A Comparison of Robotic Hand Thumb Designs

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The ever-growing world of robotic prosthetics encompasses many different areas of the human body, and one paramount area is the development of hands. Prosthetic hands are all different in their modeling approach but have similar design, with the exception of the carpometacarpal joint of thumbs. The thumbs from these designs thus have the potential for differing movement capabilities and ease. The purpose of this study was to test the effectiveness of differing degrees of mechanical freedom on a prosthetic hand's ability to perform simple tasks. It was hypothesized that the hand possessing more degrees of mechanical freedom would outperform the more simple hand design, on the assumption that the additional degrees of freedom better enable movement. The hand designs were sourced from the internet, and then created using a 3D printer. These hands were then evaluated by a series of success-based grip and motion tests to determine the effectiveness of degrees of freedom. The t-test showed that there was a significant difference between the motion of the hands, $t(180)= 2.95$, $SEM= 0.23$, $t = 1.6535$, $p< 0.01$. The results of this experiment show that additional degrees of freedom in a thumb do not enable a prosthetic hand with increased practical dexterity.

Introduction

In today's society, prosthetic design has advanced far beyond the peg leg to the point of having fully functional robotic prosthetics, capable of doing any action that a normal human hand can. These advancements in design allow for someone missing any part of their body to regain lost functions, therefore improving their quality of life (Freedom Prosthetics, 2020). Across the varying designs of hands, however, there are very present differences between the designs of the joints of the thumb, specifically with the carpometacarpal (CMC) joint (Marzke & Marzke, 2000). As they are all different, they have the potential to possess different values of Degrees of Mechanical Freedom (DoF, degrees of statistical freedom will be represented differently) as defined by Bandyopadhyay (2014). A DoF is simply a direction of motion, where a joint with one DoF has movement on either a transverse, longitudinal, or vertical axis. The object that is moving (in this case the joint) can control movement on this particular axis. This ability to have controlled movement is what amounts to a DoF. Commonly, most prosthetic hands have one DoF, allowing a finger to fully contract and straighten on one axis. The design of the thumb from the "Unfinished Robot Hand" (Kaetemi, 2014), then, possesses multiple DoF due to its ability to move across multiple axes (Cotton et al, 2007). In practice, however, this may not be the case. The multi-jointed thumb may have more movement, but controlling the movement and utilizing it are an entirely different matter. Additionally, repeated use of the complicated joint may cause more failures and demonstrate general unreliability (Yang et al, 2021). Overall, more degrees of freedom may not enable the hand to pick up more objects, but it should certainly be sufficient to make the hands more dexterous and wield objects more easily.

The purpose of research was to compare two variations of thumb joints in basic prosthetic hands, one simple double-jointed model and a more complicated model with three joints and a swivel. Keep in mind that though one model possesses more joints, the ability to make full use of said joints may not be possible.

It was hypothesized that an increase in DoF would result in a wider range of motion and higher dexterity and ability to successfully complete a set of motion tests. The thumb designs tested in this experiment, as previously stated, differ in degrees of freedom by joint count. The "Unfinished Robot Hand" (Kaetemi, 2014) is the thumb that possesses the more complicated movement, while the Ada Robot hand (Open Bionics, 2016) is the more simple design, only possessing two simple hinge joints rather than the Unfinished hand's swiveling joints. While the hand with more joints may possess more degrees of freedom via the definition (Bandyopadhyay, 2014), the actual versatility of these joints could be seen as similar if not less than that of the double-jointed thumb. To test the two models, each of the robotic hands was created using a 3D printer. These hands were then subjected to a series of grip and motion tests, and were scored on a pass or fail basis.

Methods

The hand parts were digitally modeled from the sourced designs and then 3-D printed out of PLA+ filament (Figures 2 and 3). The fingers that were not being moved during the experiment (all fingers but the thumb) were fixed into optimal positions with hot glue, while the thumb was controlled with a hydraulics system (Figure 4). The hydraulic system described was composed of graduated syringes connected with IV tubing, such that pressing down on a syringe on one side would cause movement on the other end of the tube, causing the connected finger to move and grip the desired object. The hands were then put through three of the grip shape tests as proposed by Konnaris et al. (n.d.) (Figures 4, 5, 6), these tests being the cylindrical, pinch, and spherical grip tests. The tests were run by placing an object of the appropriate shape (a paper towel tube for cylindrical, a DVD for the pinch, and a tennis ball for the spherical) into the palm of the hand, and then manipulating the syringes, causing the hand to attempt to grip the object. If the hand could successfully hold onto the object, it was counted as a success and registered within the data as a one. Inversely, if the hand failed to grip or quickly dropped the object, it was marked as a zero in the data. The tests were run for 30 trials each for significance (Figure 1).

Results

The Ada Robotic and Unfinished Robot hands were tested on the pinch, cylindrical, and spherical grips. The mean success rates for the Ada Robotic hand were 70% on the pinch test, 86% on the cyllindrical test, and 56% on spherical. The Unfinshed Robot Hand's results were 0%, 63%, and 87% respectively. These tests yielded results seeming almost parallel to the original hypothesis which states that the Unfinished Robot hand will have a higher overall success rate. Table 1 contains the raw data from the experiment, as well as the success rates of the hands for each specific test. The data The sample size for each data point is 10, and the level of significance is 0.01

Discussion

This research was performed to test the value of degrees of freedom's impact on a prosthetic thumb for improved movement and increased dexterity. It was hypothesized that the increase in degrees of freedom would have a positive effect on the movement and dexterity. The results of the experiment ended up demonstrating that the less complicated hand actually demonstrated higher success than the supposedly more dextrous one, as shown by the Ada hand's higher mean success rate, $t(180)= 2.95$, $SEM= 0.23$, $t= 2.756385889$ (Pinch), 2.67373362 (Cylindrical), 2.67572222 (Spherical), $p< 0.01$. Other research similar to this in nature is the creation of the MCR Hand III (Yang et al., 2021), along with other designs from Carrazoa et al. (2006), Cotton et al. (2007), and Konnaris et al. (n.d.). These researchers all designed hands with varying thumb and joint mechanics, and quantitatively measuring the success of said variations was a focus of all of the studies. The results of all of these studies stated that higher levels of articulation of the joints made for more successful hands, which is not supported by this study. However, it should be noted that these hand designs went through a much more intensive design process than the methods of this research.

