MANUAL GROSS DEXTERITY ANALYSIS OF FOUR POPULAR STYLES OF ENABLE 3D PRINTED PROSTHETIC HANDS USING THE BOX AND BLOCK TEST

Eric Malani[1]

1 Department of Biology and Physical Sciences, Marymount University, 2807 N Glebe Rd, Arlington, VA 22207,

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BACKGROUND

eNABLE, a worldwide volunteer group, working to design and print prosthetic hands, arms, and fingers has found a practical use for 3D printing that helps bring free prosthetics to people throughout the world. The work by eNABLE has gained international media attention, however, the effectiveness of the prosthetic hands has never been formally tested. We tested the manual gross dexterity of the four most popular styles of eNABLE hands, the Unlimbited Phoenix, Phoenix V2, Raptor Reloaded, and Osprey hands using the so-called Box and Block Test (BBT) of Mathiowitz et al. 1985. The box and block test is a clinical evaluation used to measure the manual gross dexterity of test subjects, particularly those with weaker gripping strength, by challenging them to move small blocks over a barrier in the span of a minute. We designed and printed a unique emulator to allow able-bodied test subjects to operate each of these four eNABLE devices in moving the blocks.

MATERIALS

Figure 1. The simple components of a box and block test.

This dexterity test is easily replicated worldwide and can serve as a benchmark for current and future hand designs.

Figure 2. The four styles of eNABLE hands we tested.

From left to right: Unlimbited Phoenix, Phoenix V2, Raptor Reloaded, Osprey

ANALYSIS

Participant Number	Regular Hand	Unlimbited Phoenix	Phoenix V2	Raptor Reloaded	Osprey
1	76	8	17	10	5
2	61	22	20	11	17
3	65	14	9	0	8
4	57	13	17	8	14
5	56	8	12	11	8
6	85	13	19	12	23
7	77	22	21	11	19
8	71	6	12	1	4
9	70	20	6	1	13
10	65	9	11	7	6
Average:	68.3	13.5	14.4	7.2	11.7

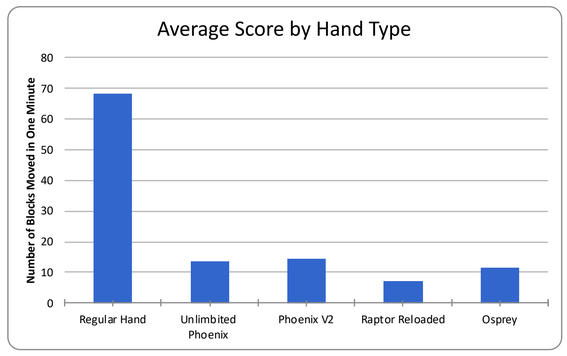
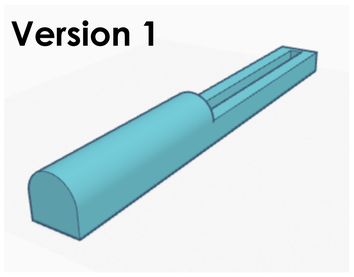
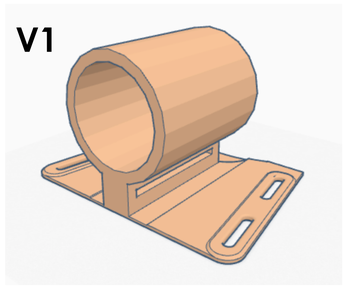


Table 1. Compilation of each participant's score on the BBT using their own hand as well as the Unlimbited Phoenix, Phoenix V2, Raptor Reloaded, and Osprey hands.

Figure 3. Average scores participants achieved on the BBT with their own hand and the 4 styles of eNABLE 3D printed hands.

Development of 3D Printed Emulator





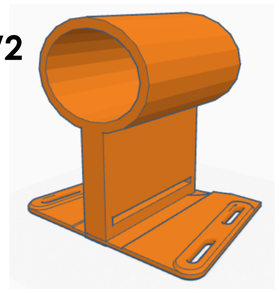
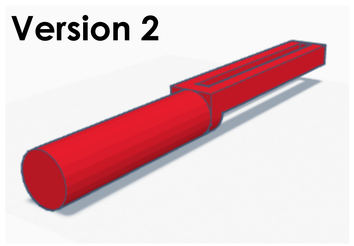


Figure 5. Differences between Version 1, 2, and 3 of the emulator gauntlet which connects the participants forearm to the gauntlet of the eNABLE hand.

Between Version 1 and Version 2, additional height was added in order to improve ergonomics of the emulator. The difference between Version 2 and Version 3 includes a slight offset between the top and bottom pieces of the gauntlet. This offset allows the participants wrist to align with the wrist pins of the eNABLE prosthetic hands.



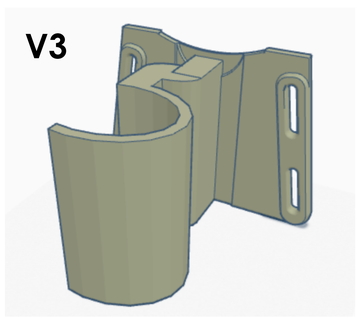


Figure 4. Version 1 and Version 2 of the emulator palm bar that is screwed onto to the palm of the eNABLE hands.

