

Human Grasping and Manipulation Follow-up

16-899 Hands: Design and Control for Dexterous Manipulation
Spring 2016

Cumulative Taxonomy: My Summary



1. Power grasps using the Palmar Gutter



2. Power grasps using Other Parts of the Palm

3. Power grasps with Lateral Stabilization



4. Precision grasps with Lateral Stabilization

5. Power grasps with Pad Opposition

4. Precision Grasps with Pad Opposition



Feix et al. Cumulative Taxonomy: My Summary



Power palm



Pad opposition

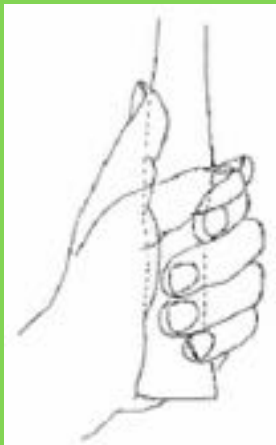


Lateral support



Feix et al. Cumulative
Taxonomy — is this sufficient?

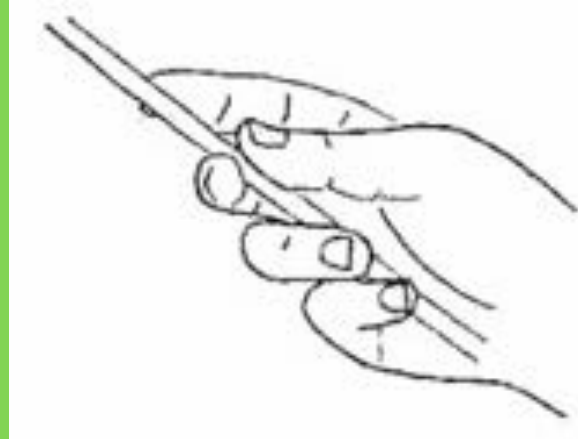
Taxonomy from a Surgeon



Power



External Precision



Internal Precision



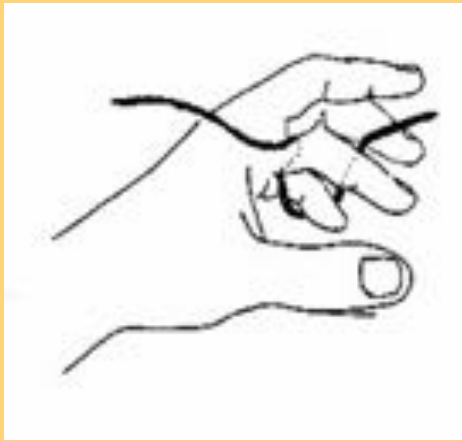
Pinch



**Power
Variation**



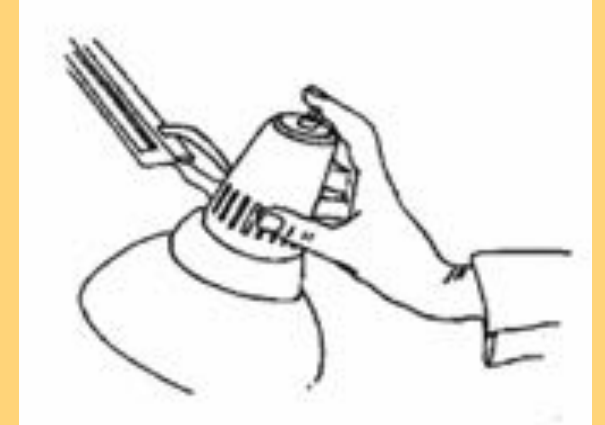
Ulnar Storage



Suture Storage



Stretching



Trigger

I-Limb Taxonomy



<https://www.youtube.com/watch?v=doWAtRT00T0>

I-Limb Taxonomy: 1 of 2

Precision Pinch Grip Options

Standard Precision Pinch (Opened)

middle, ring and little finger remain fully opened and switch off. Index finger and thumb provide grip



Standard Precision Pinch (Closed)

middle, ring and little finger automatically close and switch off. Index finger and thumb provide grip



Thumb Precision Pinch (Opened)

middle, ring and little finger remain fully opened and switch off. Thumb automatically moves to a partially closed position. Index finger will move to provide grip against a fixed thumb.



Thumb Precision Pinch (Closed)

middle, ring and little finger automatically close and switch off. Thumb automatically moves to a partially closed position. Index finger will move to provide grip against a fixed thumb.



Triped Grip Options

Standard 3 Jaw Chuck (Triped) (Opened)

ring and little finger remain fully opened and switch off. Thumb, index and middle fingers move to provide grip



Standard 3 Jaw Chuck (Triped) (Closed)

ring and little finger move to terminal close. Thumb, index and middle fingers move to provide grip



Thumb 3 Jaw Chuck (Triped) (Opened)

ring and little finger remain fully opened and switch off. Thumb automatically moves to a partially closed position. Index and middle fingers move to provide grip against a fixed thumb.



Thumb 3 Jaw Chuck (Triped) (Closed)

ring and little finger move to terminal close. Thumb automatically moves to a partially closed position. Index and middle fingers move to provide grip against a fixed thumb.



I-Limb Taxonomy: 2 of 2

Thumb Park Continuous

all four fingers remain open and switch off, only the thumb will move.



Thumb Park Quick

all four fingers remain open and switch off, for 1.5 seconds the thumb will close and then automatically return to an open position.



Grasp

hand forms a shape appropriate for grasping an object. Fingers flex rapidly when any user signal is applied



Cylindrical

hand forms a shape appropriate for grasping a cylinder



Lateral Grip

all four fingers fully close and switch off. only thumb will move.



Rotate Thumb

thumb and all four fingers fully open and switch off. Only thumb will rotate



One Finger Trigger

hand forms a shape appropriate for using a spray bottle with the index finger active



Trigger Two Finger

hand forms a shape appropriate for using a spray bottle with the index and middle finger active



Thumb Trigger

hand forms shape appropriate for using an aerosol spray can with thumb active



Index Point

thumb, little, ring and middle fingers close and switch off. Only the index finger will move.



Open Palm

hand forms a shape appropriate with holding plate or saucer



Mouse

hand forms shape appropriate for using a computer mouse



Handshake

hand forms a shape appropriate for shaking another persons hand



Custom Grip

all fingers automatically move to a user defined position. The user can choose to keep certain digits active and switch others off.



Custom Gesture





all fingers automatically move to a user defined fully opened or fully closed position and switch off.



Don Doff

hand forms the proper shape for donning and doffing a cover



Standard Precision Pinch Opened		Middle, ring and little fingers remain fully opened and switch off. Both index finger and thumb will move to provide grip.	Allows for a wider opening than thumb precision. Aids with visualization or for pinching objects where the non-active digits may get in the way.	<ol style="list-style-type: none"> 1. Returning cards or money to wallet 2. Picking up napkins 3. Folding laundry
Thumb Precision Pinch Opened		Middle, ring and little fingers remain fully opened and switch off. Thumb automatically moves to a partially closed position. Only index finger will move to provide grip against the fixed thumb.	Accuracy is improved when picking up an object by allowing you to place the thumb against the object to be pinched. Only the index finger moves to grasp the object. Ideal for repetitive tasks.	<ol style="list-style-type: none"> 1. Pick up pencil or slim, long objects 2. Thread needle 3. Sort/Pick up medications
Lateral Grip		All four fingers fully close and switch off. Only thumb will move.	Holding onto plate, papers, CD or other flat objects. Improved stability with use of the side of the index finger.	<ol style="list-style-type: none"> 1. Hold plate while serving food 2. Hold clipboard 3. Get card from ATM 5. Open ziplock bag 6. Tie Shoe Laces
Thumb Park Continuous		All four fingers remain fully open and switch off. Only the thumb will move.	For longer dressing period that will require more than the 1.5 seconds of thumb park quick or grasping light weight flat objects. Can also use stalling out digits to complete, putting pressure against index to little and closing thumb in to hand.	<ol style="list-style-type: none"> 1. Put on jacket 2. Grasp flat objects, such as a book or a tablet computer or clipboard 3. Allows readjustment of the object opening letters or sorting paperwork.

