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An Investigation of Grasp Type and Frequency in Daily Household and Machine Shop Tasks

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Abstract — **This paper presents a study on the usage frequency of different grasp types throughout the daily functions of a professional house maid and a machinist. Subjects wore a head-mounted camera that recorded their hand usage during their daily work activities. This video was then analyzed, recording grasp type and associated time stamps, as well as information related to the task and object. The results show that nearly 80% of the time the house maid used just six grasps and the machinist used nine. This data, in conjunction with established grasp taxonomies, will enable a better understanding of how people utilize different grasps to accomplish tasks throughout the day, as well as inform the design of robotic and prosthetic hands.**

I. Introduction

UNDERSTANDING how humans utilize their hands has long been a topic of interest. Initially, this interest was primarily related to applications such as biomechanics, hand surgery, and rehabilitation [1-4]. With the advent of robotics into manufacturing tasks, the study of hand function received new life as researchers began to investigate human hands in order to shed light on the design and control of robotic end effectors.

This study presents an investigation into grasp type and frequency for common classes of manipulation tasks. In particular, we investigate the hand use behavior of a full-time house maid and a professional machinist – two areas of interest for robotic assistants. Previous grasp studies have been done in related areas, primarily focusing on the hand posture used for pre-selected objects, as opposed to recording unstructured human manipulation behaviors. An early study related to prosthetics [3] photographed 12 subjects to determine hand prehension shapes used in picking up 27 objects and the "hold-for-use" posture for 57 objects. Santello et al. asked subjects to imagine grasping fifty seven test objects while a motion capture system records 15 finger joint angles [5]. Through principal components analysis, the results showed that the first two components could account for 80% of the variance. As described in detail in section II, Cutkosky studied the grasps utilized by machinists using single-handed operations in working with metal parts and hand tools. The machinists were observed and interviewed and their grasps were recorded as they worked in order to generate the grasp taxonomy [6]. Kemp created a wearable system including a head-mounted camera and orientation sensors mounted on the body to learn body kinematics (not including the hand) and record manipulation tasks. A large amount of manipulation video was recorded but was never analyzed for details of grasp and object type [7]. While these previous efforts have helped better understand human grasp behavior, none have formally recorded and evaluated grasp type and frequency over a large time span of daily use.

For robotic and prosthetic applications, there are a number of reasons why the human hand should not or cannot be simply copied in order to produce effective end effectors and terminal devices. With its 21 degrees of freedom, 38 muscles, and thousands of sensory organs, the human hand is incredibly complex, both mechanically as well as to control. Current state of the art in engineered systems simply cannot achieve that level of complexity and performance in the same size package. Furthermore, with added complexity comes added cost and lower durability. In fact, the authors are unaware of the development of any robotic or prosthetic hand that allows for the full 21 DOF of the human hand.

However, very few, if any, practical grasping and manipulation tasks for robotics or prosthetics require the fully complexity of the human hand. Indeed, as evidenced by the widespread use of simple prosthetic terminal devices such as the single DOF split hook [8], even the simplest devices, if well-designed, can have a great deal of utility.

The benefits of lower-complexity devices have not been overlooked in the robotics and prosthetics research communities. A number of simplified hands have been developed, many of which are underactuated to provide passive adaptability and, in turn, a larger range of grasp configurations per actuator (e.g. [9-12]). The design of prosthetic hands comes with additional challenges related to the limited amount of space and weight that can be implemented, particularly in light of the fact that amputations can be performed at various points on the limb, limiting most devices to the space distal to the wrist (e.g. [13, 14]).

Due to the many reasons why the full spectrum of human hand capabilities cannot be practically achieved, some smaller subset of those must be chosen. We expect this study to help to motivate that choice by informing which human grasp types are most commonly used for household and other

