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3D Printing and Occupational Therapy: The Process of 3D Printing Adaptive Devices

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Three-dimensional (3D) printing has been used in the healthcare field in order to create devices that improve the lives of patients. In occupational therapy, this technology is being used to create splints and adaptive devices that allow patients to heal and better perform tasks in their everyday life. Some of the benefits of 3D printing is that allows devices to be created faster and cheaper than traditional treatment methods. The purpose of this project was to determine how feasible it would be to buy a 3D printer and use it to print open-source assistive devices that could be used by potential clients. This project describes the start to finish process of using the FlashForge Finder printer to print twelve different devices, including writing aids, typing aids, bottle openers, and key turners. The cost analysis of the project reveals that each device costs under one dollar to print and only takes up to a few hours. The results of this study show that an entry-level printer is fairly easy to use and can be a beneficial tool for an occupational therapist. Some of the limitations of this project included a small print area and the ability to only print using one material.

Keywords and phrases: occupational therapy, three-dimensional printing, healthcare, process of 3D printing, 3D printing and occupational therapy, FlashForger Finder, assistive devices, 3D assistive devices

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Introduction

Due to the availability of three-dimensional (3D) printers, there is an increasing popularity of using this technology in the field of health care. Over the past several years, there has been an increase in research in order to determine the many uses for 3D printing and how it can be applied by health care practitioners in order to better the lives of their patients. Due to the limited research associated with the use of 3D printing in the field of occupational therapy, the purpose of this project was to analyze how feasible it would be to buy a 3D printer and implement its use in an occupational therapy practice. The project will analyze some of the open-source devices available on the internet and how they can be used by an occupational therapist.

Background

In the field of healthcare, there have been many advances in the application of three-dimensional printing over the past several years. Dodziuk (2016) discusses the uses of 3D printing in several different healthcare fields, including hearing aids, dentistry, prosthetics, implants, surgery, and medical devices. For hearing aids, 3D printing the devices has shortened the production time from over one week to about a day. In dentistry, 3D scanning is used to create crowns, bridges, and orthodontic devices, such as aligners and guides. New FDA approved material and material that kills bacteria has allowed for more applications in field of dentistry. 3D printed prosthetics allow for the printing of fully customized designs at a cheaper cost than manufactured prosthetics. Implants, such as those for spine, hip, pelvis, and trachea can be printed on a 3D printer. By using 3D imaging, the implants can be personalized specific to the size and shape of the client. Surgeons use 3D printing for surgical planning in order to create replicas of organs which allow them to practice surgical procedures. 3D printed medical devices include stethoscopes, multi-sensory perception simulator, glass frames and lenses. Finally, there have been advances in using biological material as the printing material for the printer. The main aim of this technology is to print organs due to the shortage of available organs around the world. The main benefits of using this technology is that it allows items to be printed at a reduced cost and faster than other available devices.

3D printing has many applications in prosthetics and orthotics because the devices can be fully customized and printed at a lower cost. In orthotics, open-sourced wrist driven orthotics can be used to improve hand strength in individuals with spinal cord injury. By printing these devices, it allows for practitioners to have more flexibility in design and address some of the issues with devices currently on the market (Portnova, Mukherjee, Peters, Yamane, & Steele, 2018). 3D printed heel cups can also be used to treat patients with plantar fasciitis in order to decrease pain. By using 3D scanning technology, these heel cups can be individualized to the patient in order to fit their specific anatomy and provide pain relief. Findings show that these printed heel cups were more effective in treating pain than traditional heel cups (Li et al., 2018). In prosthetics, 3D printing can be used to create functional, low cost hand prosthetics. Current designs have their limitations and the designs could be improved to create a more user-friendly hand (Ferreira, Duarte, Alves, & Ferreira, 2018). 3D printed prosthetic devices can be as useful as manufactured hands but offer more customization for the individual.

