

## VISUAL FEEDBACK AND THE GRASPING FUNCTION OF PROSTHETIC HANDS

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### ABSTRACT

Upper limb amputees lack the benefit of tactile and proprioceptive feedback while using their prosthetic hands. It has been theorised that they rely almost exclusively upon vision to determine how well objects are grasped, if slippage is occurring, or if the object is being crushed by excessive force. An understanding of how visual feedback affects grasping performance could be an important tool for the prosthesis designer.

A method of quantifying visual feedback and its effects on prosthetic grasping function is presented. Methods-Time Measurement was used for evaluation. A head mounted camera was used to record what the user could see while performing a grasping task. The data from subjects with natural and prosthetic hands were evaluated and suggest that the technique is suitable to aid in the understanding of the role of visual feedback related to grasping function. Results indicate that the shape of objects grasped, as well as visual feedback were important factors in determining the grasping performance. Recommendations are suggested for further research.

### BACKGROUND

The human hand is an engineering marvel. It is an adaptable instrument that can apply brute force or effect fine manipulation. Simultaneously, it provides intricate tactile, proprioceptive and temperature sensory feedback. In comparison, current prosthetic hand replacements are exceptionally crude mechanisms. It would be difficult to identify whether prosthetic hand function is limited more by the lack of mechanical sophistication or sensory systems. Modern electromechanical anthropometric hands have made advances in mechanical performance over the conventional body powered split hooks while the hook provides better visual feedback to the user. Still, no commercial prosthetic prehensor incorporates systems to improve the sensory feedback to the user.

Visual feedback is a noted functional benefit of the conventional split hook over anthropometric prostheses [1]. The orientations of the grasping surfaces to the user's line of sight and the slim profile are potential reasons for this advantage. The importance of visual feedback for anthropometric designs is illustrated in a recent pilot survey involving 5 upper limb prosthetic centres where visual feedback was identified as an important but lacking characteristic of current child-sized myoelectric hands [2,3].

Grasp configuration of the prosthesis has been reported to influence both visual feedback [4,5], and grasping performance [6]. It was also suggested that while performing grasping tasks, improved visual feedback should result in a reduction in compensatory movements.

There has been considerable interest in alternative feedback mechanisms for powered prehensors in an effort to reduce visual dependency [7,8,9,10]. Even with these additional sensory inputs, visual cues are suggested to be the most important.

### PROBLEM STATEMENT

To date, there have been no published methods to evaluate or quantify the visual feedback of prosthetic hands. Likewise, there has been no suggestion as to what constitutes "good" or "bad" visibility related to prosthetic grasp. This lack of knowledge prevents a systematic optimisation of prehensor configurations to enhance this characteristic.

### OBJECTIVE

The objective of this research was to identify how visual feedback relates to the grasping performance of a prosthetic hand. A test was proposed that attempts to determine how the visibility of specific areas of anthropometric prosthetic hands affects the time required for a user to attain a grasp. It was suggested that this can be used to quantitatively evaluate how visual feedback affects the performance of various electromechanical prosthetic hands. The ultimate goal of this research is to provide additional information to aid the prosthesis designer to produce a more functional prehensor.

### RESEARCH QUESTIONS

- 1- Can the effects of visual feedback be quantified?
- 2- Does the method proposed quantify visual feedback?
- 3- Can correlations be found between visual feedback and the grasping performance of a prosthetic hand?

### TEST METHOD

To identify a correlation between visible areas of the hand and grasping performance of a prosthesis, three areas were addressed. First, a task was developed that required the user to demonstrate diversity of the independent variable, visual feedback. Second, a method of evaluating performance was proposed. Finally, a method of identifying what visual feedback the user has while performing the task was implemented.

### Grasping Task

The grasping task was developed to encourage a variety of grasp approaches thereby changing the visual feedback to the subject. The task involved reaching for and grasping a small cylinder then moving it to another defined position and releasing it. Nine of these cylinders are arranged in a 3 by 3 matrix scaled to the subject's dimensions made up a single trial. Each cylinder was aligned in one of three orientations, vertical (orientation 0), horizontal facing away (orientation 1), or across (orientation 2) the subject. The orientation of the cylinders was in a Latin square such that each orientation occurred only once in any row or column to facilitate data analysis. Each subsequent trial randomly altered the orientation pattern of the matrix to reduce learning effects.