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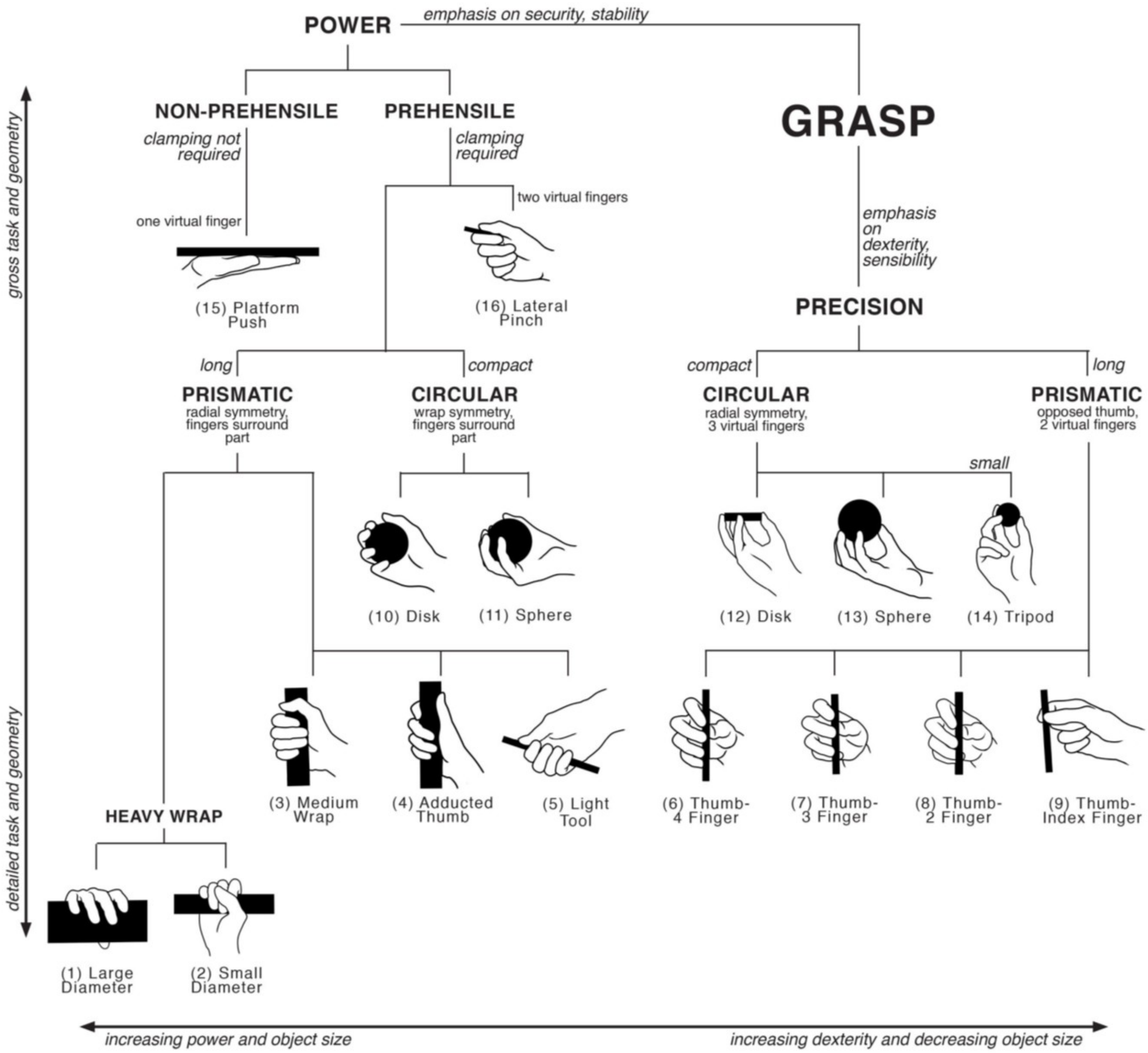

Fig. 1. Cutkosky grasp taxonomy. Adapted from [6].

important tasks.

We begin this paper with a discussion of human grasp classification, presenting an overview of previous work and laying out the terminology used in this paper. We then describe our experimental methodology, including details on the subjects used, apparatus, and protocol. We then present the results for two subjects, a professional housekeeper and a professional machinist, identifying the frequency of grasp type use for each. Finally, we discuss limitations of the current study and future work on the subject.