3D printing technology has also been used to assist students with visual impairments in the classroom. A study conducted by Jo et al. (2016) used 3D printing to create maps and replica relics for students in a history class. This enhances the education of the students and allows them to have a better understanding of the material that is being presented to them in class. I et al. (2016) conducted a study to determine how 3D printing can be used to help students who are blind or visually impaired with writing. 3D printed literacy aids were created that taught the students how to read braille and write the alphabet. Students found that using these aids were effective in allowing them to practice their writing and were easier to use than paper literacy aids. 3D printing technology has a positive impact on students in the classroom by allowing them to use tactile objects to support their learning.

In occupational therapy, many of the applications for 3D printing apply to the development of splints. Nam, Seo, Joo, Kim, & Park (2018) discusses the uses of finger splints in treating burn patients. Splints are often prescribed to burn patients but can pose a severe financial burden to those in burn care. By printing the splints on a 3D printer, it can significantly reduce the cost while maintaining the benefits of the splint. Paterson et al. (2014) focused on how computer aided design (CAD) could be used to help splinting practitioners create customized devices on the 3D printer. Specific patient data was used in the creation of each splint to allow for optimum comfort. Practitioners found it easy to use the software to create the devices for their clients and to customize the material and design based on patient needs. Compliance of braces is an important factor in the healing and recovery of patients. Poor adherence to the treatment regimen could occur as a result of a number of factors related to the splint, such as uncomfortable fit and difficulty removing the splint. 3D printed splints have many benefits that make them ideal to use with patients, such as comfort and fit, proper ventilation, lightweight, and aesthetic features. They are also low-cost compared to conventional methods and lead to more patient adherence in the treatment plan (Ganesan, Al-Jumaily, & Luximon, 2016).

Occupational therapists have also used 3D printers in order to create other devices, such as sensors and assistive devices. 3D printed strength test devices allow occupational therapists to create more effective strength testing. It will also be easier for the therapist to assess hand strength in the client. The printed devices will also allow for information to be directly entered on the computer and adapted to the client (Cutler & Hamilton, 2018). Assistive devices have been applied to the classroom to help students who have hand problems. Some of the devices that have been created include a Highlter grip holder, container grip, bottle grip holder, rocker grip holding device, large crayon holder, and paintbrush holder. All of these devices allow students to complete their daily tasks in the classroom easier (Ganesan et al., 2016). The addition of 3D printing to an occupational therapy practice can have many benefits to clients.

Selecting a Printer

Before buying a 3D printer, there are many factors that need to be considered, including the price, size, software, and types of filaments that can be used. The price of

3D printers has dropped significantly over the past several years and now people can find a quality 3D printer for under $1000. The average cost of a 3D printer is around $700, but they can range anywhere from $200 to several thousand dollars ("How much," 2019). The price of the printer depends on the type of printer that is being bought and the uses of the printer. There are five different categories of 3D printers: entry level, hobbyist, enthusiast, professional, and industrial. The entry-level printers are the cheapest and are best for people who are just starting to learn how to use 3D printers. The price of these printers ranges from $200 to $400. There is normally a small learning curve associated with these printers, but it is helpful in allowing people to learn about the technology. However, these printers do have limitations, including a small print surface area and the ability to only print one material. They can also be noisy, slow, and produce poor quality prints. Hobbyist printers will allow for a bigger print volume than entry level printers and allow for more flexibility in the material that can be used. The price range of these printers is $300-$1,500. The software for these printers will be better at auto-leveling and cleaning up the printer and the print is smoother than the entry-level printers. Enthusiast printers range from $1,500-$3,500 and produce much better prints than the previous two categories. These printers will have user friendly features, have a large print volume, print faster, and allow for use of a wide variety of materials. Professional printers cost $3,500-$6,000 and produce high quality prints and can use a variety of different filament types. The industrial printers are the most expensive printers, costing between $20,000 and $100,000. These printers print faster than any other category, but the filament can cost more, and material availability may be restricted ("How much," 2019).

When considering which 3D printer to buy, it is important to consider the build volume of the printer and the size of the 3D printer itself. The print volume of the printer depends on the use of the printer and the price. The print volume refers to the length, width, and height that the printer is able to print. The entry-level 3D printers tend to have the smallest print volume, only printing around 3-4 inches in width, length, and height. Hobbyist printers tend to have a slightly larger print area of around 5-6 inches. Enthusiasts printers have a print volume of 8-12 inches and some professional printers have a print volume of over 12 inches. The industrial printers can potentially have a much larger printer area than any of the other categories ("How much," 2019). It is also important to make sure that the size of the 3D printer will be able to fit in the designated area.