One Object, One Task, 17 Subjects



Lateral



Precision Disk



Palmar Pinch



**Parallel Extension
Variation?**



**Ventral
Variation?**



**Palmar Pinch
Variation?**



**Palmar Pinch
Variation?**



**Bimanual
Lateral**



**Bimanual Parallel
Extension?**



**Bimanual
Cupping**



**Bimanual
Ring**

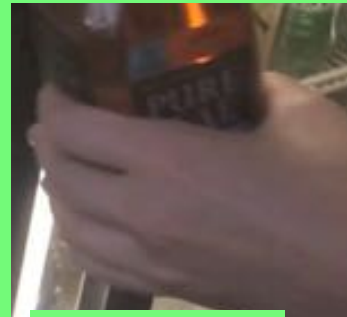
3 Minutes of Shopping, One Subject



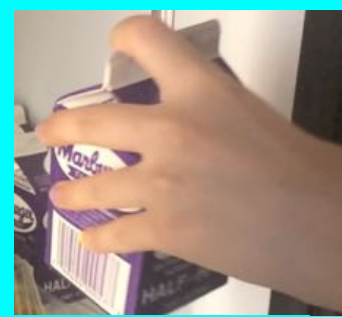
Power Sphere 3



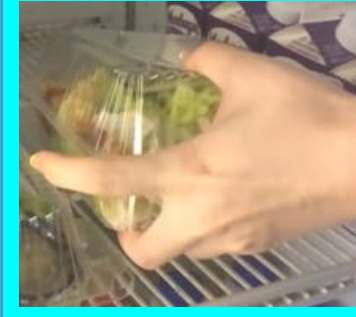
Small Diameter Heavy Wrap 1



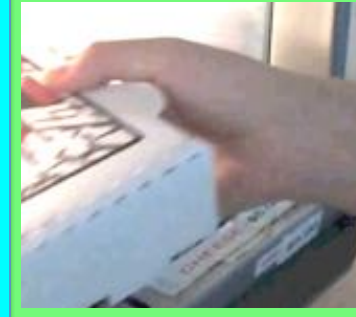
Large Diameter Heavy Wrap 8



Large Diameter Heavy Wrap / Index Top 3



Power Parallel with Index Side 2



Power Parallel 1



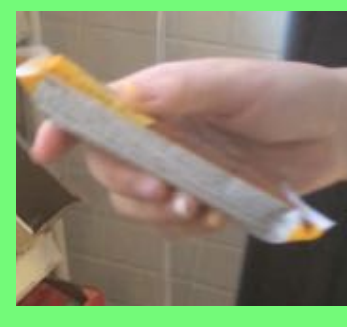
Power Grip Distal Type 1



Multi-Item 3



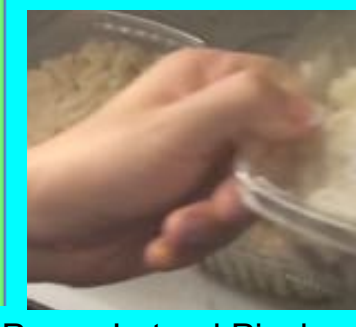
Power Medium Wrap 1



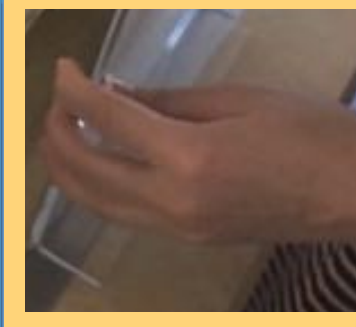
Power Grip Extension Type 3



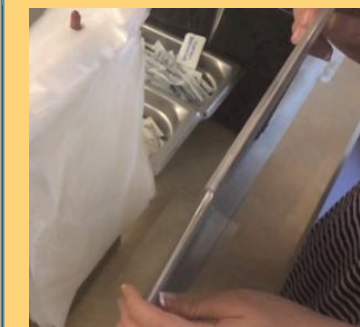
Power Lateral Pinch 3



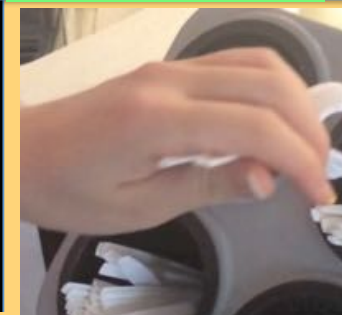
Power Lateral Pinch Torque Supported 2



Power Non-Prehensile 1



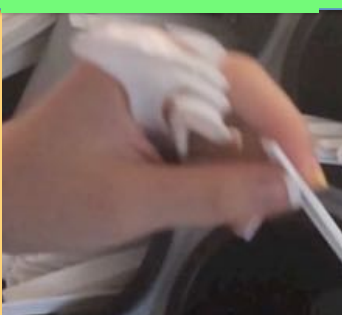
Two-Hand 1



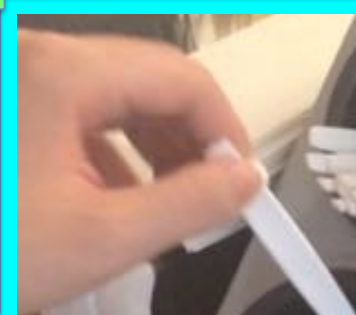
Thumb Proximal Phalanges Pinch 4



Ulnar 7



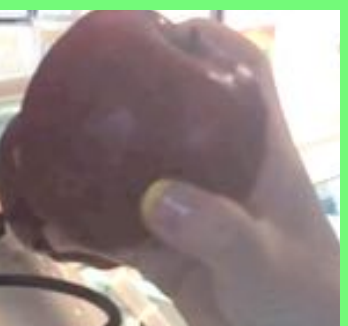
Ulnar Plus Pinch 3



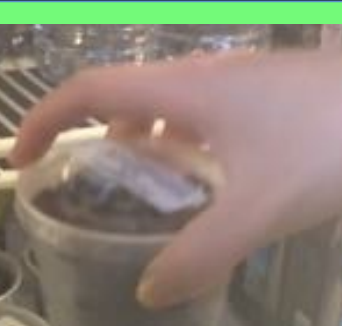
Thumb Index Pad Pinch 8



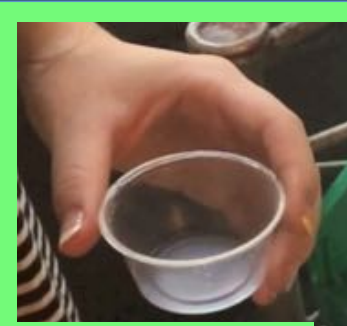
Power Lateral Pinch, Middle 3



Precision Sphere 1



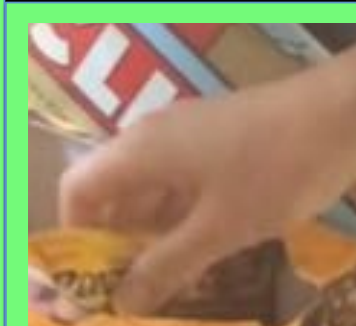
Precision Disk 4



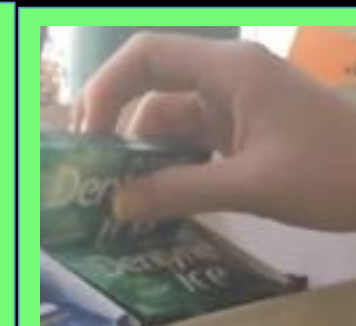
Precision Thumb 2-Finger 1



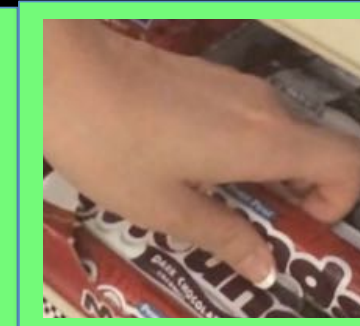
Precision Tripod 2



Precision Thumb 4-Finger 4

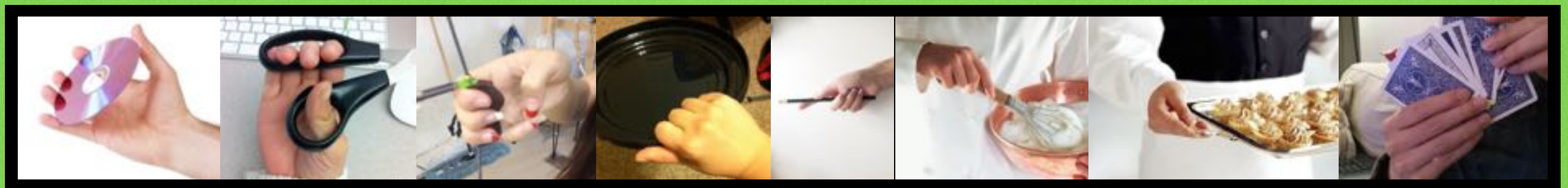
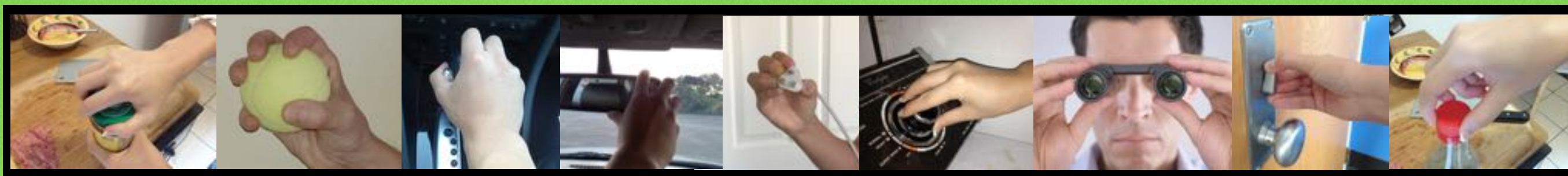
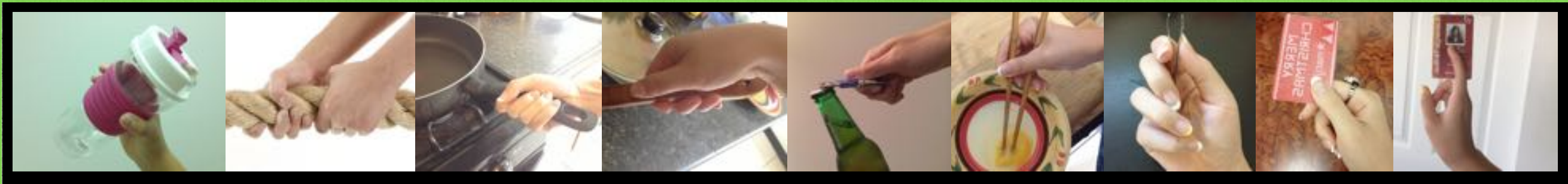


Precision Thumb 3-Finger 3

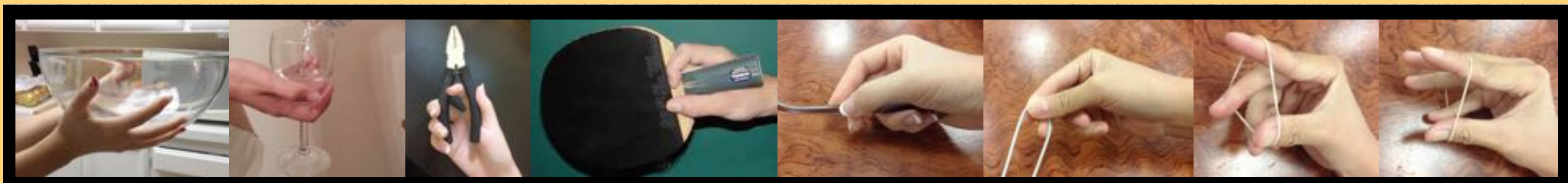
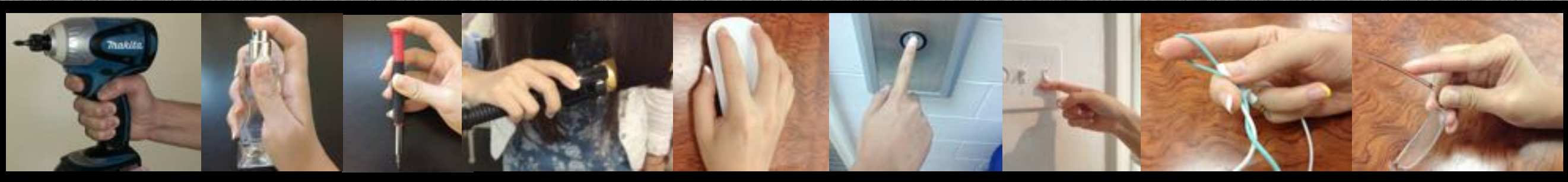
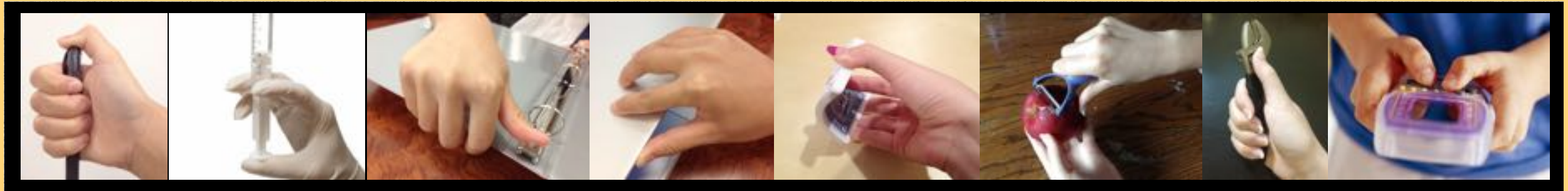


