives to assistive devices being sold on the market.

Cost Savings. As suggested by our preliminary research, many OTs in our study found 3D printers saved them money. In many occurrences, printing objects on site would ultimately be cheaper than purchasing items from a third party. Many OTs spoke about how 3DP saved them money because prior to having a 3DP system, they would regularly spend their own money to purchase tools or products for their clients. Often, therapists create or purchase items out of their own pocket for the benefit of their client. The utilization of 3DP would limit the financial burden of therapists. Therapists shared that with 3DP, they are more comfortable giving assistive devices to clients without having to worry about the item getting lost, because 3DP made these products more affordable. In our study, OTs mentioned that they do not want to burden their clients with purchasing products, especially in low income communities. Through 3DP, affordable alternative options are as abundant as ever, providing OTs a wonderful opportunity to provide tools and opportunities for our clients. Within our field, fairness and equality to our clients are emphasized, thus taking measures to ensure accessibility pledges commitment to OT values.

Cheaper Alternatives. The literature and our findings were aligned regarding the affordability of 3DP products compared to the traditionally purchased alternatives. Creating 3DP items in house would often become more economic than spending money to receive products from third party conveyors. Most therapists that we interviewed mention that they primarily use 3DP due to its ability to cut the costs of creating products, meaning it is easier to provide access to what clients need. OTs using 3DP in practice were able to create products for their clients because they can now be created for a fraction of the cost. In the field of OT, providing affordable custom-made prostheses, orthoses, and assistive devices are also crucial in practicing fairness and equality. A typical body powered prostheses ranges from $5,000 to $10,000. In contrast, a 3DP body powered prostheses for a partial hand amputee can be created by using 3DP for $50 to $200 (Silva et al., 2015). A study by Gretsch et al. (2015) investigated the discrepancy in cost between traditionally manufactured externally powered prostheses and a 3D printed externally powered prostheses. Results showed a significant price difference, of between $25,000 to $50,000 versus $2,000 (Gretsch et al., 2015). This drastic monetary difference may be the determining factor between a child amputee receiving a prosthetic or not. A common problem for children in need of prosthetic limbs is the issue of constantly outgrowing the fit, which challenges affordability and deters parents. With 3DP, alternatives to adaptive equipment are created at a fraction of the cost. The literature mentioned that high cost is a determining factor between a child receiving assistive devices like prosthetics in a pediatric setting (Gretsch et al., 2015). Affordability may be the determining factor of whether children can get access to assistive devices. 3DP can be the solution that ultimately provides better accessibility for our clients.

Material Price. The affordability of material costs was echoed across the interview findings and the literature. Research indicates that as the field of 3DP grows, equipment and materials become more affordable making this process more affordable (Paterson et al., 2014). There were price disparities between the 3D printers mentioned in research and the printers used by OTs in practice. While our research found that commercial printers can cost upwards of $5,000 with the advantages of printing various filaments and durability (Silva et al., 2015). However, most OTs that we interviewed used printers between $300-$400 which they identified as sufficient enough for their practice. Many therapists considered 3DP as a long-term investment, because after the initial cost of the 3D printers, they have found the cost of running of a 3DP system—of buying filament and electricity—to be quite low. Many of the OTs mentioned that with a $20 spool of filament they were able to create many items that would traditionally cost over $20.

Reimbursement. Lastly, our research discussed the concept of reimbursement, which was not covered in any existing literature. Many OTs mentioned that they were not directly reimbursed by their work for 3DP. This can be explained due to the novelty of the technology in the field. Currently billing codes do not reflect manufacturing assistive devices with 3DP technology, so many therapists used other codes for billing. However, other therapists did not bill for any of these products at all. Therapists did not use 3DP in their practice for financial gain. However, they were able to offset production costs.

Ultimately, therapists shared that 3DP provided cost savings and better access to assistive devices.

Education

The educational themes prevalent in the experiences and opinions of the six participants interviewed for this study reveal significant ties to the literature. The capacity to improve with 3DP proficiency is increased in those who have more experience with technology such as computers (Alcock, Hudson & Chilana, 2016). That statement is clearly illustrated in the results found within the improved learning category. Findings indicated that experiential learning was a leading determinant in the mastery of 3DP as a technological tool for the OTs recruited for this study.

Improved Learning with Experience. Studies have shown that computer or other technological experience was a significant determinant in people's abilities to succeed with 3DP proficiency (Alcock et al., 2016). All but one of the therapists felt there was a benefit of improved learning through trial and error, also known as learning through experience, in acquiring 3DP skills. As mentioned in the time subsection, OTs were confident that as they got more comfortable using 3DP, they would be able to expedite the learning process, be more accurate, and reduce overall time spent (Hofmann et al., 2019). The individuals in this study expressed much of the same feelings, showing how nearly all of them needed to develop personal experience in order to master this technology. OTs are a valuable and untapped resource in the creative digital space and integrating 3DP could improve the level of patient centered care provided. Imperfections and mistakes made along the way were considered trivial compared to the patient benefits and valuable takeaways from attempting 3DP. The benefits of learning through one's own experiences of troubleshooting and recovering from mistakes was evident in the majority of the participant responses.