Some of the 3D printers that are available will need their own unique software in order to print items off the printer. It is important to investigate the software that will be needed for the specific printer that is being bought. The software needs to be compatible with the computer being used. It is also important to research any other programs that might be used with the printer to make sure that the software is compatible. The software for each printer could have a learning curve and the software for entry level printers is the easiest to use.

Finally, it is important to consider the filament that can be used by the printer. Entry-level printers often only print one type of filament and can only use one color at a time. More advanced printers allow for the use of multiple types of filaments and printing two filaments at a time. Filaments are necessary in order to print any project on the 3D printer. It is important to consider the projected uses of the printer in order to determine which material will need to be used on the printer. There are around 18 types of filaments available which range in uses, colors, and prices. The most common filament is Acrylonitrile Butadiene Styrene (ABS) which is a plastic filament that is strong, lightweight, and slightly flexible with a variety of uses. ABS filament is used for moving parts, automotive parts, electronic housing, toys, pipes, protective headgear, musical instruments, and LEGO bricks. This is the cheapest thermoplastic on the market. Some of the disadvantages of this material is that it is non-biodegradable, requires a high melting point and creates mild fumes while printing. Another popular material is Polylactic acid (PLA) which is the most popular material in the 3D printing community due to its biodegradability and low-toxicity. The applications of PLA include medical suturing, surgical implants, food packaging, disposable tableware, hygiene products and diapers. This is considered the easiest material to work with and is less prone to warping. Some drawbacks of this material are that it is prone to clogging the printer nozzle and it attracts water molecules which can make it difficult to print. Polyvinyl Alcohol (PVA) is a water-soluble plastic filament that is used in paper adhesive, packaging film, children's play putty or slime. This material is safe for food and has a low flexibility. However, it is expensive, hard to use, and difficult to source. PolyEthylene Terephthalate (PET) comes in different versions and is an easier material to use for printing. It is more flexible than ABS and PLA and is hard and shockproof. There are also other unique materials that can be used for printing, which include nylon, wood, sandstone, metal, magnetic iron, conductive PLA, carbon fiber, flexible, and glow in the dark ("18 3D printer," 2019). Each of these materials differ in price and difficulty in use.

The Printer

For the purposes of this project, the selected printer was the FlashForge Finder. This printer is considered an entry level printer and cost around $300. It has a print area of 5.5 inches by 5.5 inches by 5.5 inches. The only material that could be used for printing was PLA and it could only print one color at a time. The software that is used on this printer is FlashPrint which is the program specific for FlashForge brand printers. This software is compatible with other programs for creating devices and supports the files used on websites with open-sourced designs.

The printer was ordered from amazon.com and arrived two days after it was ordered. The printer came with one spool of filament and two other spools were also ordered at the time of purchase. After receiving the printer, it was fairly easy to set up and start printing. The printer did not require any assembling but did require some adjustments before it was ready to use. The platform required some adjustments in order to ensure it was level before anything was printed. In order to make these adjustments, the settings area on the printer had a leveling button which gave instructions on how to level each part of the printer. There were three screws located on the bottom of the printing platform and each one had to be twisted until the printer made a noise to indicate that it was leveled. The printer also needed to have the filament loaded in order to print. The printer also had a filament button which provided instructions on how to properly load the filament in the printer. The filament just needed to be loaded through the printing nozzle and then the printer was ready for use.

Finding Items to Print

After completing the printer set-up, the next step in the printing process is finding items to print. For the purposes of this project, the items that were being printed related to adaptive devices that could be used by an occupational therapist. In order to find items to print, there are many websites available that offer open sourced items which can be printed on a 3D printer. One popular website that allows users to share their designs with other makers is thingiverse.com, which offers thousands of designs which can be printed. In order to find designs that would work for this project, some search terms that were used included “occupational therapy,” “adaptive devices,” “writing aids,” “typing aids,” and “key turners.” After searching through the possible designs that could be used, several designs with different uses were selected. When selecting these designs, it was important to check the size of the device to make sure it fit the print area of the printer that was being used. Twelve different designs were chosen to be printed for this project in order to examine the different uses that these items could have for occupational therapists.