Precision Thumb Index Finger 1

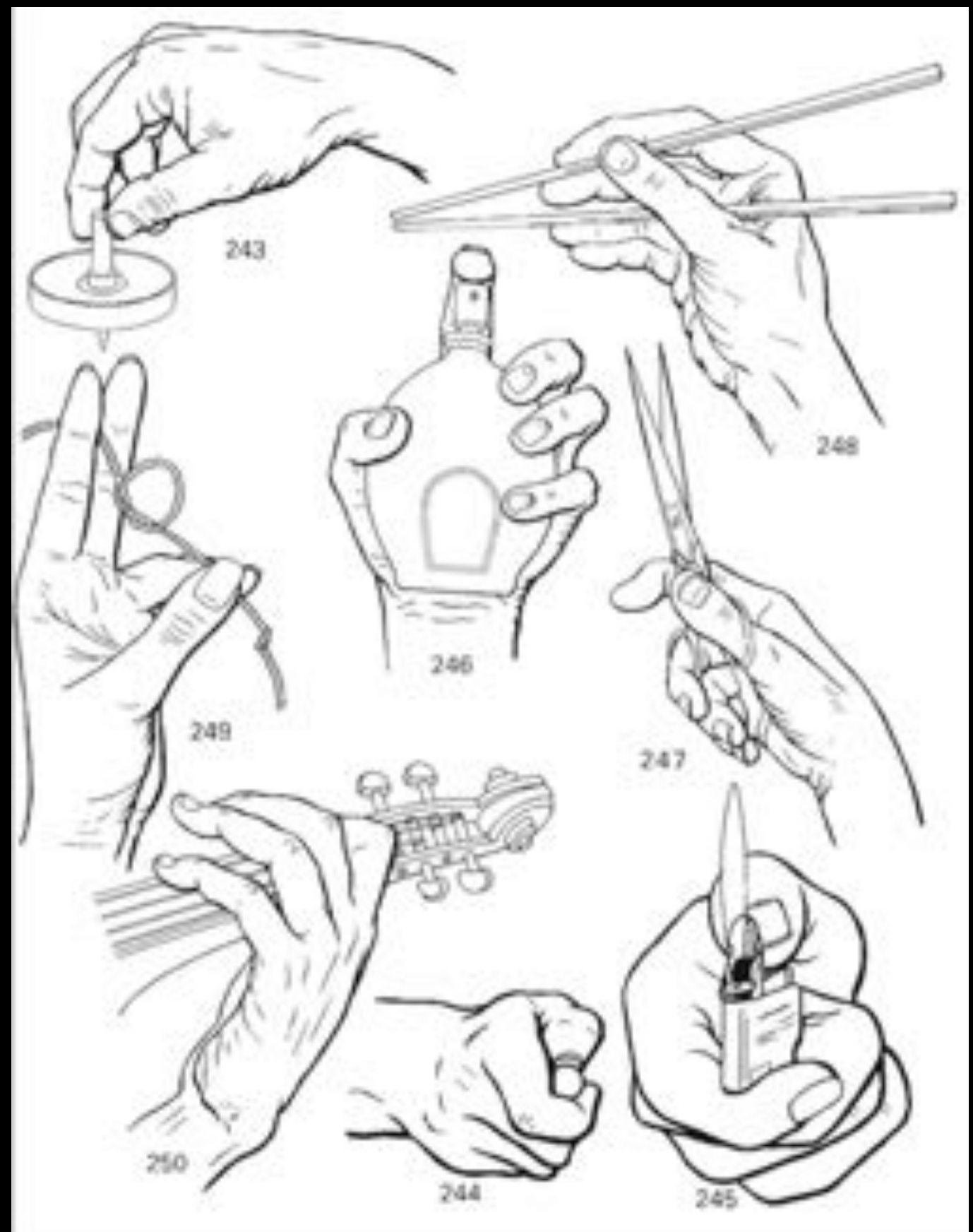
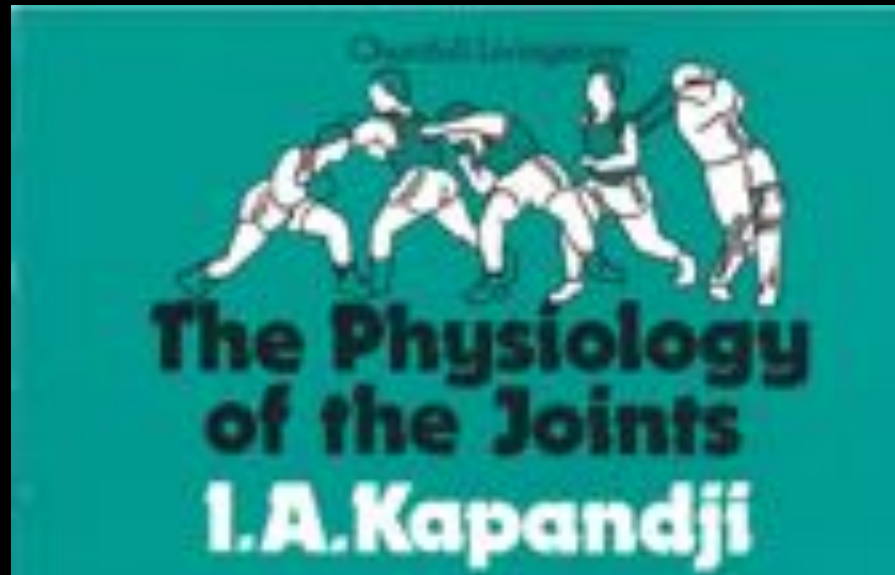
1 Day, Two Subjects, Grasps from Feix et al.



1 Day, Two Subjects, “Grasps” NOT in Feix et al.



Grasps in Action: Two Pages from Kapandji



Let's start with hand shape

Hand shape is not enough

Motion, Force, and Stiffness

Lateral (Pinch) Grasp

Example		
Force Type	Pull	Pull
Motion Dir	-x (hand)	xz plane (hand)
Force Dir	-	-
Flow	Bound Motion/ Bound Force	Half Bound Motion/ Bound Force
Annotation	Put on gloves(along the arm)	Drag toilet paper
Example		
Force Type	Twist	Twist
Motion Dir	around y axis (hand)	around x axis (hand)
Force Dir	-	-
Flow	Bound Motion	Bound Motion
Annotation	Twist the key to start up the car	Twist the knob in car

Example		
Force Type	Hold	Rub/Stroke
Motion Dir	xy plane (hand)	xy plane (hand)
Force Dir	-	inwards (hand)
Flow	Free Motion/ Half Bound Force	Half Bound Motion/ Bound Force
Annotation	Give card to someone	Wipe classes
Example		
Force Type	Hold	Hold
Motion Dir	z (global)/ -z (global)/ around x axis (hand)	around x axis (hand)
Force Dir	-	-
Flow	Free Motion/ Bound Force	Half Bound Motion/ Bound Force
Annotation	Eat with scoop	Pour washing powder

J. Liu, F. Feng, Y. Nakamura, and N. S. Pollard, 2014. A Taxonomy of Everyday Grasps in Action, IEEE International Conference on Humanoid Robots (Humanoids 2014), Madrid, Spain, November 2014.

<http://www.cs.cmu.edu/~jialiu1/database.html>

People prefer expressing forces as verbs

20 Verbs for 173 Observed Grasps

Force Type	Definition	Frequency
Break off	Remove a part of an object	3
Extend	Apply outward forces from within the object	3
Grab	Hold or secure without opposing gravity	32
Hold	Grasp object in a way that resists gravity	41
Lever	Pivot one end of an object around a fixed end	4
Lift	Apply upward force greater than gravity	7
Place	Put something in a specified position	1
Press	Exert force in a direction away from the shoulder	31
Pull	Exert force in a direction towards the shoulder	18
Punch	Press or push with a short, quick movement	1
Put in	Insert one object into another	4
Roll	Cause rotation without prehension	3
Rub/Stroke	Move back and forth while pressing	9
Scratch	Rub with something sharp or rough (with the hand directly or a tool)	2
Squeeze	Apply compressive force around object greater than needed to hold object	4
Take out	Remove one object from another	2
Throw	Propel an object through the air	3
Turn	Flip or rifle through pages	1
Twist	Cause rotation with prehension	13
Swing	Move with a smooth, curving motion like hand waving or arm swinging	6

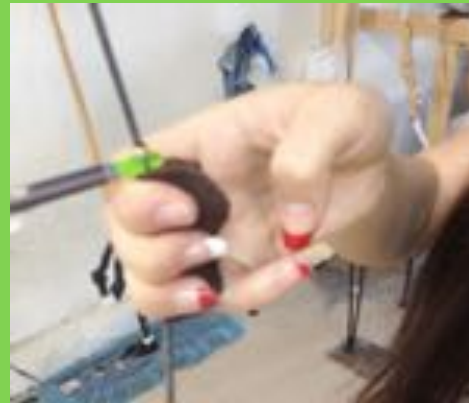
Twist



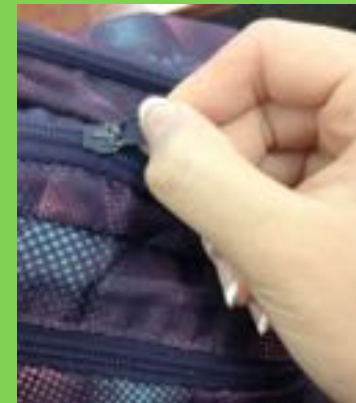
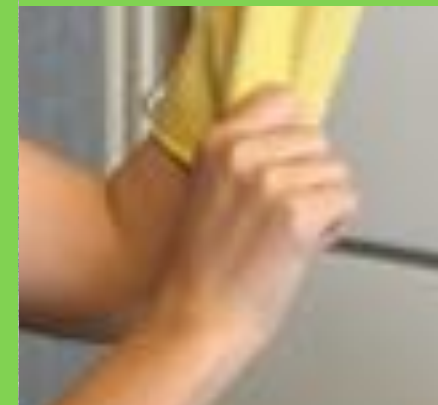
Twist