II. Human Grasp Classification

The first major attempt to organize human grasping behavior into distinct categories was by Schlesinger et al., which categorized grasps into six types: cylindrical, tip, hook, palmar, spherical, and lateral [2]. These grasps are primarily defined by the object that the hand interacts with. However, human grasps are often less dictated by size and shape of the object, but more by the tasks that need to be accomplished. In 1956, Napier suggested a scheme that would divide grasps into power and precision grasps [1]. Unfortunately not all the grasps fell cleanly into either of these two categories, with the lateral pinch in particular serving both power and precision functions.

In studying the grasps required for manufacturing tasks, Cutkosky provided a much more comprehensive and detailed organization of human grasps (Fig. 1) [6]. This taxonomy was acquired through a set of observational surveys on professional machinists and is essentially an integration of the previous work done by Schlesinger and Napier. The taxonomy tree is organized such that it is first divided into power and precision grasps from left to right, and by shape and function down the tree.

Fig. 2. Camera and receiver hardware (top), example of the apparatus as worn by a subject (middle), and sample image from the system in use.

The Cutkosky taxonomy, reproduced in Fig. 1, is currently the most widely used in the field of robotics. A small number of successive taxonomies, built primarily from the Cutkosky taxonomy, have been proposed since (a comprehensive overview can be found in [15]). However, these include mostly minor variations and have not yet been extensively adopted by the research community. We therefore base our analysis in this study using the Cutkosky taxonomy [6].

Though there have been a number of efforts focused on classifying types of human grasps, no previous studies have examined the frequency of these grasps as they are used in various settings. The frequency data is important as it will further clarify the relationship between task requirements and the grasp types. Furthermore, it will prioritize grasp types by importance according to the most frequently used in the examined daily activities. This is important to motivate the practical robotic and prosthetic hand design tradeoffs between complexity and performance.

III. METHODS

Two subjects participated in the study presented in this paper. The first, a 41 year old right-handed male, was a professional machinist who had worked in his profession for more than 20 years. The second, a 30 year old right-handed female, was a full-time house maid who had been working in that capacity for over 5 years. Neither subject had any injury or disability that would alter their grasping and manipulation ability from what would be expected as typical for their profession.

Candidate subjects were evaluated according to the following primary enrollment criteria: substantial experience as professionals in their field, of normal physical ability, employed to perform a wide range of tasks considered typical and representative for their respective fields, and able to participate to the extent to provide 8 hours of data. Subjects were paid $10/hour for their participation.

A. Experimental Procedure and Apparatus

After it was determined that the subjects met the enrollment criteria described above, they were enrolled in the study and provided instruction regarding the protocol. Both subjects wore the head-mounted camera shown in Fig. 2 (top and middle). The wire from the camera is routed to the recorder on the back of the subject over the top of the head to the waist, with safety pins used to pin the wire to the subject's clothing so that it would not interfere with their hands or arms. Subjects were instructed on how to start and stop the recording in cases where privacy was required.

A total of at least eight hours of hand usage was recorded for each subject, over multiple days. The days and times of recording were carefully chosen according to the subject's feedback such that there would be a wide range of tasks representative of the span of the job requirements performed throughout the total eight hours. Therefore, days and times for which the subject was performing a small number of tasks repetitively were not included.

The hardware, shown in Fig. 2, consists of a tube camera (RageCams, model 3225, 200g, 22mm dia x 60mm long, 640x480 resolution) with a wide-angle fisheye lens (2.5mm, ~140 degrees field of view) attached to a three-band head strap taken from a hiker's lamp. This setup allows the camera to rest on the subject's head without being intrusive or uncomfortable. The camera is connected to a mini digital video recorder (AngelEye 2.4GHz PVR, 115x65x25mm, 30 FPS) with approximately 2 hours of recording time (stored in a 2GB SD memory card). An external battery pack (12V, 8xAA) is used to power both the camera and the receiver. Both the receiver and battery pack are worn in the back pocket of the subject.

The setup is able to acquire video of sufficient quality for manual grasp classification. The overhead view was chosen after informal testing showed this to be the most useful for our purposes as it shows the entire workspace of both left and right arms in front of the body as well as enough of the surroundings to give the context of the grasps in addition to the grasp itself. Fig. 2 (bottom) shows a sample image taken with this setup.

IV. Results

The results below show the analysis of four hours of video for each of the two subjects - house maid and machinist. During the four hours analyzed, the subjects were performing a wide range of tasks associated with the regular demands of their profession.