The cylinder dimensions (12 mm dia. x 65 mm length) required a precisely aligned tip or pulp type grasp with the prosthesis so that each orientation required a different grasping posture that could be effected by adjustments in wrist orientation or compensatory motions of the shoulder and torso. The cylinders were balanced on 4 closely spaced pins, 12 mm above the table surface to increase the grasp alignment accuracy required. This prevented the subject from pushing the cylinder into a preferred orientation before picking it up.

Twelve trials were performed per test so that each orientation occurred in each position 4 times for a total of 108 grasps.

### Evaluation of Performance

Gilad, 1986, identified the ability to align and attain a grasp using a prosthesis to be the most affected function when compared to the natural hand using Methods-Time Measurement (MTM) [11]. MTM is a standard method of motion analysis based on a breakdown of activities required to perform a given task into its component parts [12]. The motion elements required in this experiment were *reach, grasp, move, position, and release*. By analysing video records of the experiment frame by frame and employing MTM standards to define the beginning and end of each activity, the time required to perform the given task can be broken into its component parts. Previous studies have shown that the time required to perform the element *grasp* is greatly affected by the prehensor configuration [6].

The subject was positioned under a mirror slanted 45 degrees below vertical allowing a single video camera to record both top and front views. Both the backdrop and table top were gridded to aid in observing movement.

### Quantifying Visual Feedback

A miniature high resolution CCD camera was mounted on the subject's head, close to the line of vision. Video tape recorded what the subject could see when performing the task. The primary grasping components of most electromechanical prosthetic hands consist of the thumb,



index and middle fingers. For recording purposes, these components were further divided into palmar, lateral, dorsal and medial surfaces of each phalangeal segment for a total of 32 segments. These areas were marked with a high contrast border that was discernible by the head mounted camera. The visible areas at the start of the grasp motion element were identified from the video tape.

## RESULTS

### Subject Information

A total of 9 trials were performed, three with natural handed subjects and six with prosthetic handed subjects. The prosthesis users included 2 traumatic and 2 congenital trans-radial amputees. Four different prostheses were considered in the experiment. In cases where the same subject was evaluated with different prostheses, they were allowed at least one week between trials to become familiar with the new prosthesis.

It was found that a single trial consisting of 108 grasps required approximately 1 hour of subject testing followed by 10 hours of manual processing to obtain raw data.

### Percent of Grasps Individual Segments are Visible

To determine what segments are commonly visible, the percentage of grasps that any one segment is visible was calculated. The results are displayed in Figure 1.

For both the natural hand and prosthetic hand data, the same group of eight segments were found to be visible for more than 75% of the grasps. Approximately one half of the segments were visible for less than 25% of the grasps for both groups. The similarity of the results of the natural and prosthetic hands suggests that similar visual feedback strategies were used. It was interesting to note that the subjects appeared to make considerable efforts to maintain visibility of certain segments of the hand even if large compensatory motions were required.

### Grasp Time Data

In order to consider the combined grasping time data for all subjects, the grasping time was normalised to account for variations between subjects due to prosthesis used and subject skill and motivation. Unless otherwise noted, the normalised grasp time will be used in this paper. Non-parametric statistical methods were used to evaluate the results since the data was found to be skewed using the Shapiro-Wilks' and Kolmogorov-Smirnov statistics [13].