Pull



Pull



Adjust	Delicately changing the position of an item in other hand (usually an item held in loose grip during this), using pinch-grip, knuckle-push, or movements of a single finger or the lips. M/W.	Pick	Pinch-grip on clearly defined object which is pulled against force of natural attachment, usually to procure the item.	Side-adjust	Re-locate a firm grip on a different portion of an item by sliding the hand, while supported with mouth, other hand, or both. M/W.	Tuck-fold	Base of leaf-bunch held by one hand, while the other hand uses digits 1, 4 and 5 to tuck in leaf-blades at the sides, before digits 2 and 3 fold over the top leaves. By definition, the hand holding the bunch is swapped over. R.
Bite-off	Use tooth to cut off portion of naturally attached or hand-supported object, either with single bite or repeated biting. (M)	Pick-at	Single digit used to damage or loosen item, e.g. to allow peel to begin. (M)	Swap-apart	Break object to break it- although not necessarily to fully detach it- supported by both hands on either side of the break. R.	Twist-apart	Object (usually leaves) held in both hands, then twisting of each hand versus the other is used to tear the object. R.
Brush-off	Using the side of a digit or digits (e.g. 1 and 2 held in "C" shape) to gently brush along stem, midrib or bundle held in hand in order to dislodge debris. R.	Pick-off	Pinch-grip or lip-grip on small item which is pulled off an object held in other hand. M/W.	Swap-off	Holding a naturally attached object in one hand and bending, then applying force to detach item. M.	Twist-fold	A special case of leaf-fold where the leaf-blades are twisted before being folded over. R.
Combine	Carrying out separate functions with fingers 1-2 and 3-5 at same time (in various functions), e.g. pinch-grip with 1-2 to pick while loose-grip of 3-5 in order to accumulate already picked items.	Pick-out	Pinch-grip or lip-grip on small item which is taken out from among a mass of items, requiring discrimination of one item from among many (such as in cleaning a food handful). M/W.	Scalp-case	Use incisor teeth to clip off outer casing (in action like that of grasscut) in order to discard the casing and expose edible part. Used typically for removing <i>Peucedanum linderi</i> casing, only occasionally for thistle. M.	Twist-in	Handful twisted as it is fed into mouth, in the case of leaves having the effect of keeping the bundle compact. M.
Crossed hands	Both hands hold flat and palm up, crossed at right angles to support greater force e.g. during scrape-off. R.	Pick-up Pinch-grip	Pinch-grip on object to lift from flat surface. First precision grip, varying in whether tip-to-tip (1-2 or 1-other) or tip-to-side (1-2 normally), usually either for support or procurement, as if holding in palm.	Spaghetti-feed	With stem held in mouth without use of the hands, lips used to feed in rest of its length - similar to eating spaghetti.		
Dig	Using fingers held flat as blade or curved, to excavate in soft earth or litter (often to get access to roots). Used typically for getting over epibothrium, e.g. of <i>Sonchis oleraceus</i> or <i>Lobelia wolkeana</i> .	Power-grip	Potentially strong, closed-hand grip (varying as to whether whole hand or 1+ fingers only, see Marks and Wulfsberg 1987); includes using both hands with thumbs pointing same way) on cylindrical object (often stem) for support or for procurement, or on a bundle while accumulating items.	Squeeze-grip (power)	Potentially strong, closed power grip of one hand on cylindrical object with thumb along the object as support. Used routinely in processing <i>Peucedanum linderi</i> .		
Flat hand	Hand held flat and palm up to support plant material e.g. during scrape-off.	Pull-apart	Holding an object in the two hands, the hands then pulling apart in a movement at a tangent to body, thus applying force to object to pull it apart. R.	Squeeze-up	Gather together a bundle of items so that they are finally held in some sort of power grip in one hand (often loose-grip becoming power-grip), using closure of first one hand for compression of loose bundle, then the other, afterwards.		
Hook	Whole hand or only certain fingers or both hands, held rather rigidly in open curve, to pull attached object (often used to leave down mass of vegetation).	Pull-off	Holding a naturally attached object with one hand and pulling, thus applying force to detach item, effect as yank.	Stem-fold	usually. Used typically by immature animals, especially with <i>Laportea alata</i> leaves. R.		
Knock-off	The knuckle of one or more digits, used with a flick of the wrist, to knock off an item (e.g. flower heads) from bundle held in hand. R.	Reach	Various sorts of grip, with one or both hands or fingers or pinch-grip, on attached object which is pulled to bring into range. (R)	Strip-down	Half-open grip (often constricted at 5 palm, but not always) around leafy stem or middle of leaf, slid down stem to detach leaves or side-shoots, sometimes supported by other hand (thus removing unwanted items during stem processing). (R).		
Knuckle-push	Flat held as in knuckle-walking to apply force to object supported by other hand. R.	Rotate-careless	Using the remainder of the last handled item (often off from those remains with a shear-line) as a basis for starting to accumulate the next (implies unstable).	Strip-out	The exposed section of stem or middle of large leaf is held in one hand and then pulled, often to the mouth, thus stripping the case away and exposing lower section of object. R.		
Knuckles	Knuckles held against object, allowing other hand to procure an item. R.			Strip-up (-over)	Half-open grip (often constricted at 1-2, but not always) around leafy stem or middle of leaf, slid up stem with thumb apparent to detach bunch of leaves, against force of substrate or other hand's supporting grip (thus accumulating leaves, the bunch protruding between 1-2). Occasionally hand reversed so that thumb away from direction of motion (-over) (R).		
Lever	Knuckles held against object, allowing other hand to procure an item. R.	Roll	While holding a loose or loosely bundle, roll against flat support (e.g. of chin or hand palm) to produce roll shape. Used typically for rolling up <i>Gallium verum</i> stems/bundles.	Swap-hand	Transfer object or handful from one hand to the other. R.		
Leaf-fold	A special case of adjust, using finger or lips to pull out leaf blades from the grip of other hand, then folded over (sometimes using thumb as fulcrum) and gripped again. Used typically for <i>Laportea alata</i> leaves, only occasionally with thistle. M/W.	Rotate	Turn or twist a long object held in strong, closed-hand grip to bring into range or into more convenient position within other hand to allow processing. R	Teeth-pick	Pinch-grip or single digit (usually 2) used to remove debris from mouth, either after mouthful has been swallowed and debris lodged between teeth, or from mouthful of food containing unwanted item. M.		
Lever-apart	Object (usually leaves) held in both hands using strong, closed-hand grip, then leverage of rocking the hands or knuckles against each other, used to tear the object. R.	Rotate-adjust	Rotate item by adjusting position in hand, whilst item is supported with mouth or other hand. M/W.	Teeth-pull	Pull with object held in tooth, against leverage of teeth. Typically used to pull up underground shoots of <i>Arenaria alpina</i> , only occasionally used with thistle. M.		
Lift-up	Power-grip on object to lift from flat surface.	Rotate-push	Turn or twist long object held in strong, closed-hand grip and pushed to break, while supported by other hand or by substrate. (R)	Teeth-strip	Partial closure of incisors around root or stem, pulling against support of hand(s), an action like that of wire-strippers. Typically used for stripping off root epibothrium e.g. of <i>Sonchis oleraceus</i> or <i>Lobelia wolkeana</i> . M.		
Lip-grip	Delicate grip with corner of lips, e.g. when removing debris from bundle.	Savage-feed	Repeated loosening of the grip and re-grasping lower down an approximately sausage-shaped food bundle, in order to feed it into the mouth as a whole, without the bundle coming apart.	Teeth-twist	Holding object in mouth and hand with strong, closed-hand grip (sometimes with other hand duplicating action of upper hand), using a twisting of hand and head to tear the object. Typically used for getting <i>Arenaria alpina</i> shoots from the ground. M.		
Loose-grip	Loose, part-open whole hand grip, usually applied to detached objects to allow delicate processing with hand or mouth (e.g. pick-out to clean, or leaf-fold) or to accumulate leaves or stems.	Scrape-off	Incisor teeth scrape with layer off harder backing while object supported with flat hand or crossed hands, movement up or down. M (and R).	Twist-grip	Grip with teeth to allow processing with hands, usually to detach item, or adjust bundle. M.		
Manipulate	Rearranging the position or shape of item(s) held in one hand, simply using the fingers and without using other hand.	Shear-bite	Shearing bites used to detach a slice of a large, compact handful of items, either singly to finish eating a handful (when remains discarded unless again included) or repeated in order to eat the entire handful. M.				
Mouth-grip	Grip using mouth (not usually possible to be sure whether or not tooth-grip), to allow processing with hands, usually to detach item, or adjust bundle.	Slide-off	Moving wrist, with finger(s), or half-open grip, or simply closed fist, to detach unwanted items, against force of substrate or support of other hand e.g. to clean leaves off thistle stem. (R).				
Mouth-peel	Use of lips or teeth to pull off covering while other hand supports the item. M.						
Peel (-back)	One hand (usually with precision grip, e.g. pinch-grip) used to pull off covering, while other hand supports. Often done with a twisting-back action (-back). R.						
Pinch-grip	Closed-hand grip of one hand on cylindrical object (usually stems) but with object caught between pair of fingers and resting on thumb (2-3 or 3-4 or 4-5), usually for support. Presumed to be an accidental variant of power-grip.						

Byrne, Richard W., and Jennifer M. Byrne. "Manual dexterity in the gorilla: bimanual and digit role differentiation in a natural task." *Animal Cognition* 4, no. 3-4 (2001): 347-361.