All data was manually recorded by a researcher trained in human grasp classification. The researcher went through the video and when the user changed their grasp (either acquiring a new object or releasing an existing object) recorded the grasp type (according to the Cutkosky taxonomy [6]), object and task being performed, and the time stamp associated with the change. Only the right (dominant) hand was examined in the present study.

A. *House Maid Results*

Table I shows the compiled results from the four hours of video of the house maid. The rows correspond to the grasp type utilized. Grasps followed by numbers in parentheses correspond to those identified in the Cutkosky taxonomy (Fig. 1) [6]. Unnumbered grasp types are labeled according the terminology utilized in [15]. Note that the last row, "no grasp", corresponds to cases in which no object was being grasped with the dominant hand. Time is in units of seconds, rounded to the nearest second.

The last two columns of the table correspond to the percentage of time in which the grasp was utilized and the percentage of the total grasp instances for the corresponding grasp type. '% Instance' would therefore treat a grasp lasting 20 seconds, for example, the same as one lasting 1 second. These two percentages are based on the total instances of grasping an object and do not include the "no grasp" occurrences. For the "no grasp" type, percent time and instance (shown in italics) are based on the full data set.

Fig. 3 shows the frequency data from Table I (i.e. % time) in a chart form, with labels for all grasp types occurring at least 2% of the time. Fig. 4 shows sample screen captures for the four most common grasps utilized by the house maid during the four hours analyzed. The tasks being performed in the images correspond to a task frequently performed by the subject utilizing the given grasp type: grasping handles (medium wrap), sweeping (index finger extension), wiping with cloth (power sphere), picking up small objects (lateral pinch).

TABLE I
Grasp Occurrence Data for House Maid

Grasp Name	*Time*	*Instance*	*% Time*	*% Instance*
large diameter (1)	222	39	2.9	3.1
small diameter (2)	41	14	0.5	1.1
medium wrap (3)	2051	273	26.8	22.0
adducted thumb (4)	94	6	1.2	0.5
light tool (5)	95	25	1.2	2.0
thumb-4 finger (6)	245	60	3.2	4.8
thumb-3 finger (7)	165	36	2.2	2.9
thumb-2 finger (8)	210	42	2.7	3.4
thumb-index finger (9)	314	91	4.1	7.3
power sphere (10)	1012	164	13.2	13.2
power disk (11)	9	5	0.1	0.4
precision sphere (12)	31	7	0.4	0.6
precision disk (13)	527	117	6.9	9.4
tripod (14)	109	5	1.4	0.4
platform (15)	49	16	0.6	1.3
lateral pinch (16)	915	131	12.0	10.5
adduction	48	4	0.6	0.3
extension type	74	7	1.0	0.6
fixed hook	17	7	0.2	0.6
index finger extension	1025	94	13.4	7.6
lateral tripod	66	20	0.9	1.6
palmar	23	1	0.3	0.1
parallel extension	163	44	2.1	3.5
quadpod	95	11	1.2	0.9
ring	11	3	0.1	0.2
sphere-3 finger	102	26	1.3	2.1
stick	13	3	0.2	0.2
thumb-middle finger	2	1	0.0	0.1
ventral	9	5	0.1	0.4
writing tripod	136	23	1.8	1.9
no grasp	4487	775	*37.0*	*38.4*

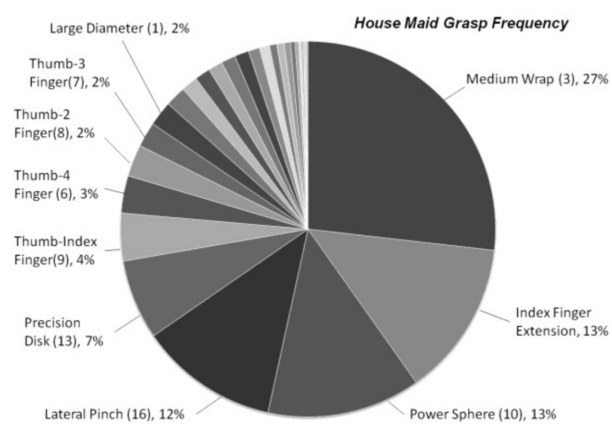

Fig. 3. Grasp frequency results for the House Maid, showing four hours of work. Grasps occurring less than 2% of the time are not labeled. The 'no grasp' case is not shown here.

