Human Prehension and Dexterous Robot Hands

PAPER BY THEA IBERALL

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- Funded by National Science Foundation
- Author of four books (two novels and two about hands)
- Poet/Playwright
- Clown
- 8 previous papers about robotic hands
  - Control
  - Human hand inspiration

Introduction

- Provide insights into designing more versatile hand
  - Powerful and stable grasp with dexterous manipulation
- Opposition Space model
- Virtual Finger (VF)
- Describe existing hand taxonomies with Opposition Space
- Simplify tasks of human hand
  - Apply intended force
  - Impart motion
  - Gather sensory information

Building from existing work

- Analysis of over 20 classifications of prehension in different areas
- References to the achievements of existing robot hands

Table 1. A Chronological Ordering of Prehensile Classifications.*

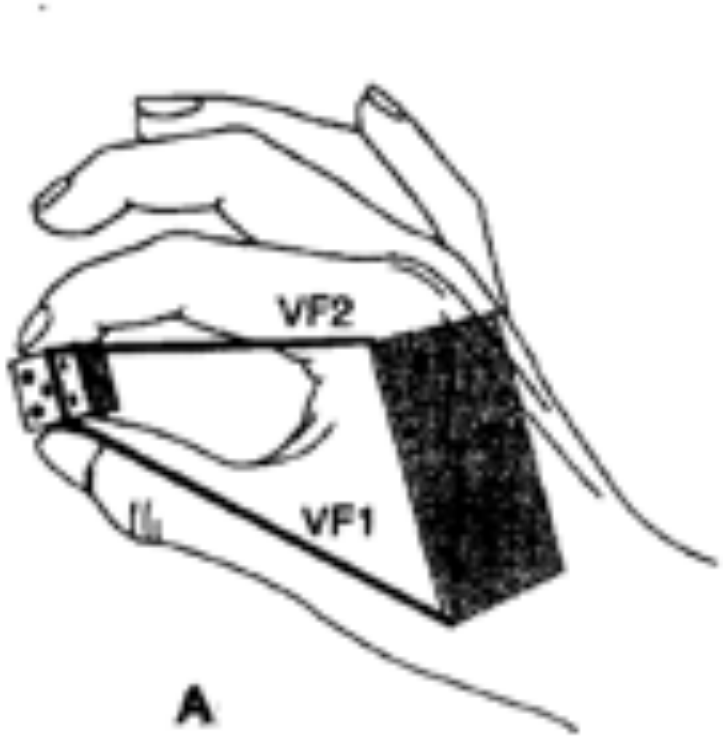
Researchers	Posture Names (bold-faced letters indicate similar postures)	
Schlesinger (1919)	Open fisted cylindrical grasp **A** Closed-fisted cylindrical grasp **B** Spherical prehension **C** Palmar prehension (pincer) **D** Tip prehension **E** Lateral prehension **F**	Hook prehension **G** Cylindrical/adducted thumb **B&F** Flat/thin (two-finger) pincer **I** Large (five-finger) pincer **J** Three-jaw chuck **K** Nippers prehension **L**
McBride (1942)	Whole-hand grasping **J** Palm, digits grasping **D**	Thumb, finger grasping **D**
Griffiths (1943)	Cylinder grip **B**	Ball grip **C**
Slocum and Pratt (1946)	Grasp **A, B, C** Pinch **D**	Hook **G**
Taylor (1948)	Palmar prehension (three-jaw chuck) **K** Tip prehension **E**	Lateral prehension **F**
Napier (1956)	Power grip **T&F, B, A, A& F** Precision grip **D, K, J**	Combined grip **B&D** Hook grip **G**

Virtual Finger (VF)

- 1 or more fingers, or the palm
- Described by kinematic components
  - Length
  - Width
  - Joint Range of motion
  - Degrees of freedom
  - Single force component
- 3 basic primitives can be combined as needed
- 3 types of VF
  - VF1 is the most stable force in grasp (palm or thumb usually)
  - VF2 opposes VF1
  - VF3 contributes torque or external force opposition (e.g. gravity)