Let's start with hand shape

Hand shape is not enough

Intrinsic hand motions

A CLASSIFICATION OF MANIPULATIVE HAND MOVEMENTS

J. M. Elliott
K. J. Connolly

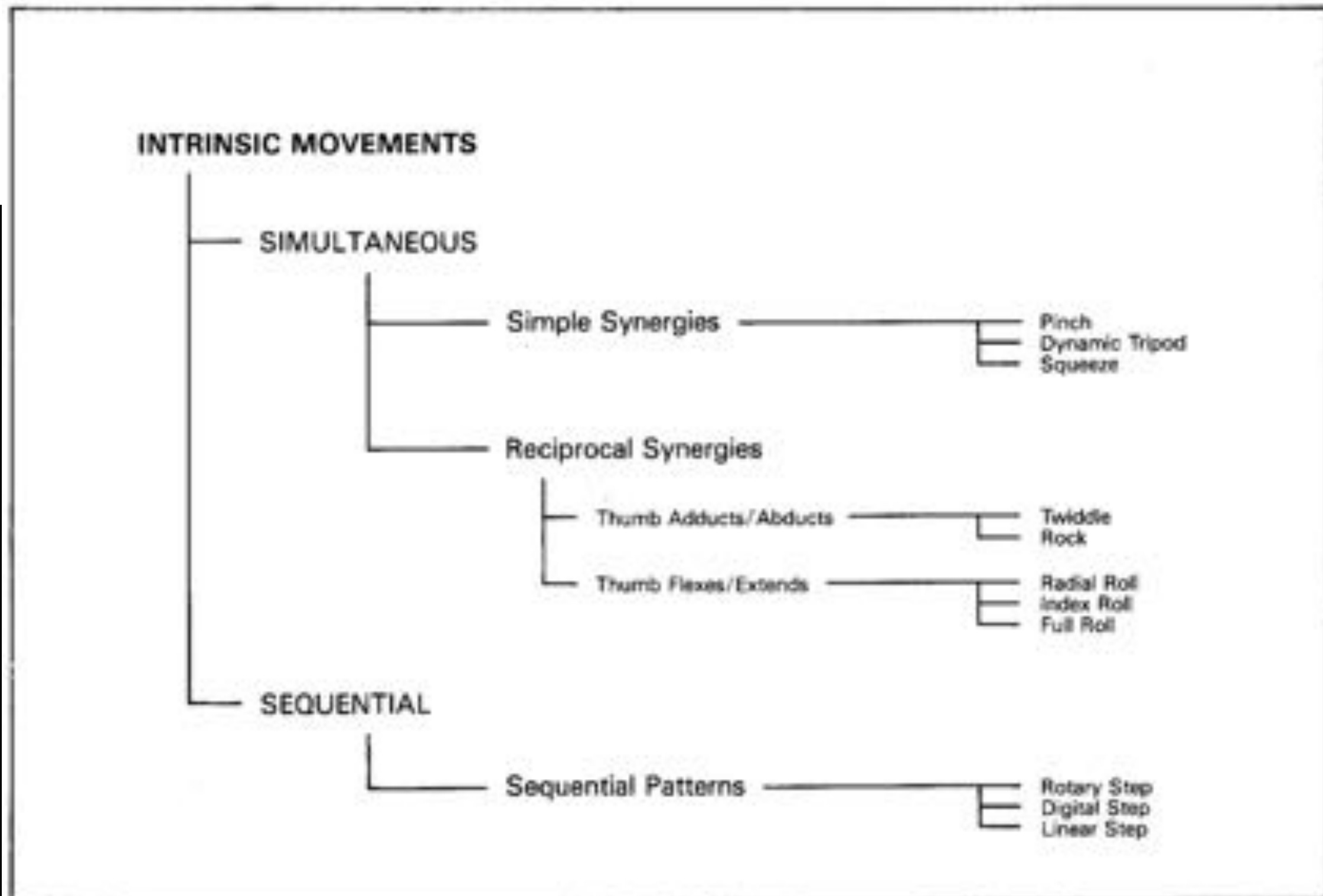
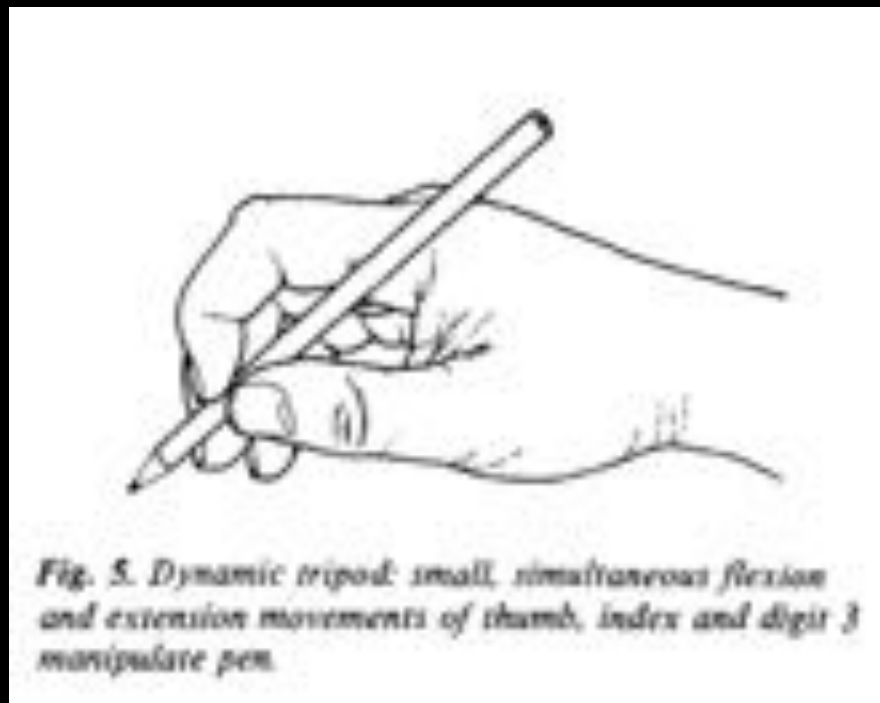
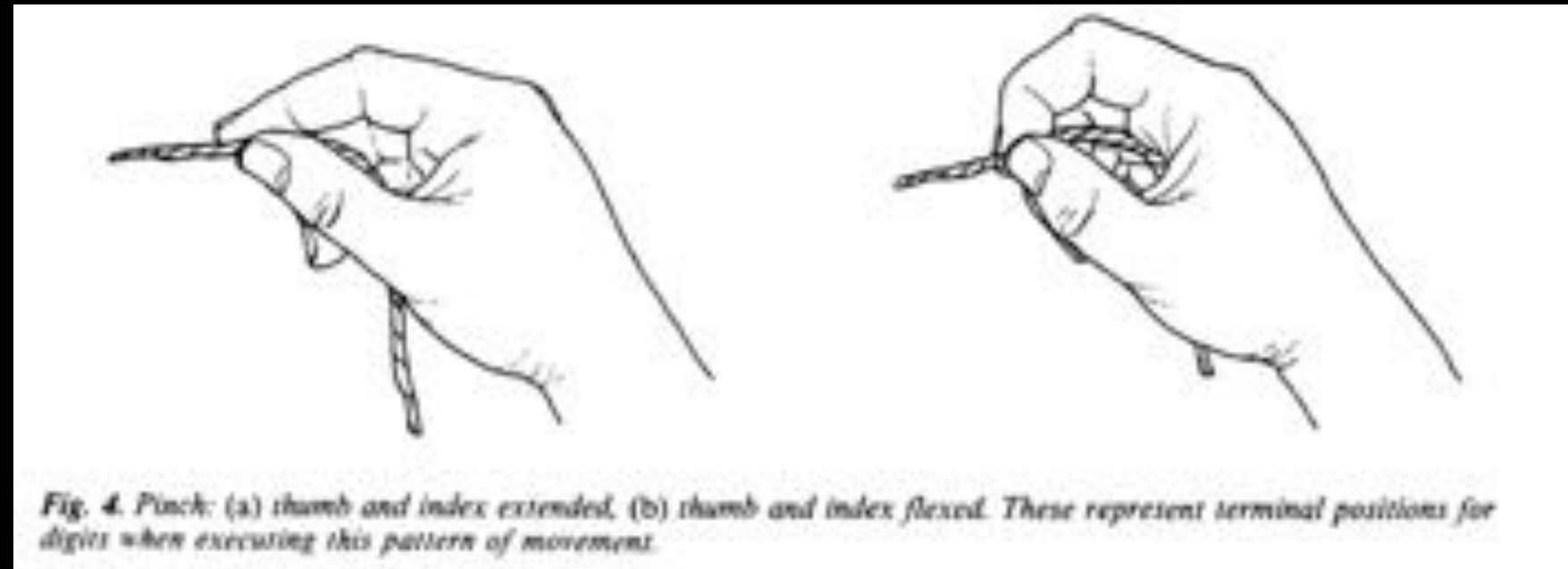


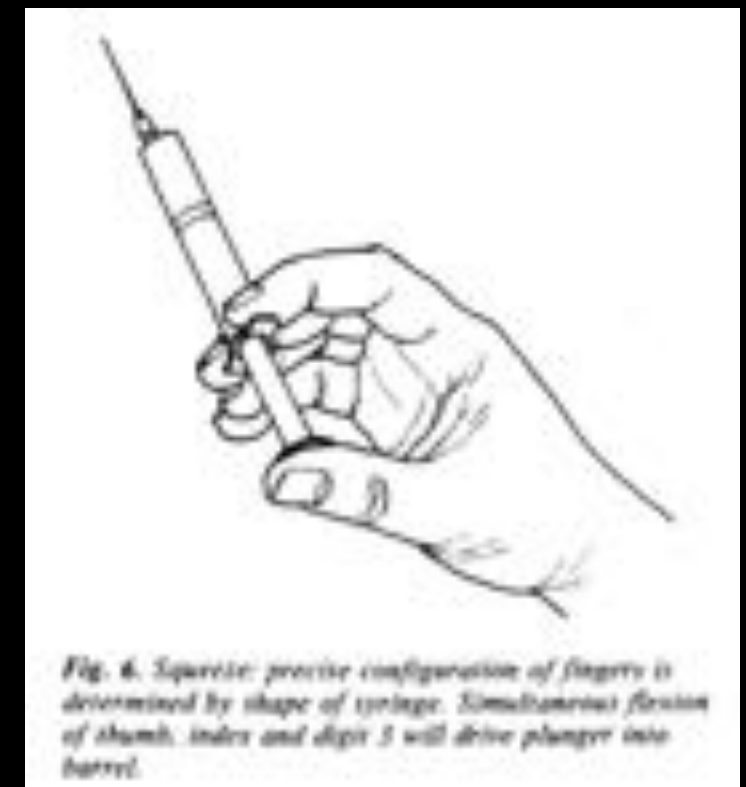
Fig. 1. Classification of intrinsic hand movements.