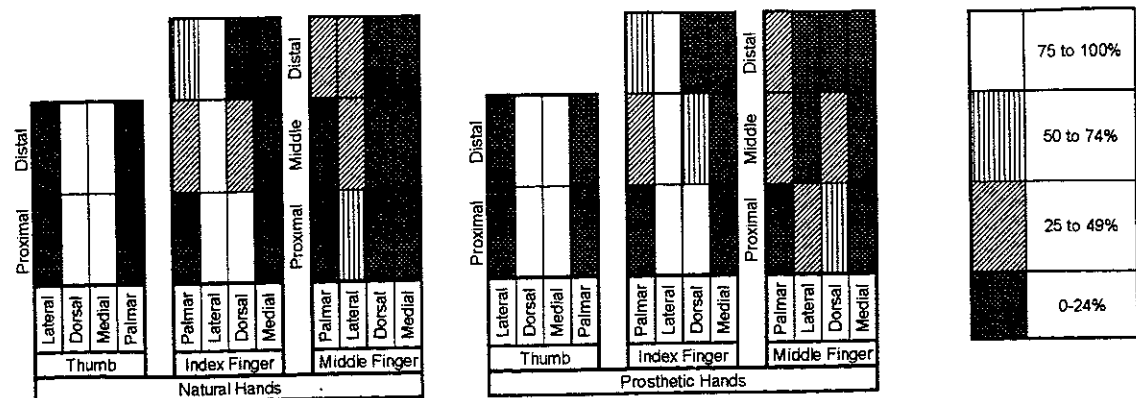


Figure 1. Frequency of Visibility of Segments.

### Geometric Factors Versus Grasp Time

To ensure that the grasping task encouraged significant variability in the grasp, the data were evaluated using the Kruskal-Wallis test to identify significant correlations between the *row*, *column*, and *orientation* of the object and grasp time.

Significant variations in grasp time were identified as a result of object *orientation* for natural and prosthetic handed subjects and also due to *row* for the prosthetic handed subjects.

### Correlations Between Visibility and Grasping Time

Grasp time was investigated for correlations with the visibility of each segment. The Mann-Whitney non-parametric test was performed for natural handed subjects and prosthesis users. As shown in Figure 2, a segment that has a significantly positive correlation would indicate a faster grasp when it is visible than when it is not. Similarly, segments with a negative correlation would indicate a slower grasp when visible.

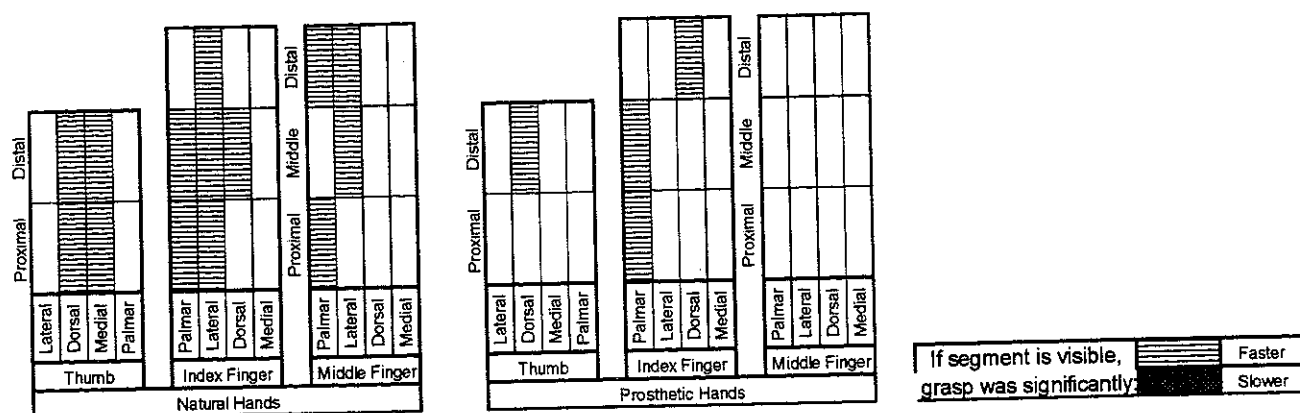


Figure 2. Segments that are significantly correlated with grasping time.

There were several segments correlated with faster grasp for the natural hand. The correlated segments were commonly the same as those most frequently visible, (Figure 1), and could intuitively be thought of as being required to align the grasping surfaces with an object to be grasped. This was not the case for the prosthetic hand data. While it was anticipated that the prosthesis users' greater reliance upon visual feedback would provide many more correlations than the natural hand, only four segments were significant.