The tests performed both in this study and the study they were sourced from were quite accurate ways to test the impact of degrees of freedom on the dexterity of the thumbs (Konnaris et al, n.d.). While DoF was not a data point used in the study, as there was no feasible way determined to compare it to the given data, it was expressed as more of a comparative point. The Unfinished Robot Hand had a flaw of overcomplication due to the addition of degrees of freedom, which was different from the Ada hand's simple construction.

Further research on this topic could potentially orient more towards connecting DoF to the movement of a hand, and technology that is currently inaccessible in order to more closely track and measure movements. In addition to this, researcher designed hands would be able to more accurately measure said correlation between DoF and potential for movement.

Acknowledgements

I would like to thank Dr. Wyatt for setting deadlines and helping me to complete quality research. I would also like to thank Mr. Price for helping me to streamline my design development process to a much more manageable and simple level. In addition, I would like to thank Juan Caicedo D.SC, Professor and Chair, Civil Engineering University of South Carolina for his assistance in the areas of 3D modeling and printing. I would like to thank Mr. Nicolas Jones for his assistance and 3D printing of the hands. Finally, I would like to thank my family for both financial aid and making sure I stayed on top of my research.

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Figures and Tables

Figure 1: Experimental Design Diagram

Title of the Experiment
A Comparison of Robotic Hand Thumb Designs

Hypothesis
This experiment's goal was to find a design for the thumb, mainly dealing with the knuckle joint, and identif suitable replacements in a robotic hand replacement that allow for the highest range of motion. Two hands w proof of concept behind the idea of this research. It was hypothesized that an increase in DoF would result in of motion and higher dexterity and ability to successfully complete the motion tests.

Independent Variable*:*

DoF in Hand Design	Ada Robotic Hand	Unfinished Robot
Tests run: Cylindrical grip Spherical grip Pinch grip	Each test completed 30 times	Each test complet

Dependent Variable
Each motion will be assessed based on pass or fail (1 or 0). DoF (Degrees of freedom) will be measured sepa testing.

Constants
Materials, hydraulic system, grip example objects,

Figure 2 shows the Ada Robot hand prior to the motion testing, showing how the wires are attached to the hand, and the mounted hydraulic setup.

Figure 3 shows an image of the unfinished robot hand prior to affixing the fingers and testing

Figure 4 shows the unfinished robot hand performing the cylindrical test as proposed by Konnaris et al. (n.d.). The hand also has the full hydraulic setup attached.

Figure 5 demonstrates the Ada Robot hand performing the pinch grip test. It also shows the Ada hand with the full hydraulic setup.

Figure 6 shows the Unfinished Robot hand performing the spherical grip test.

Table 1: Sample of Grip Test Results

Ada Robotic Hand			Unfinished Robot Hand		
Pinch	Cylindrical	Spherical	Pinch	Cylindrical	Spherical
0	1	0	0	0	1
1	1	0	0	1	1
0	0	1	0	1	1
1	1	0	0	0	1
0	1	1	0	1	1
1	1	0	0	1	1
0	1	1	0	1	0
1	1	0	0	1	1
1	0	0	0	0	1
1	1	1	0	1	1

Table 1 possesses a sample of the raw data from the experiment, as well as the mean success rates for each sample sorted by test. The data is discrete, where 1 is a success and 0 is a fail.

Table 2: T-Test Tables for Each Grip

Pinch Grip Test

	Ad	*Unfinished Robot Hand*
Mean	0.7	0
Variance	0.2172413793	0
Observations	30	30
Hypothesized Mean Difference	0	
df	29	
t Stat	8.22597512	
P(T<=t) one-tail	0.000000002269106082	
t Critical one-tail	2.46202135	
P(T<=t) two-tail	0.000000004538212165	
t Critical two-tail	2.756385889	

Cylindrical Grip Test

	Ad	*Unfin*
Mean	0.8666666667	0.6333333333
Variance	0.1195402299	0.2402298851
Observations	30	30
Hypothesized Mean Difference	0	
df	52	
t Stat	2.130712581	
P(T<=t) one-tail	0.01893083981	
t Critical one-tail	2.400224681	
P(T<=t) two-tail	0.03786167963	
t Critical two-tail	2.67373362	

Spherical Grip Test

	Ad	*Unfinished Robot Hand*
Mean	0.5666666667	0.8666666667
Variance	0.2540229885	0.1195402299
Observations	30	30
Hypothesized Mean Difference	0	
df	51	
t Stat	-2.688436778	
P(T<=t) one-tail	0.004836628875	
t Critical one-tail	2.401717513	
P(T<=t) two-tail	0.009673257749	
t Critical two-tail	2.675722224	

These descriptive statistics tables contain all the data necessary to perform t-tests, the results and level of significance are presented within the discussion.