Printing an Item

After selecting an item to print, there were several steps that had to be taken in order to prepare the item for the printer. On thingiverse.com, each design shows design files which can be downloaded directly to the computer. After downloading the specific file needed for the selected design, the design was automatically uploaded to the FlashPrint software used by the printer. Once in the software, there are several different options that can be used to prepare the design for print. The design is shown on a virtual printing platform, so the user can ensure the design is placed correctly for printing. It can be viewed from each different angle (right, left, front, back, top, and bottom) and it can be moved around on the platform if space allows. The model can also be scaled up or down to change the size and cuts can be made to the design in order to remove certain parts. An important part of this process is supports which ensure the device is printed properly. Supports are additional structures in either treelike or linear form which can be used to support designs with overhang. The supports allow for devices with overhanging components to be properly printed. After the device is printed, the supports are removed from the print.

Once the device is ready for print in the software, the user will press the “print” button and can make additional adjustments specific to the printing of the devices. This includes if the device will print with supports or a raft, which is a thin layer of filament that is printed before the device and can be used to secure the supports if they are needed. Other adjustments include layer height, shells, infill, speed, and temperature. The layer height refers to the height of each filament layer in the print. Prints with thinner layers create more detailed prints but take longer to print. Thicker layers will provide for a faster print, but it will be easier to see the individual layers (“3D Slicer Settings,” 2019). The shell of the 3D print refers to the outer layers of the print. The shell thickness refers to the number of times the outer walls are traced before the inside, hollow portioned of the print are traced. The thickness of the side walls is an important factor in the strength of the print (“3D Slicer Settings,” 2019). The infill of the print is the density of the space inside the outer shell of the design. The infill is measured in percentage, so 100% infill means the object is solid on the inside. The higher the percentage of infill, the stronger and heavier the object will be. However, this also means it will take longer to print and will use more filament ("3D Slicer Settings," 2019). The FlashPrint software provides four different options for the infill: linear, hexagon, triangle, and 3D infill. Each option provides different support for the object being printed. The print speed is the speed at which the print nozzle moves as it is laying down the filament. The speed of the printer depends on the object being printed, the filament being used, the printer, and the layer height. While it is important that the design is printed in a timely manner, printing an item too fast can result in a messy print and complications ("3D Slicer Settings," 2019). The final adjustment is the temperature which refers to the temperature of the nozzle. The temperature depends on the type of the filament that is being used for the print. The specific filament type provides information on the melting point and suggested temperatures for the printer.

After making all the necessary adjustments to the settings of the printer, select the "OK" button. A pop-up window will allow the item with its settings to be saved to the computer or to a USB drive. If the device is saved to the computer, it will need to be connected to the printer in order to be printed on the 3D printer. If the device is saved to a USB drive, it can be placed directly in the printer. After the device is saved, the rest of the printing process is completed directly on the 3D printer. The software will provide a pop-up window after the device is saved which gives information on the estimated amount of time it will take for the device to print and the estimated material used.

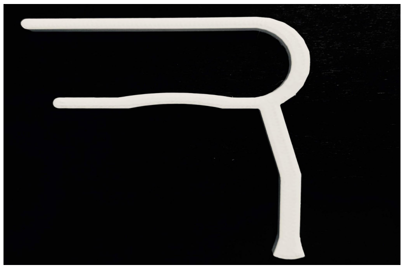
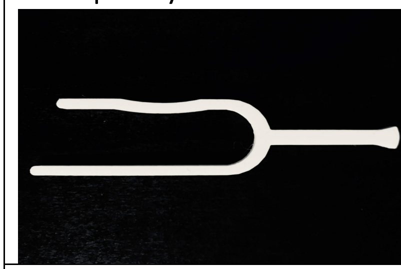
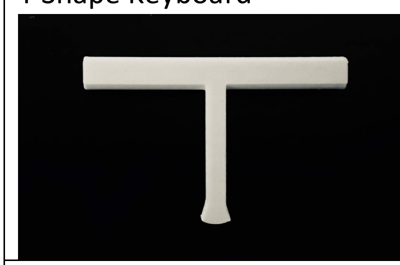
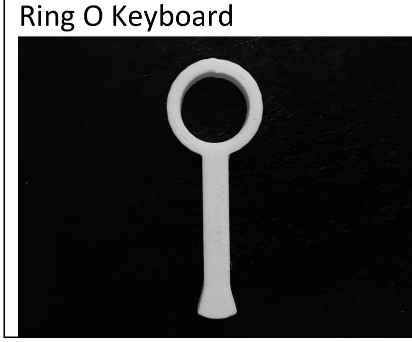
On the main menu of the 3D printer, select the "print" option and then select where the device has been saved. If the device was saved on a USB drive, select that option and then select the appropriate design from the list of devices that have been saved. After finding the design, select it and then press the print option. The printer will now begin to heat to the desired temperature and then print the device based on the settings selected.