Self-Taught Learning. Self-taught learning was utilized by the entire participant population for this research. Motivation was observed to be a key component of this method of learning in each of the therapists who incorporated it into their education process. It also agrees with a study by Lunsford et al. (2019), which stated that the integration of 3DP into the invention and personalization of equipment for client rehabilitation is a clear advantage for therapists. The final common theme that consistently stood out in the interviewing process was the self-taught learning method.

The self-taught learning approach clearly showed how this learning method proved it is possible to achieve success in overcoming the 3DP learning curve. As mentioned prior, one participant specified how the self-taught process was fundamental to their own discovery of this technology's capabilities and the knowledge required to become adept in its use. That statement clarified just how the self-taught learning process can assist a new 3DP user in ways other than the above-mentioned video or media method. These conclusive results on how self-taught learning techniques were consistently employed by the OTs interviewed unveil how interest and motivation are crucial driving forces in the educational process.

Learning Resources. A key component of this research was the variety of learning resources utilized by the OTs involved. This study found that a formal educational setting was supported by multiple participants as well as those involved with 3DP demonstrations, educational tutorials, and standard class lectures (Buehler, Comrie et al., 2014). Participant 2 clearly stated how he wished there were more opportunities for him to learn this technology during college. There is a prominent lack of textbook or classroom-based learning resources available to new students and end-users (Ford & Minshall, 2019). Due to his promotion of such a concept, it makes sense that others have thought similarly and therefore done accordingly in their own programs. Institutions such as Touro College offer their students the chance to learn 3DP by incorporating the material into their regular college programs (Wagner et al., 2018). Participant 2 voiced frustration in having to trouble-shoot solutions, therefore showing a clear need of more available educational resources for 3DP technical issues.

This study's results also included the ways individuals learn through media-based resources such as YouTube or other internet-supported mediums. Although YouTube is a media outlet that is not exclusively for training course videos, it includes multiple filmed resources for 3DP creation tips and techniques. This online form can be utilized in various settings throughout the work, public community, and home environments. For instance, a surplus of other online tutorial-type videos and lessons can be found in online 3DP teaching programs (Ford & Minshall, 2019). Nearly all the participants in this study verified that they used media-based learning resources largely through the utilization of YouTube, not anything in specific. As mentioned in the results section above, at least two of the OT participants indicated how advantageous this resource had been to their efforts in framing their personal education in 3DP skills to incorporate into their practices by giving them clear directions and aiding visually in how to overcome learning obstacles.

Limitations

The objective of this study was to converse with OTs who are currently using 3DP. Due to a limited population pool and a participant recruitment time of 2 months, sample size was small (n=6). Stratified sampling was used to ensure recruitment of participants from different settings. The method of stratified and convenience sampling may alter how representative the sample is of the population. This study included participants from different U.S. states and an individual from Japan. Testaments from a larger sample size of different regions would yield more accurate and representative data.

Conclusion

Through the detailed responses derived from OT professionals, this study shows that the integration of 3DP into OT is a feasible prospect. The perceived barriers are indeed valid and common amongst current users; however, study findings indicated that these barriers can be addressed and overcome. 3D printed items can be highly customizable to meet specific needs. It also mitigates purchases of higher priced manufactured items allowing finances to be allocated to other non-replaceable needs. The time effectiveness of 3DP enables OTs to focus on less automated OT domains such as intervention planning and documentation. Lastly, virtual platforms that 3DP users utilize allow for idea sharing across physical locations. With these assets, 3DP warrants further exploration.

Future studies may consider a correlational study comparing clients that received 3DP equipment to those that received traditionally manufactured items to determine if intervention outcomes differ. A feasibility study that analyzes the exact cost of creating 3D printed items to buying factory manufactured items can provide quantifiable data on the realistic cost saving benefits of 3DP. To further supplement an emerging area of research, examination of first time 3DP users in academic settings can showcase the educational trials and experiences of novel users. Additionally, exploration of the applications of 3DP with common conditions, such as stroke, spinal cord injury, or traumatic brain injury in an OT context, may provide evidence-based literature for practicing OTs to refer to in a clinical setting.

In accordance with AOTA's Centennial Vision, this study contributes evidence-based literature regarding a science-driven technology to promote the advancement of OT. When adopted by the OT community as a more readily utilized tool, 3DP has the ability to connect people globally and elevate the future standard of care.

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Appendix

Interview Questions:

1. What setting would you consider yourself in?
2. How long have you been practicing?
3. What prompted you to start using 3DP in your practice?
4. How long have you been using 3DP?
5. How did you learn 3DP? What was that experience like?
6. In your experience, what are some pros and cons of 3DP?
7. There is a common preconception that 3DP is expensive to use. What do you think about the cost?
8. What are your opinions about time consumption?
9. Tell us about the ways you have used 3DP in your practice.
10. Are you willing to share any photos of your creation and would you like your name to be shown in the project?
11. Do you have any advice for OTs exploring 3DP?
12. Any additional comments?