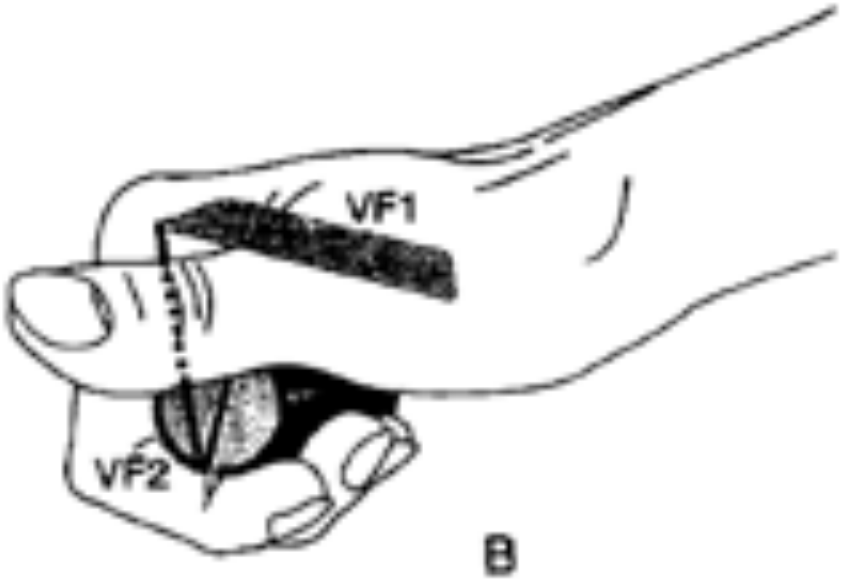
Pad Opposition

- Pad means fingertips
- Small forces
- Fine motion
- Precise sensing
- High compliance
- >=3 DOF
- Low stability
- Low slipping resistance



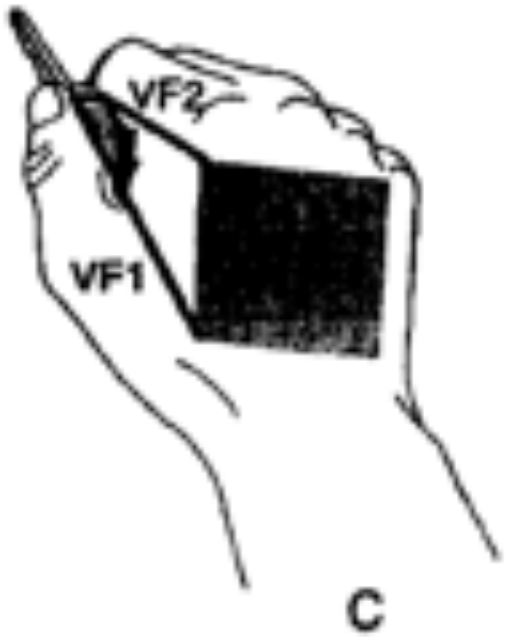
Palm opposition

- Larger forces
- Very stable
- Use arm/wrist
- Loss of skin sensitivity under heavy loads
- Low manipulability
- Low compliance
- High slip resistance
- Form and force closure



Side Opposition

- Side of a finger is used in grasp
  - Can be with the thumb or another finger's side
- Medium range of forces
- Sensing from thumb pad
- "bridge between power and precision grasps"