After the printer has completed the print, the design is almost ready for use. The device needs to be removed from the printing platform. A small, flat, thin object can be used in order to pry the edge of the device off the printer which allows for easy removal from the platform. If the device used a raft during the print, that needs to be removed from the device. Also, any supports that were needed in order to print the device need to be removed. If the object has any rough edges, sandpaper can be used in order to smooth out the design.

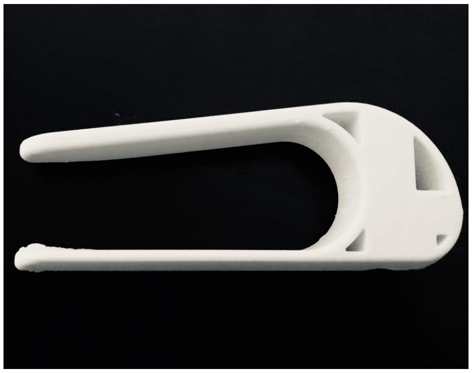
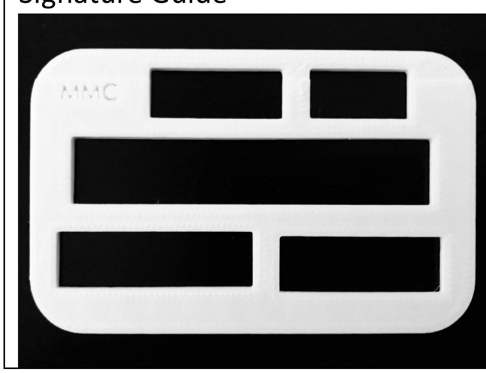
Adaptive Devices

The twelve devices that were created for this project can all be used by clients of occupational therapists with specific needs. A summary of the devices can be found in Table 1 with information about the cost, time, material and pattern along with a photo of the finished product. The first five designs are focused on adaptive keyboard devices which can be used by people with limited hand or wrist movement. The two bottle openers can be used by people with limited hand strength, such as those with arthritis. The three pen holders can be used by those with poor hand movements and pincer strength required to hold a pencil. The key turner can be used by people with poor wrist strength or motor skills. The signature guide offers many different size openings to help people write or sign their name.

Table 1: Description of Devices

C Shape Keyboard 	Time: 16 minutes Material: 1.15 m PLA Cost: $ 0.07 Pattern: https://www.thingiverse.com/thing:2930181/files
U Shape Keyboard 	Time: 16 minutes Material: 1.12 m PLA Cost: $ 0.07 Pattern: https://www.thingiverse.com/thing:2930181/files
Ring 8 Keyboard 	Time: 12 minutes Material: 0.77 m PLA Cost: $ 0.05 Pattern: https://www.thingiverse.com/thing:2930181/files
T Shape Keyboard 	Time: 20 minutes Material: 1. 52 m PLA Cost: $ 0.09 Pattern: https://www.thingiverse.com/thing:2930181/files
Ring O Keyboard 	Time: 7 minutes Material: 0.49 m PLA Cost: $ 0.03 Pattern: https://www.thingiverse.com/thing:2930181/files