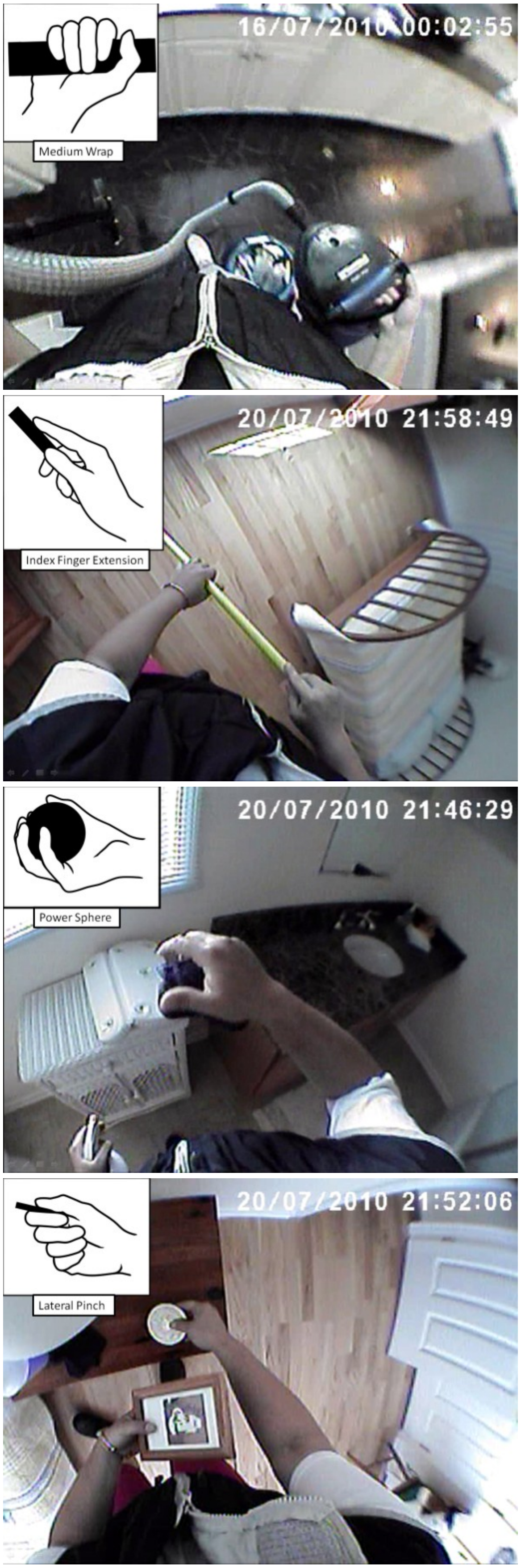

Fig. 4. Video stills from the House Maid experiments showing the four most commonly-used grasps and typical tasks performed using them.

B. *Machinist Results*

Table II shows the compiled results from the four hours of video of the machinist. The formatting of this table is similar to that showing the House Maid data (Table I). A description of the specific meaning of the terms utilized in Table II can be found in section IV.A above.

Fig. 5 shows the frequency data from Table II (i.e. % time) in a chart form, with labels for all grasp types occurring at least 2% of the time. Fig. 6 shows sample screen captures for the four most common grasps utilized by the machinist during the four hours analyzed. The tasks being performed in the images correspond to a task frequently performed by the subject utilizing the given grasp type: holding parts (lateral pinch), using small tools (light tool), holding small parts and knobs (tripod), using larger tools (medium wrap).

V. Discussion

From the results summarized in Figs. 3 and 5, it can be seen that only a small number of grasp types comprise the majority of those used. For the House Maid, nearly 80% of the time was spent utilizing six grasp types: medium wrap, index finger extension, power sphere, lateral pinch, precision disk, and thumb-index finger. Nearly 80% of the Machinist's time grasping utilized nine grasps: lateral pinch, light tool, tripod, medium wrap, thumb-3, thumb-4, index finger extension, thumb-2, and thumb-index. Note that all sixteen grasps identified in [6] occurred in both subjects' data, with the 'power disk' occurring least. However, two grasps frequently utilized by the subjects (index finger extension and writing tripod, >3% for both subjects) are not represented in the Cutkosky taxonomy. It is also interesting to note that the house maid primarily used power grasps while the machinist used a balance of both. Furthermore, the machinist switched grasps more often (~2500 in four hours vs. ~2000).