Simple Synergies

Pinch



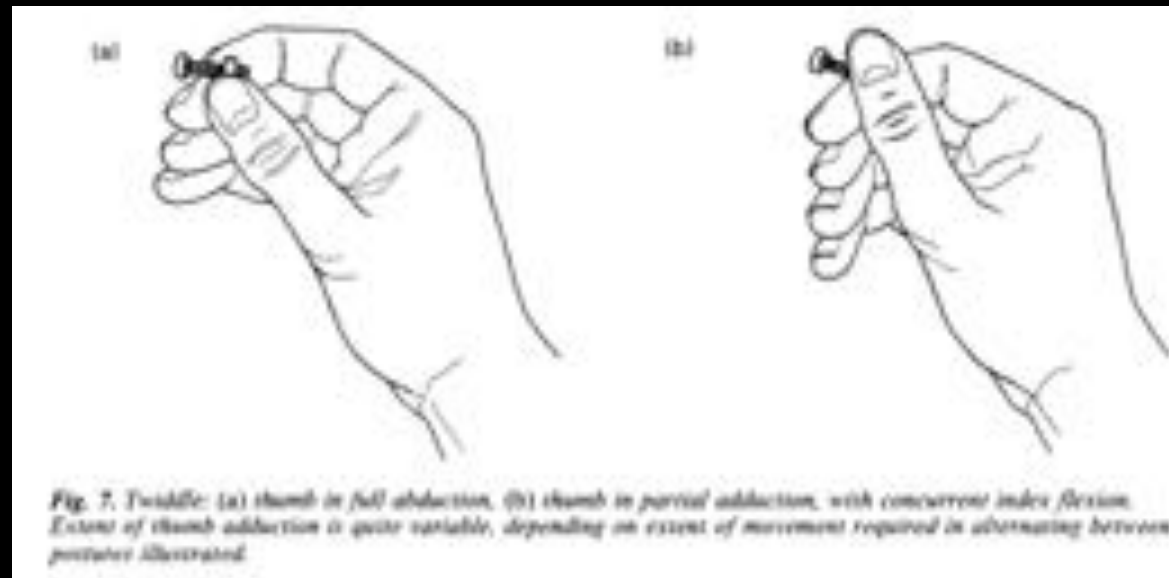
Dynamic Tripod



Squeeze

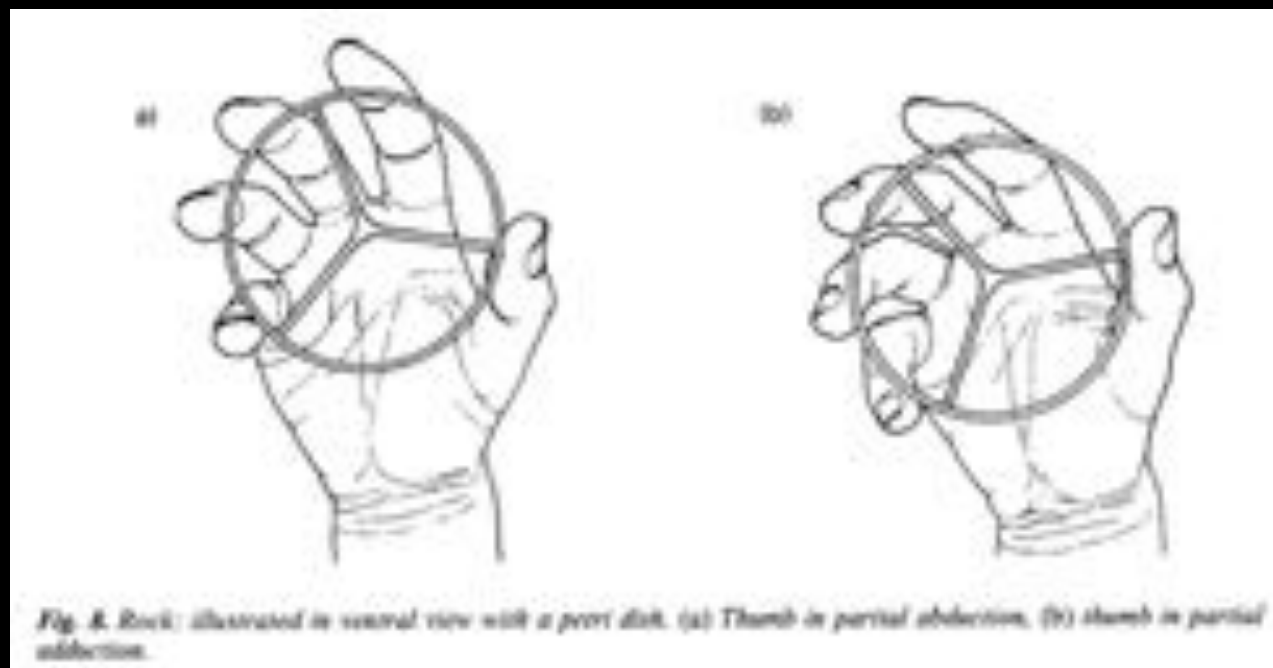
Reciprocal Synergies

Thumb Abducts/Adducts

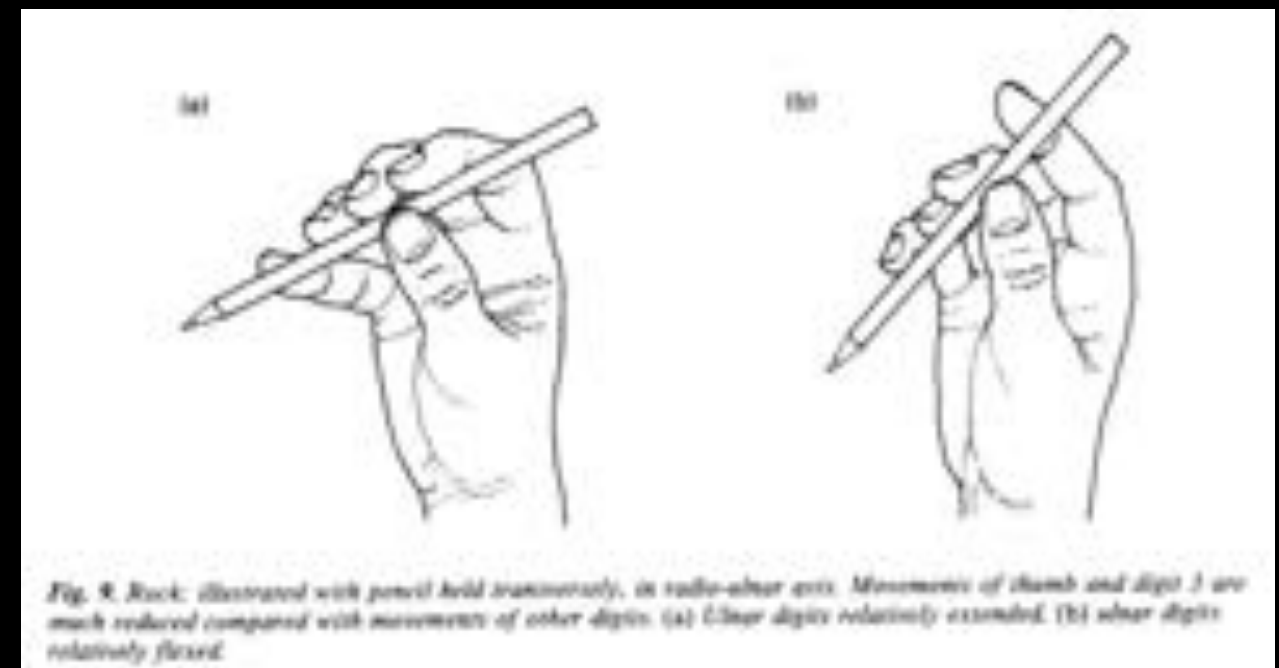


Twiddle

Rock



Rock



Reciprocal Synergies

Thumb Flexes/Extends

Radial Roll



Fig. 18. Radial Roll. In this example the thumb is adducted throughout; in other instances it may be partially abducted, consequently operating radial index more distally. (a) Index less flexed, (b) index more flexed.

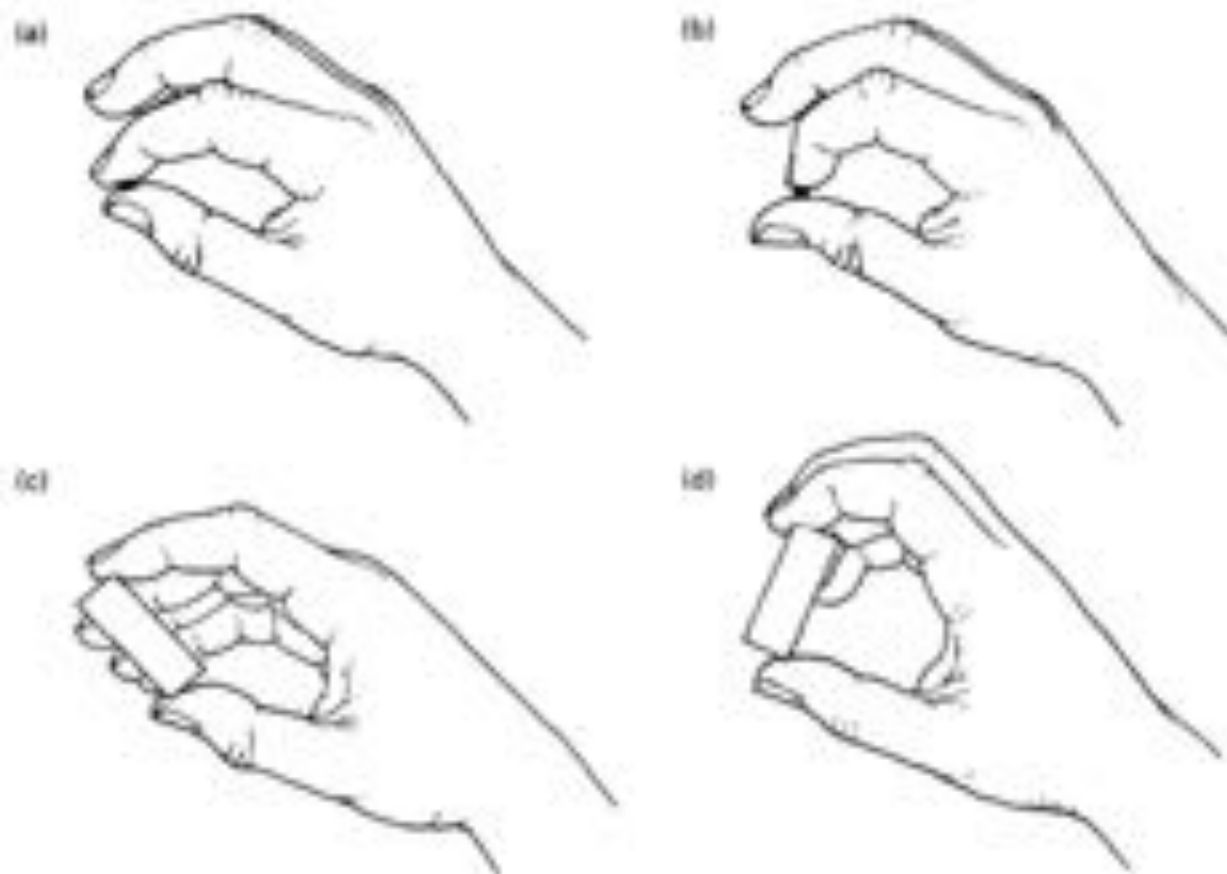


Fig. 17. Index Roll (a,b), showing slight reciprocal flexion of thumb and extension of index (a), and the reverse (b). Full roll (c,d), as for index roll, but with involvement of additional digits. The object rocks about the radial-ulnar axis as result of movement between positions illustrated.

Index Roll

Full Roll

Sequential Patterns

Rotary Step

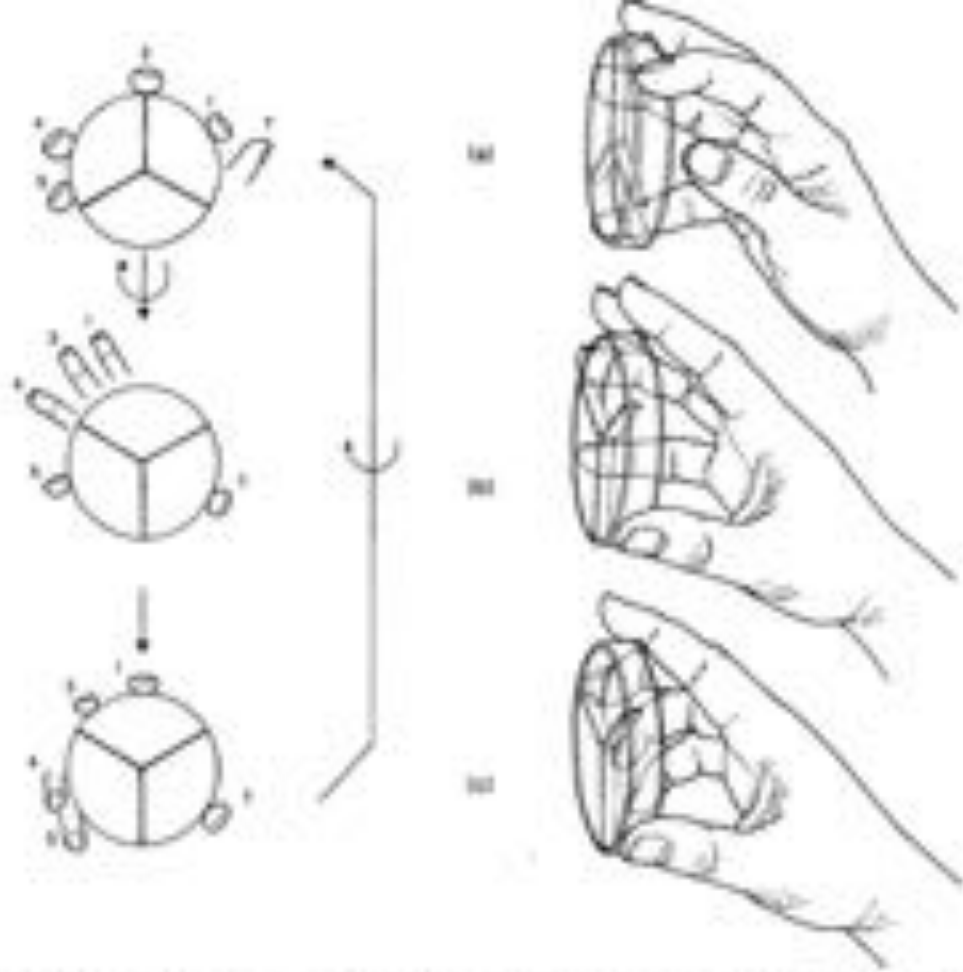


Fig. 12. Rotary Step. A schematic representation of positions in which the digits are placed (left), and successive positions of the hand (right). Sequence (a-b-c-a) shows successive phases in clockwise rotation involving approximately 120° of object rotation. This occurs between transitions a-b and c-a, as indicated by the rotary arrow.