Bottle Opener 1 	Time: 1 hour 43 minutes Material: 7.61 m PLA Cost: $ 0.46 Pattern: https://www.thingiverse.com/thing:2801157
Bottle Opener 2 	Time: 1 hour 33 minutes Material: 7.51 m PLA Cost: $ 0.46 Pattern: https://www.myminifactory.com/object/3d-print-bottle-opener-5560
Pen Holder 1 	Time: 24 minutes Material: 1.5 m PLA Cost: $ 0.09 Pattern: https://www.thingiverse.com/thing:2802074
Pen Holder 2 	Time: 31 minutes Material: 1.62 m PLA Cost: $ 0.10 Pattern: https://www.thingiverse.com/thing:2802077

Palm Pen Holder 	Time: 2 hours 22 minutes Material: 9.80 m PLA Cost: $ 0.49 Pattern: https://www.thingiverse.com/thing:2810064/files
Key Turner  	Time: 46 minutes Material: 2.97 m PLA Cost: $ 0.18 Pattern: https://www.thingiverse.com/thing:2802082
Signature Guide  	Time: 27 minutes Material: 1.82 m PLA Cost: $ 0.11 Pattern: https://www.thingiverse.com/thing:3192347

Cost Analysis

The cost of the FlashForge Finder 3D printer was $349 on amazon.com. The filament that was bought for the printer was Hatchbox PLA 1 kg spool, 1.75 mm and it cost $20 on amazon.com. Each 1 kg spool contains approximately 330 meters of filament. This information was used to determine the cost of each product. The most expensive device that was created was the palm pen holder which cost $0.49 and used

9.80 meters of filament. The cheapest device was the ring o keyboard device which cost $0.03 and used 0.49 meters of filament. Compared to the cost of commercially available devices, it is more cost effective to use a 3D printer to create the device. Overall, it was not that expensive to run the 3D printer and create these devices.

Benefits

There are many benefits to using a 3D printer in an occupational therapy practice in order to create adaptive devices that can be used for clients. One of the main benefits of using the 3D printer is that it can allow practitioners to create devices for the clients in a timely manner. It is also much cheaper to print an item than buy it. Another benefit is that the 3D printer can be used to create customized devices for the clients, such as wrist or finger splints. Printers that allow for multiple types of filaments to be used can also be beneficial in the health care settings. For example, food safe filament can be used to print an eating utensil with an adaptive handle.

Limitations

There are also some limitations associated with using a 3D printer in an occupational therapy practice. One of the limitations is the size of the printing area that is allowed by the printer. If the printing area is small, there will be many limitations in the types of devices that can be made on the printer. There will also need to be some training on how to use the printer and the software that is associated with the printer or creating devices. If the printer can only use one type of filament, there will be a limitation on the types of devices that can be made.

There are also some complications that can arise when printing on a 3D printer. Jennings (2019) discusses the many complications that can arise from 3D printing and how they can be addressed. One of these complications is when nothing is coming out of the print nozzle. This could be caused by the printer being out of filament, the print nozzle being too close to the print bed, the nozzle being blocked, the printhead missing the bed, snapped filament, stripped filament, extrusion of filament stopped mid-print, print not sticking to the print bed, and the supports falling apart. Another main complication could be the print looking bad. This could be caused by the first layer being messy, the print bowing out at the bottom, warping, the infill is messy and incomplete, gaps between the infill and outer walls, cracks, layers not aligning, layers are missing, print leans when it shouldn't, and web-like strings. The print could also become stuck to the bed which makes it hard to remove the process. In order to address these problems, the printer provides a troubleshooting guide and there are many articles and forums on the internet which can provide guidance on addressing these issues.

Conclusion

The purpose of this project was to determine the feasibility of using a 3D printer in an occupational therapy setting. After completing this project, it can be determined that it is fairly easy to buy an entry-level, low cost printer and adapt its use in a therapy setting. Aside from using a printer to print adaptive devices, it can also be used for splints or as an activity with a client. There were minimal complications using the FlashForge Finder and it was easy to set-up and start printing. Due to the availability of device patterns on the internet, it is easy to find devices that can be used by the clients. In the future, more research needs to be conducted on how to create devices using modeling software and further uses of 3D printing with an application in occupational therapy.

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