In order to allow able-bodied individuals to actuate and subsequently test the dexterity of eNABLE hands, we needed to design an emulator. The emulator we created is the first of its kind, meant specifically to fit the majority of eNABLE hand styles, in a variety of sizes. The emulator is still a work in progress as we are continuing to improve efficiency and ergonomics.

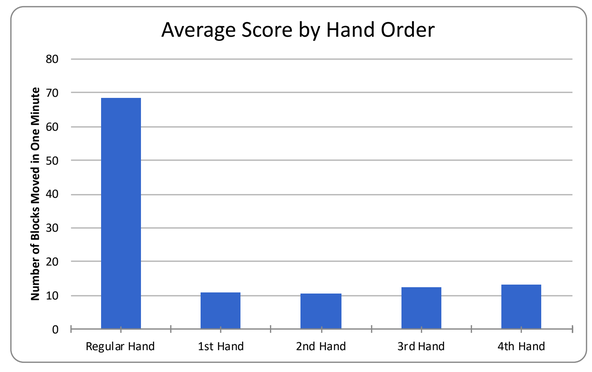
DEXTERITY ANALYSIS

We found that the Raptor Reloaded hand performed significantly worse when compared to the Phoenix V2 and Unlimbited Phoenix hands with $p < 0.05$. Conversely, there was no statistically significant difference between the Raptor Reloaded and Osprey hands with $p=0.096$. Additionally, there was no statistically significant difference between the Phoenix V2, Unlimbited Phoenix, and Osprey hands tested. We also found that there was no statistically significant difference between the order of hands being tested, thus eliminating hand order as a confounding variable. Although the box and block test is not the only clinical test for determining gross dexterity it is one of the most simple and commonly used tests. This data provides a good benchmark of current eNABLE hand styles and a good comparison to commercially available prosthetics which have also undergone box and block testing.

Participant Number	Regular Hand	1st Hand	2nd Hand	3rd Hand	4th Hand
1	76	5	8	10	17
2	61	20	11	17	22
3	65	14	9	0	8
4	57	14	17	8	13
5	56	8	12	11	8
6	85	19	13	23	12
7	77	11	21	22	19
8	71	4	6	1	12
9	70	6	1	20	13
10	65	6	7	11	9
Average:	68.3	10.7	10.5	12.3	13.3

Table 2. Compilation of each participant's score on the BBT based on the order of 3D printed hands they tested.

Figure 8. Average scores participants achieved on the BBT with their own hand and the 4 styles of eNABLE 3D printed hands.



The eNABLE hands were tested by participants in a random order to minimize hand testing order as a confounding variable. An ANOVA Test was performed on the participants' scores based on hand order and no statistically significant difference was found between the first, second, third, or fourth hands tested with $p=0.71$. This indicates that randomizing the order in which the hands were tested was successful in eliminating hand order as a confounding variable.

Comparison of 3D Printed and Commercial Prosthetics

A

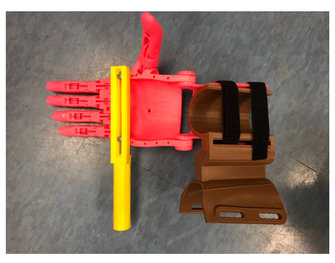


Figure 6. eNABLE Unlimbited Phoenix hand with our 3D printed emulator

B

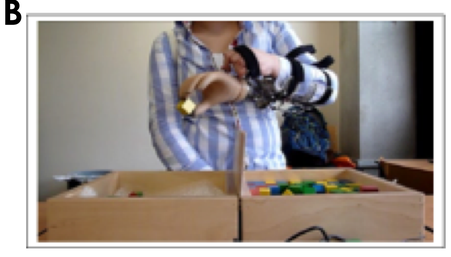


Figure 7. Commercially available prosthetic preforming a BBT (Haverkate, Smit, & Plettenburg, 2016)

Haverkate, Smit, & Plettenburg found that participants controlling the otto bock hand, a commercially available prosthetic, (Fig. 7) scored an average of 17.4 on the BBT. This score comparable to the Phoenix V2 mean score of 14.4. The results demonstrate that the dexterity of commercial prosthetics, as assessed by the BBT, is only slightly higher than that of the eNABLE hands we are currently printing in our lab.

Conclusions

- -The Raptor Reloaded hand performed significantly worse than the Phoenix V2 and Unlimbited Phoenix hands
- -There was no statistically significant difference between the Phoenix V2, Unlimbited Phoenix, and Osprey Hands
- -Through randomization, the order of hand testing was not a confounding variable
- -Scores achieved on the BBT using the eNABLE Phoenix V2 hand are comparable to scores achieved using the commercially available otto bock hand

Acknowledgements: We would like to thank the Marymount University Discover Program for their generous funding of this research project.

References:

Haverkate, L., Smit, G., & Plettenburg, D. H. (2014). Assessment of body-powered upper limb prostheses by able-bodied subjects, using the Box and Blocks Test and the Nine-Hole Peg Test. *Prosthetics and Orthotics International,40*(1), 109-116. doi:10.1177/0309364614554030

Mathiowetz, V., Volland, G., Kashman, N., & Weber, K. (1985). Adult norms for the Box and Block Test. *American Journal of Occupational Therapy,39*(6), 386-391.