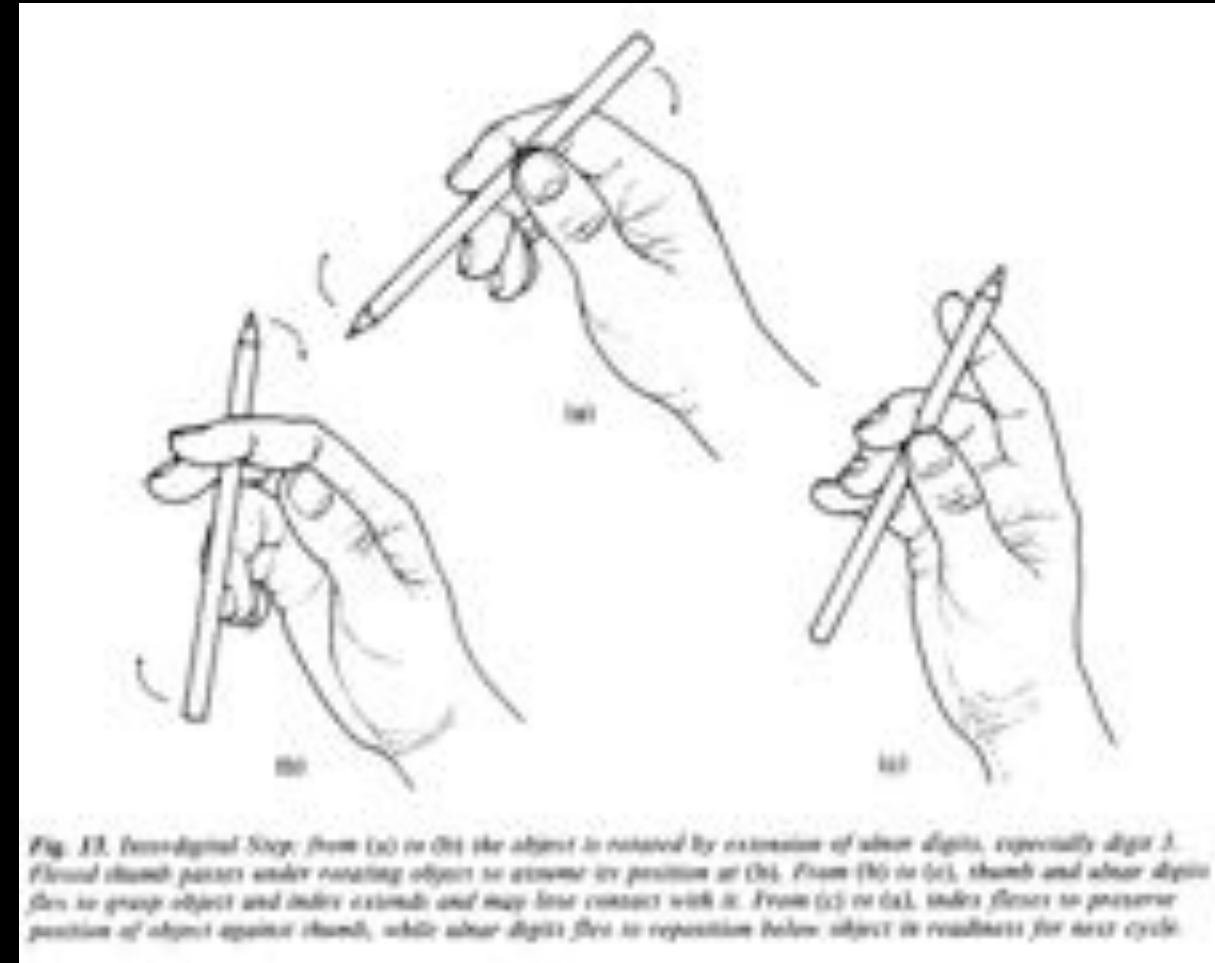


Fig. 13. Interdigital Step: from (a) to (b) the object is rotated by extension of ulnar digits, especially digit 3. Flexed thumb passes under rotating object to assume its position at (b). From (b) to (c), thumb and ulnar digits flex to grasp object and index extends and may lose contact with it. From (c) to (d), index flexes to preserve position of object against thumb, while ulnar digits flex to reposition below object in readiness for next cycle.

Digital Step

Linear Step

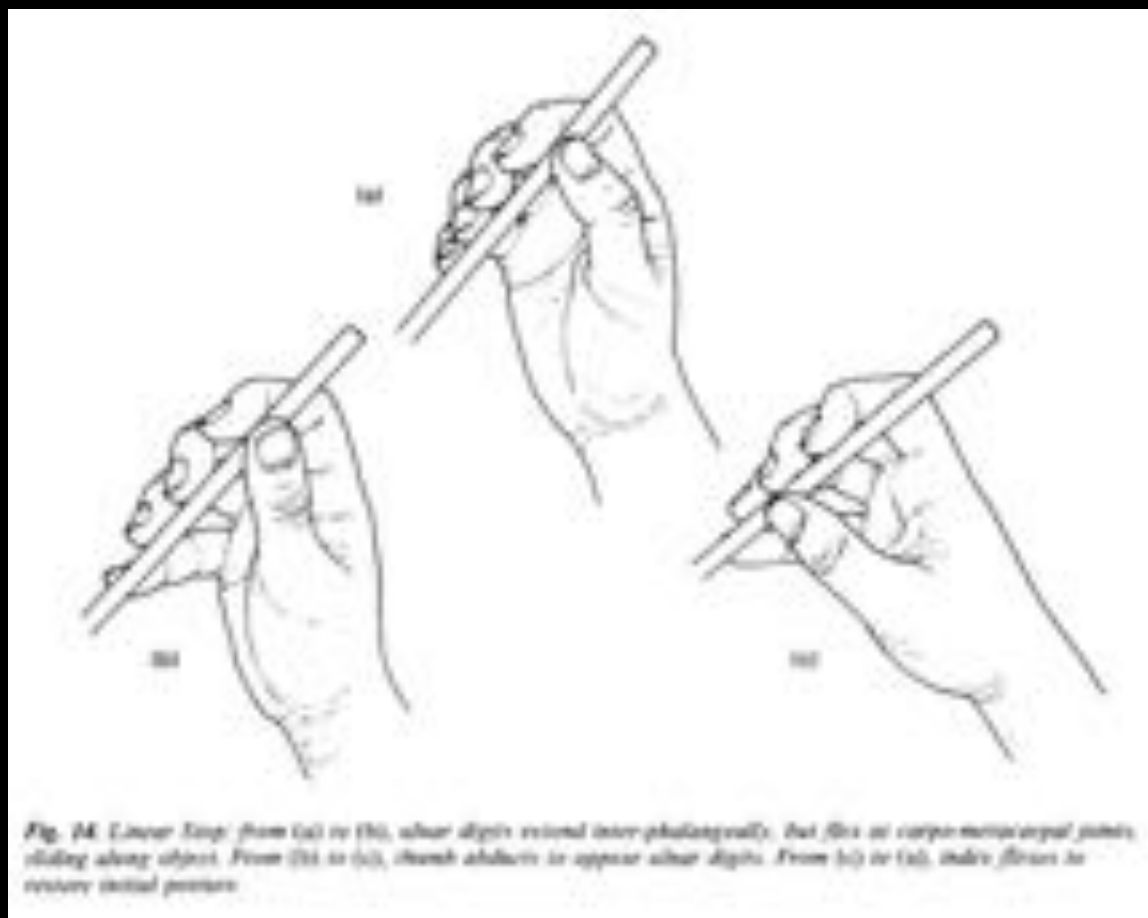


Fig. 14. Linear Step: from (a) to (b), ulnar digits extend inter-phalangeally, but flex at carpometacarpal joints, sliding along object. From (b) to (c), thumb abducts to appear ulnar digits. From (c) to (d), index flexes to restore initial position.