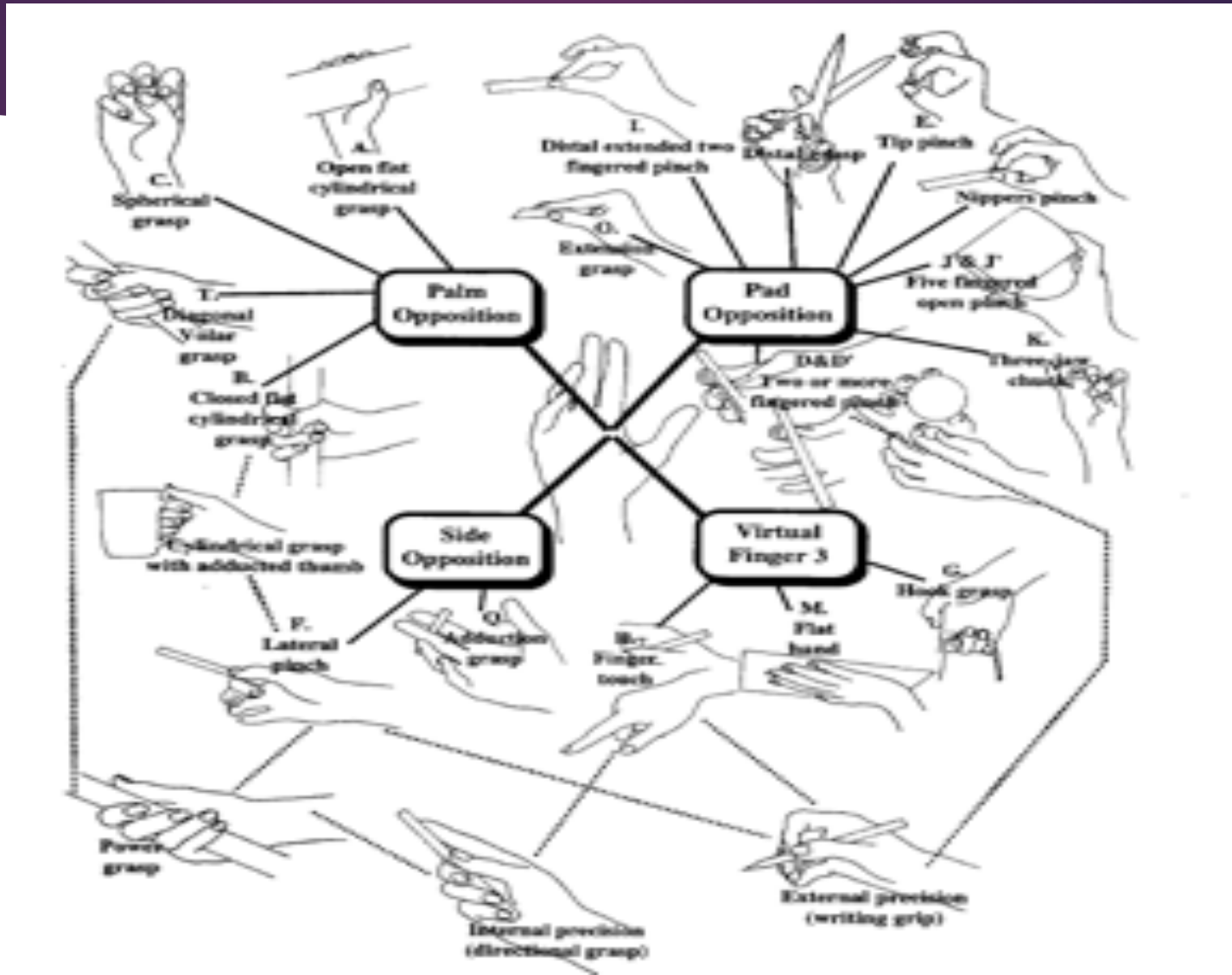
Combining Primitives

- Removing pen cap
  - Palm opposition with pinky, ring, and middle finger
  - Pad opposition with thumb and index finger
- Writing
  - Side opposition with middle finger
  - Pad opposition with index finger and thumb

