e-NABLE: Add lateral wrist movement to an e-NABLE hand design

Haley Yagodinski, Kelly Starykowicz, Jack Metzger,
Claire Mitchell, Liam Granlund, Courtney Florin
Client: Mr. Ken Bice of BadgerHands - Advisor: Dr. Ed Bersu

Abstract

The e-NABLE community is working to help kids in need of upper limb prosthetics, knowing they will grow out of them within 1-2 years. The solution is to 3D print hands that can be altered in size to fit the individual in need. Multiple designs have been created, including *The Raptor Reloaded.* With this, the user bends the wrist forward (flex) to clench a fist, and backward (extend) to release the grip. However, that is the only degree of freedom of the device. For those with sufficient lateral movement of their wrist, a means of turning the prosthetics wrist laterally would provide the benefits of this second degree of freedom. This second degree of freedom is currently not possible due to hinges on the side of device. By adding this motion, everyday tasks like twisting off a cap or taking a drink of water can be done. The proposed design will replace the hinges with an accordion style material at the wrist area, which would allow for both degrees of freedom. After testing, the goal is for the individual to get the most use out of their 3D printed prosthetic. It can turn the user from the kid with the "weird hand" to the kid with the cool hand.

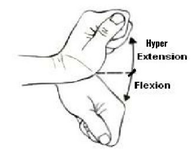
Motivation & Background

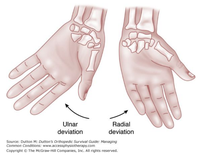
Motivation

The e-NABLE community is a dedicated group of volunteers who use their time to create 3D printed prosthetic hands for individuals who need them. Currently, the e-NABLE created prosthetic known as the *Raptor Reloaded* only has one degree of freedom, but by completing the goal of adding a lateral wrist movement to the device, users will be able to do everyday tasks like twist off a bottle cap.

Important Aspects of Wrist

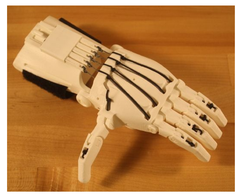
- Flexion and Extension
- Typical ranges of motion:
  - Abduction: 17°, Adduction: 40°
- Rotation occurs at the elbow
- Two degrees of freedom





Current Design: Raptor Reloaded

- Used for individual with a palm, but no fingers
- One degree of freedom: wrist flexion closes fingers
- Fingers close in the same motion
- Ideally, thumb and pointer finger can be used to pinch
- 3D printed with PLA



Design criteria

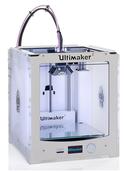
- **Maintain Current Capabilities.** Cannot interfere with first degree of freedom (wrist flexion).
- **Full Range of Motion.** Match adduction and abduction degrees of typical human motion.
- **Patient Comfort.** Be comfortable to wear for an extended period of time.
- **Ease of Use.** Function the same every time and be easy to put on.
- **Durable.** Withstand all operating conditions for 1-2 years.
- **Reproducible.** Be easily printed in all parts of the world.

Materials and Methods

PLA: Hand, fingers, and gauntlet
- Stiff and reliable strength
- Inexpensive and easy to print
- Good shelf life
- Environmentally friendly
- Good dimensional analysis
- Most commonly used 3D printing material

TPU: Accordion piece
- Plastic with rubber-like characteristics
- Resistant to abrasion
- Used in many medical devices
- Stretched up to twice its length
- Durability doesn't change with density

	Tensile Strength	Density
PLA	37 MPa	1.25 g/cm^3
TPU	65.5 MPa	1.21 g/cm^3

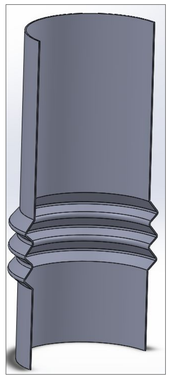


Ultimaker 3 Printer: Used to print parts of hand with PLA and TPU.

Printer Settings:
- Speed: 20mm/s
- Temperature: 235°C
- Infill and support density are adjusted for each piece

Final Design

Arc Length: 180°
Thickness: 0.7mm

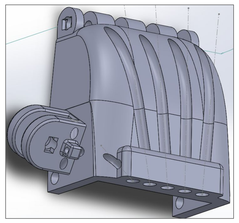


(Above) *Bottom view of Accordion:*
Pictured above is the wrist attachment piece designed with accordion style folds to allow for lateral movement.