Not Classified

Palmar Slide

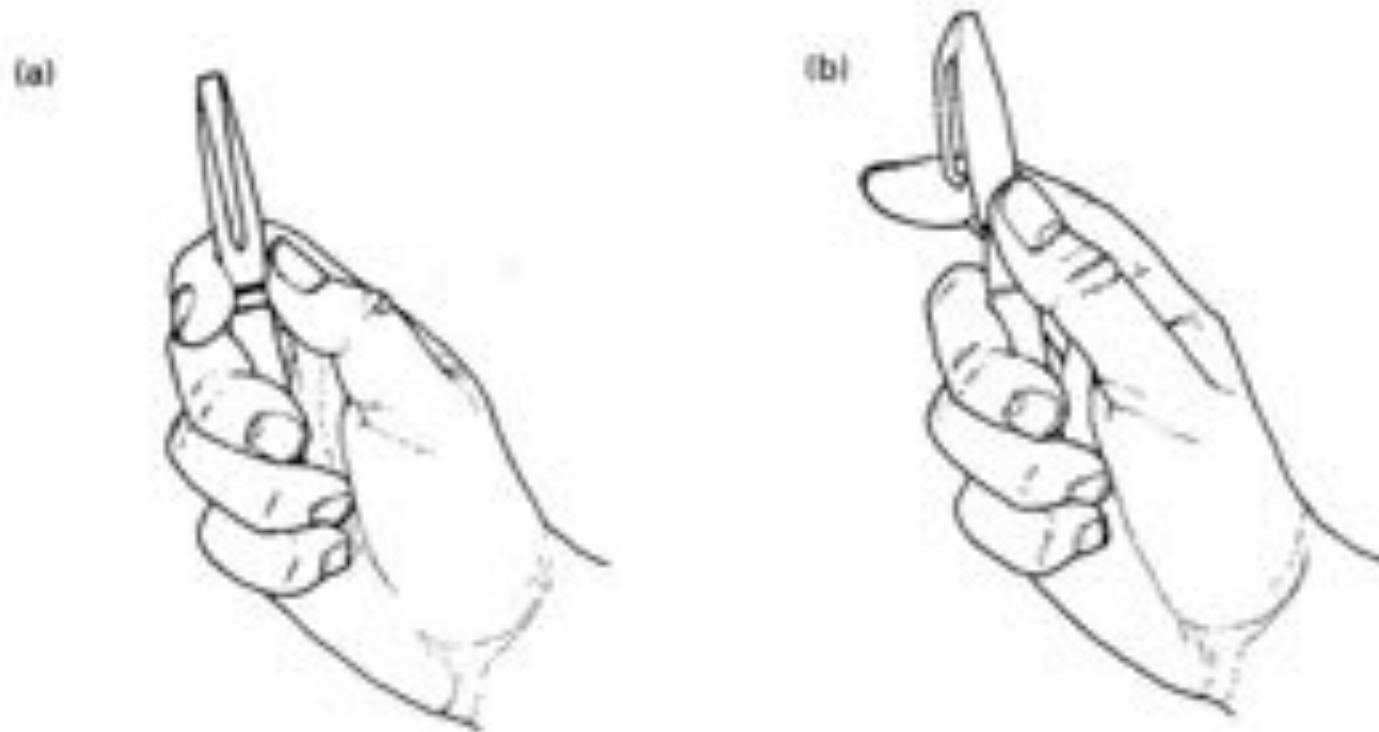


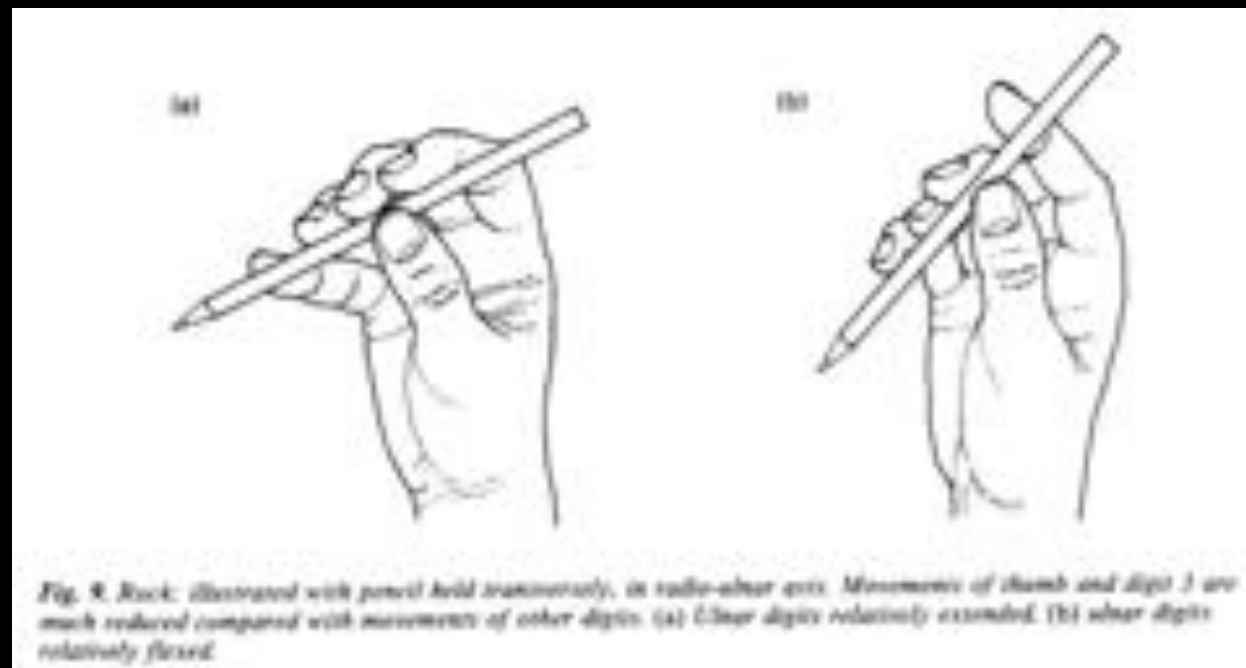
Fig. 15. Palmar Slide: the movement, illustrated in change from (a) to (b), involves extension of thumb and radial deviation of index, with some extension.

Transitions



**6. Prismatic
4-finger**

Rock



29. Stick



**6. Prismatic
4-finger**



32. Ventral

Transitions



9. Palmar

Pinch



Fig. 4. Pinch: (a) thumb and index extended, (b) thumb and index flexed. These represent terminal positions for digits when executing this pattern of movement.



24. Tip Pinch

Transitions



**20. Writing
Tripod**



**23. Adduction
Grip**

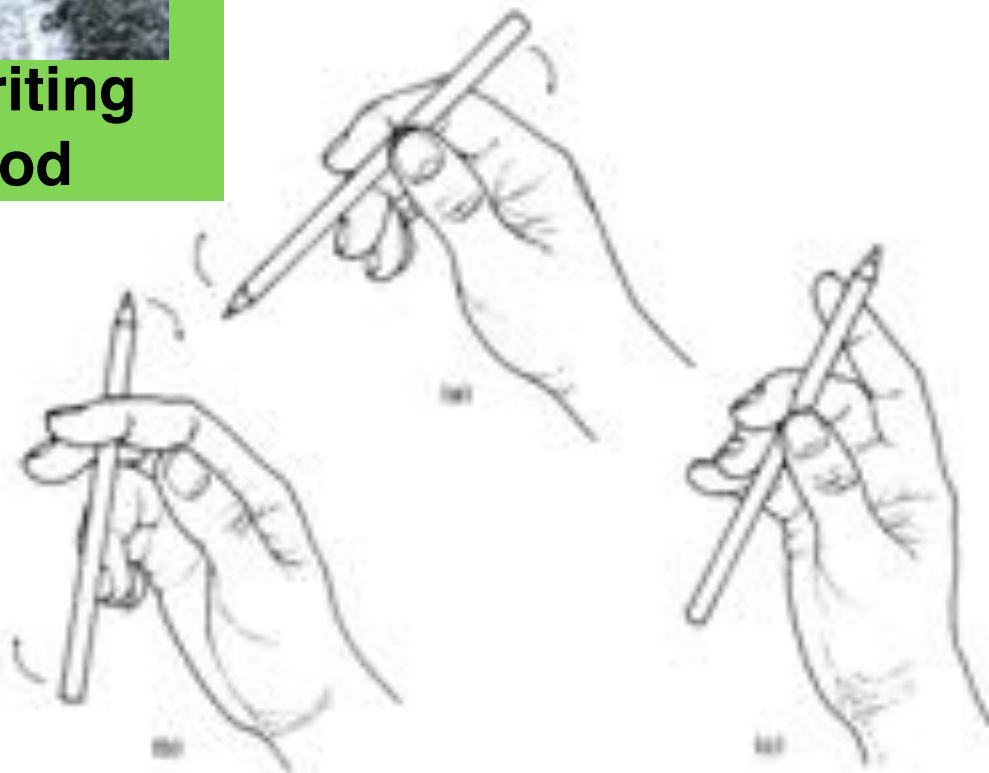


Fig. 13. Digital Step: from (a) to (b) the object is rotated by extension of ulnar digits, especially digit 3. Around thumb passes under rotating object to assume its position at (b). From (b) to (c), thumb and ulnar digits flex to grasp object and index extends and may lose contact with it. From (c) to (d), index flexes to preserve contact of object against thumb, while ulnar digits flex to reposition below object in readiness for next cycle.

Digital Step



32. Ventral



**6. Prismatic
4-finger**

Power Palm



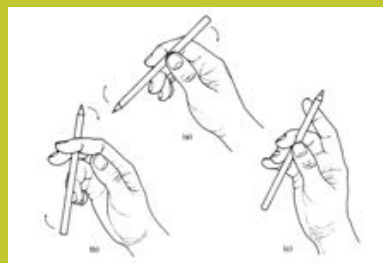
Palmar Gutter



Power Pad



Transitions



Power Lateral



Precision Pad



Precision Lateral

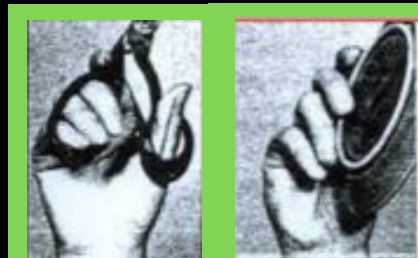


Grasp Network

Power Palm



Palmar Gutter



Power Pad



Transitions



Power Lateral



Precision Pad

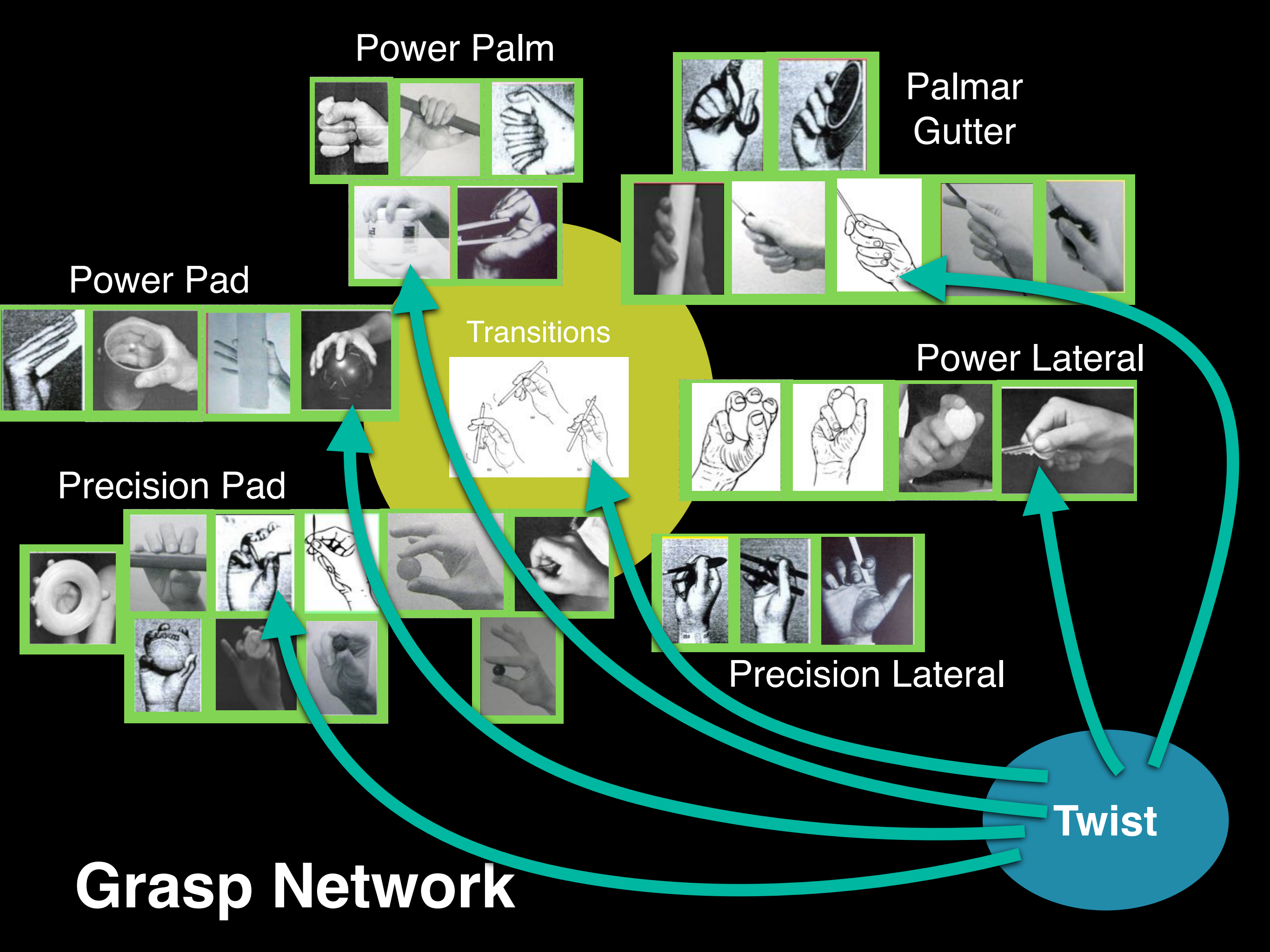


Precision Lateral



Twist

Grasp Network



Our current data collection effort



Grasps from the 3min shopping video plus Elliott and Connelly



Finger and thumb tip triangles in
back of the hand frame