Insights from existing taxonomies

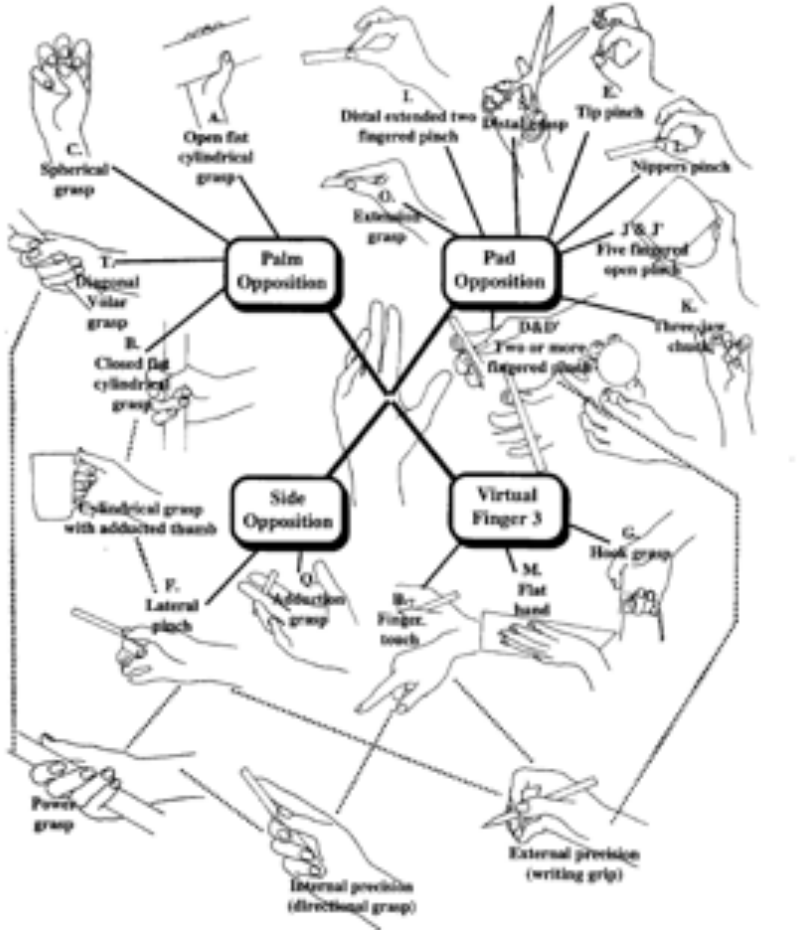
- The hand as a tool
- Gravity dependent grasps
- Power versus precision grasps
- Precision handling and dynamic grasps
- Bridge between power and precision grasps
- Adduction grasp
- Finger as an antenna
- Combination grasps

One diagram to unify them all



The Hand as a Tool

- Section based on Schlesinger (1919) paper
- Classifications based on:
  - Object shape
  - Hand surfaces
  - Hand shape
- Just to name a few
  - Open fisted cylindrical grasp
  - Close fisted cylindrical grasp
  - Spherical prehension
  - Hook grip

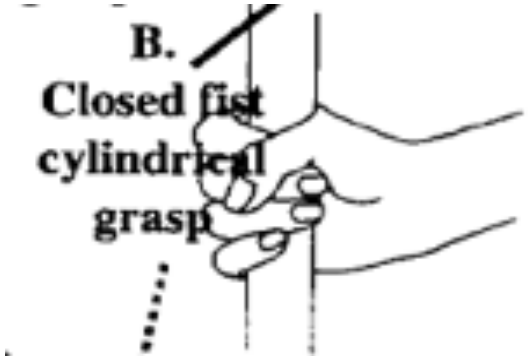


Gravity Dependent Grasps

- Different postures that defy gravity
- Opposing external force directly is VF3

Power Versus Precision Grasps

- Based on Napier (1956) paper
- Classify grasps based on primary goal of grasp
- Power and precision requirements
  - Power = apply/resist arbitrary force
  - Precision = small adjustments control the direction of force
- Just to name a few
  - Coal hammer grip (maximum power)
  - Precision grasp (uses fingertips)



Precision Handling and Dynamic Grasps

- Significant relationship between thumb, middle, and index finger
- Writing Grip as an example
  - Pad and side opposition
  - Thumb is VF1
  - Index is VF2 in pad opposition
  - Middle is VF2 in side opposition
  - Cleft of thumb is VF3 to steady your pen