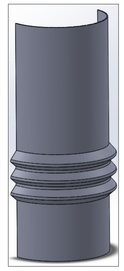
Adds Second Degree of Freedom
- Hinges removed, which restricted lateral movement
- Accordion allows for 43.3° of adduction
- Accordion allows for 23° of abduction

Maintains Current Capabilities
- Wrist flexion of a typical individual is 54°
- Wrist extension of a typical individual is 60°
- The final design maintains close to the typical flexion and extension abilities (45.3°), so our design provides moderate interference with the current capabilities

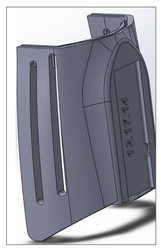
Improves Ability to Perform Everyday Tasks
- Adding lateral wrist movement allows for more functionality
- Can grip an object (wrist flexion closes fingers) and twist (with lateral movement)
- Examples:
  - Take a drink of water
  - Twist off a cap
  - Wave



(Left) *Palm*:
The drawing shows the palm after the joint was cut off and holes were added for the new attachment.



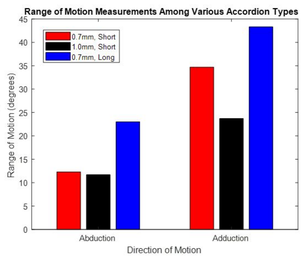
(Left) *Accordion*:
Shown is the outer view of the accordion attachment, the longer side attaches to the palm with a pin and the short side attaches to the gauntlet by sliding into a track.



(Left) *Gauntlet:*
Displayed is the redesigned gauntlet with the joint cut off and a track carved into it for the accordion attachment.

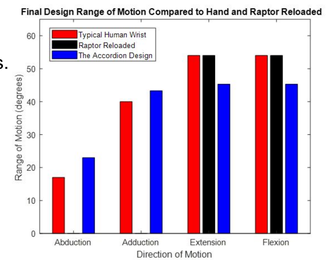
Results

Testing Procedure:
- Adduction and Abduction:
  - Held gauntlet down and moved palm laterally with human force.
  - After 3 trials, the angles were measured with a protractor.
- Flexion and Extension:
  - Placed hand on a group member and marked path that hand took during flexion and extension.



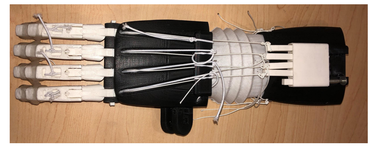
Left:
Comparison of the range of motion measurements among our different types of accordions. From this data, we decided to use the 0.7 mm long accordion.

Right:
Comparison of the range of motion measurements between the final accordion design, the Raptor Reloaded, and a typical human wrist.



Discussion

- Testing Conclusions
  - 2 One-sample t-tests were performed for range of motion
    - Null hypothesis: $\mu_{Accordion} = \mu_{Typical\ Human\ Wrist}$
    - Alternative hypothesis: $\mu_{Accordion} > \mu_{Typical\ Human\ Wrist}$
    - Significance Level: $\alpha = 0.05$
  - Abduction: p-value = 0.00457
    - The Accordion design has a range of motion greater than that of a typical human wrist.
  - Adduction: p-value = 0.2196
    - The Accordion design has a range of motion equal to that of a typical human wrist.
- Limitations
  - Ultimaker printer assigned to TPU prints broke
  - Time allotted to complete design and testing
  - Not having access to equipment needed for testing
  - Only having one printer allocated towards TPU prints
  - 3D printing takes significant time to complete



Future Work

- Future Testing
  - Test durability of TPU over time (tensile test using MTS machine)
  - Test range of motion after significant use
- Areas of Improvement
  - Collaborate with other e-Nable design groups to add increased grip strength and thumb function
  - Improve wrist attachment to make reproducibility easier
  - Create folds in accordion that can improve tensile ability
  - Use different pins that don't interfere with patient comfort
  - Modify accordion piece to provide less hinderance on flexion/extension

Acknowledgements & References

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