One particularly interesting question that was raised during our analysis related to how to classify grasps of non-rigid objects. The house maid in particular often used a rag or other cloth to wipe down surfaces for cleaning. We have classified these grasps primarily as 'power sphere', based on the observation that the subject utilized all five fingers in the grasp. However, a new subset of grasp types for compliant objects might be developed.

While four hours is a fairly large amount of grasping data (>2000 grasps per subject), these results will, of course, change to some extent based upon the specific subject being examined. Future work will involve completing the eight hours of video analysis for these two subjects, as well as investigating grasp behavior for additional professions that may be of interest to robotics, such as food preparation, machine maintenance, and others. We welcome suggestions from the research community as to the nature of these further investigations.

TABLE II
GRASP OCCURRENCE DATA FOR MACHINIST

Grasp Name	*Time*	*Instance*	*% Time*	*% Instance*
large diameter (1)	120	32	1.6	2.1
small diameter (2)	90	8	1.2	0.5
medium wrap (3)	769	169	10.5	11.0
adducted thumb (4)	88	14	1.2	0.9
light tool (5)	801	174	11.0	11.4
thumb-4 finger (6)	438	86	6.0	5.6
thumb-3 finger (7)	485	116	6.6	7.6
thumb-2 finger (8)	305	66	4.2	4.3
thumb-index finger (9)	284	84	3.9	5.5
power disk (10)	5	7	0.1	0.5
power sphere (11)	229	64	3.1	4.2
precision disk (12)	108	17	1.5	1.1
precision sphere (13)	56	11	0.8	0.7
tripod (14)	772	232	10.6	15.1
platform (15)	16	5	0.2	0.3
lateral pinch (16)	1376	203	18.8	13.2
adduction	109	25	1.5	1.6
extension type	89	16	1.2	1.0
fixed hook	9	2	0.1	0.1
index finger extension	309	41	4.2	2.7
inferior pincer	17	4	0.2	0.3
lateral tripod	132	38	1.8	2.5
palmar	0	1	0.0	0.1
palmer pinch	69	5	0.9	0.3
parallel extension	13	4	0.2	0.3
quadpod	74	18	1.0	1.2
ring	134	27	1.8	1.8
sphere-3 finger	74	8	1.0	0.5
sphere-4 finger	7	2	0.1	0.1
stick	93	18	1.3	1.2
thumb-ring finger	2	1	0.0	0.1
ventral	53	9	0.7	0.6
writing tripod	189	26	2.6	1.7
no grasp	5719	949	43.9	38.2

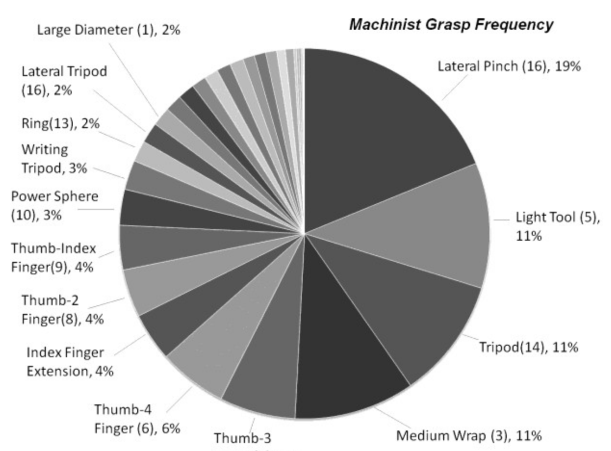

Fig.5. Grasp frequency results for the Machinist, showing four hours of work. Grasps occurring less than 2% of the time are not labeled. The ‘no grasp’ case is not shown here.

Fig. 6. Video stills from the Machinist experiments showing the four most commonly-used grasps and typical tasks performed using them.

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