A stepwise, linear, multiple regression was performed to attempt to create a relationship that could predict the grasping time knowing which segments of the hands were visible. The result for the natural hand could explain 21% of the variability of grasping time. The prosthetic hand result only explained 4.5%. This suggests that there may be other significant predictors of grasping time. In an attempt to better understand the prosthetic hand results, the data were divided into 6 groups by subject. This showed that the segments that were correlated with grasp time varied from one subject to the next but the number of correlated segments were still few.

The data for all prosthetic hand subjects combined were divided into three groups by the orientation of the object being grasped. Several new correlations were identified as shown in Figure 3. Eleven segments correlated with faster or slower grasping times for the vertical cylinder orientation that correlated in the opposite direction for the cylinders oriented away from the subject. These correlations could be understood intuitively for orientation 0 but were counter-intuitive for orientation 1. Orientation 2 still resulted in very few correlations.

The original video tape records were reviewed in an attempt to explain these results. It was found that various approach strategies were used on orientation 1. The strategy that best allowed the correlated segments to be visible involved large compensatory motions of the shoulder in abduction and flexion to align the forearm vertically over the cylinder to be grasped. This suggested that compensatory motions may be a potential influence on the grasping performance of prosthetic hands.

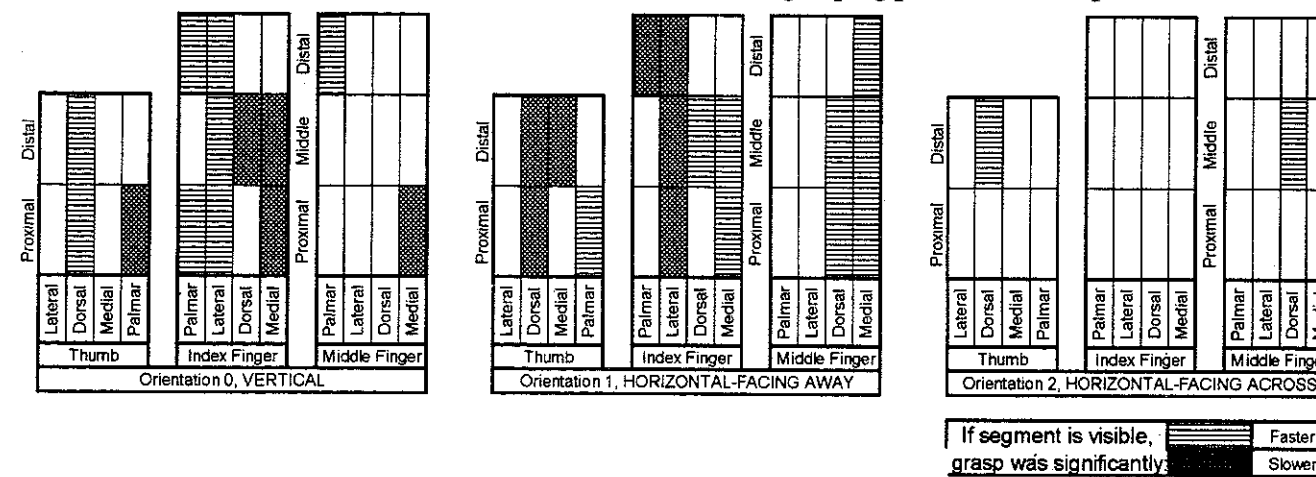


Figure 3. Significant correlations between grasp time and segments visibility for prosthetic hand users. Data divided by object orientation.

### CONCLUSIONS

The analysis showed that the grasping task provided adequate variability in both grasping time and visibility. There were no substantial problems regarding the mechanics of collecting and processing these data.

Visual feedback of several segments were correlated with grasping time for persons grasping objects using their natural hands. When a prosthetic hand was used, correlations were identified between visual feedback and grasping time only when the data was divided by cylinder orientation. It is theorised that the object orientation influences the compensatory postures required to perform the grasp. The latter in turn affect the grasping performance.

The original goal of this research was to provide a measure of performance of prosthetic hands based solely on visual feedback. The lack of correlation between performance and visual feedback for a range of object grasps does not permit optimising the prosthesis based solely on this parameter. Further investigation into factors such as compensatory postures are suggested in order to obtain a more general understanding of hand configuration and grasping performance.

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