Bridge Between Power and Precision

- Lateral pinch
  - Side opposition between thumb and side of index finger
- Precision from moving and sensing with thumb
  - Lacking full manipulative range
- Powerful but not as much as palm opposition

Adduction Grasp

- Side opposition between index (VF1) and middle finger (VF2)
- Other fingers can perform the same grasp, but not with the same strength

Finger as an Antenna

- Index finger is best antenna
  - Relative independence of movemer
- Internal precision grip
  - Surgeons sense tissue thickness
- Receive and transmit force
  - Counteract large forces
    - Cutting meat
- Index finger is VF3
- Thumb (VF1) in side opposition with middle (VF2)

Combined Grasps

- Precision grip in radial fingers (thumb and index)
- Power grip in ulnar fingers (pinky and ring)
- Tying a knot in a chord
- Holding chopsticks
- Pad opposition combined with palm opposition

Results

- There is a problem with previous taxonomies
  - Too specific
  - Don't cover everything
  - "promotes observation…with the shape of the test object rather than…the hand using the test object"
- Opposition space provides a more expansive view
  - Combining 3 primitives can yield all the symbolic descriptions of grasps from the papers that were analyzed
  - Can choose forces (VFs) that are desired and synthesize grasp from primitives

Is this useful?

- Future citations of this paper are small references
- How do you decide between many variations of a single primitive?
- How do you maneuver a hand into the grasping shape that you intend?
- Is it easy to decide where you would want a virtual finger to be?
  - Copying human hand directly solves this problem

Citation of Iberall

"These studies suggest that, while the configuration space of dexterous hands is high-dimensional and very difficult to search directly, most useful grasps can be found in the vicinity of a small number of discrete points. This approach has generated significant interest in both human and robotic grasping research; in this section we review a number of results on autonomous grasp planning for robotic hands.

-"Hand Posture Subspaces for Dexterous Robotic Grasping" (2016)

Citation of Iberall

"One way of limiting the large number of possible hand configurations is to use grasp preshapes. Before grasping an object, humans unconsciously simplify the task to selecting one of only a few different prehensile postures appropriate for the object and for the task to be performed. These postures have been enumerated in various grasp taxonomies"

-"Automatic grasp planning using shape primitives" (2003)

Citation of Iberall

"When finely manipulating objects, we mostly use our fingertips and distal phalanges. On the other hand, inhuman and animal grasping, the fundamental role played by the inner parts of the hand (palm and proximal phalanges)to enhance both the stability of the grip and the versatility of operation, can be frequently observed (see, e.g., [37] and[70]). To transfer this enhanced robustness into robotic devices, researchers have conceived hands with the ability of using inner surfaces for contacting the object, and capable of sensing contact interactions"

-"Hands for dexterous manipulation and robust grasping: a difficult road toward simplicity" (2000)

Citation of Iberall

"In many tasks, several fingers work together as a functional unit, the virtual finger (VF)[31]. Fingers belong to the same VF if they apply forces in a similar direction and act in unison. Depending on the grasp type, one or more fingers or hand parts can be assigned to one VF. The VFs oppose each other in the grasp, as it would be the case for a simple gripper or vice. In the example shown in Fig. 1(a), the thumb (mapped onto VF1) opposes the index finger (mapped onto VF2). In the case of palm opposition [see Fig. 1(b)], the palm of the hand is assigned to VF 1 and the four fingers act against it as VF 2. If one or more fingers are opposing a task-related force or torque, these fingers are assigned VF 3; otherwise, VF 3 will not be assigned [29]. Studies on human grasping found evidence supporting this concept"

-"The GRASP taxonomy of human grasp types" (2015)

Citation of Iberall

"Iberall reviewed a large field of work on grasp taxonomies, from areas such as anthropology, medical, rehabilitation and robotics. These studies suggest that, while the configuration space of dexterous hands is high-dimensional and very difficult to search directly, most useful grasps can be found in the vicinity of a small number of discrete points."

-"Dimensionality reduction for hand-independent dexterous robotic grasping" (2007)