Activation Patterns of the Thumb Muscles During Stable and Unstable Pinch Tasks

M. Elise Johanson, MS, ***Palo Alto, CA,*** **Francisco J. Valero-Cuevas, PhD,** ***Ithaca, NY,*** **Vincent R. Hentz, MD,** ***Palo Alto and Stanford, CA***

The ability to direct forces between the thumb and fingers is important to secure objects in the hand. We compared the coordination of thumb musculature in key and opposition pinch postures between stable and unstable tasks. The unstable task (producing thumb-tip force wearing a beaded thimble) required well-directed forces; the stable task (producing thumb-tip force against a pinch meter) did not. Fine-wire electromyography of thumb muscles and thumb-tip force magnitudes were recorded. We found no statistical differences in thumb-tip force between postures or stable versus unstable tasks, indicating that the highest magnitudes of force can be accurately directed. Abductor pollicis brevis and extensor pollicis longus were significantly more activated in the unstable tasks, suggesting their importance in directing thumb-tip force. Understanding how pinch forces are directed might influence the choice of muscle–tendon transfers performed to restore function to the severely paralyzed thumb. We introduce a device to quantify the ability to control pinch force magnitude and direction simultaneously. (J Hand Surg 2001;26A:698–705. Copyright © 2001 by the American Society for Surgery of the Hand.)

Key words: Normal hand, pinch, thumb, muscle coordination, electromyography.

Weak and poorly coordinated pinch is associated with spinal cord injury, selective damage to the ulnar and/or median nerves of the upper extremity, and arthritis.[1,2] The inability to produce a functional pinch force between the thumb and the other fingers can interfere with normal daily activities. Pinch function is most often characterized by the magnitude of force that can be measured by a pinch-gauge–type dynamometer with a flat or concave surface to accommodate the fingers. It is commonly assumed that if the pinch force of the weakened or paralyzed thumb can be increased, then functional performance will be improved. For example, after spinal cord injury tendon transfer and joint stabilization procedures are performed to improve the ability to produce adequate key and tip pinch forces to accomplish functional tasks.[3,4]

Activities of daily living may include using pinch to secure or manipulate objects that are small or shaped with convex surfaces (eg, pills, writing instruments). Successful performance of these pinch tasks requires the ability to control the direction of the force exerted by the thumb-tip and the magnitude

From the Rehabilitation Research and Development Center and Hand Surgery Service, Veterans Affairs Palo Alto Health Care System, Palo Alto, CA; Neuromuscular Biomechanics Laboratory, Sibley School of Mechanical and Aerospace Engineering, Cornell University, Ithaca, NY; and the Division of Hand Surgery, Stanford University Medical School, Stanford, CA.

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Reprint requests: M. Elise Johanson, MS, Rehabilitation Research and Development Center, VA Palo Alto Health Care System, 3801 Miranda Ave, 153, Palo Alto, CA.

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of the force.[5,6] Joint instability and muscle weakness or imbalance can result in both the reduction and misdirection of thumb-tip force. Knowledge of the coordination of thumb musculature during pinch tasks with different requirements for directing thumb-tip forces can expand the ability to assess pinch deficits and treatment outcomes. A better understanding of which muscles are important to direct thumb-tip forces in pinch might influence the choice of muscle–tendon transfers performed to restore function to the severely paralyzed thumb, for example in tetraplegic patients.

The activation of the thumb musculature has been studied by electromyography (EMG) to identify the timing of muscle action during functional pinch,[7] to compare the function of thenar and hypothenar muscles,[8] to identify synergistic relationships as subjects produced low forces,[9,10] to investigate the relationship of EMG activity and isometric force from thumb musculature,[11] and to quantify the effects of median nerve block on force production in different directions of thumb movements.[12] Studies comparing the effects of changing the requirements for directional accuracy of force production in different pinch tasks have not been reported.

The purpose of this study was to analyze differences in the coordination of thumb musculature during the execution of key and opposition pinch tasks in both stable and unstable conditions. Our experimental paradigm was designed to require greater directional accuracy in thumb-tip force in the unstable tasks. We hypothesized that there would be a difference in coordination patterns between stable and unstable pinch tasks and between key pinch and opposition pinch postures.

In addition, we propose that a simple but novel set of spring-like devices could be used to quantify the ability to simultaneously produce and control the direction of thumb-tip force.

Materials and Methods

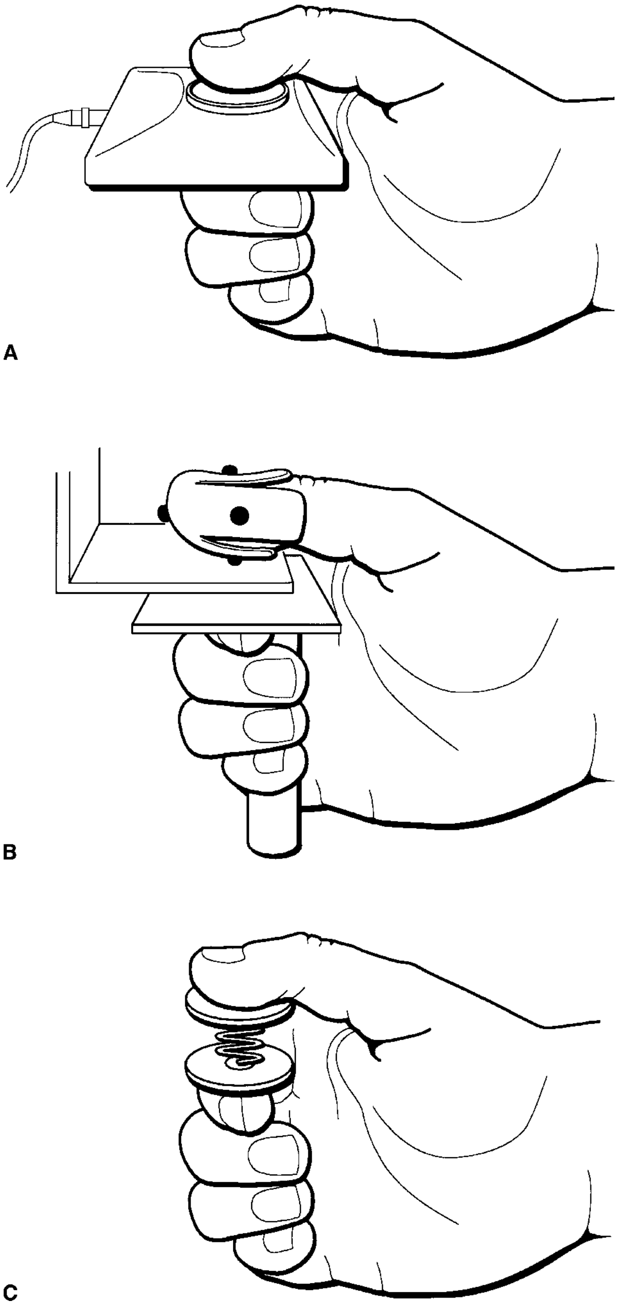
Seven right-handed individuals with no history of hand impairment or prior injury were recruited for the study. Institutional review board approval was obtained. The group consisted of 5 women and 2 men with an average age of 28.6 years (SD, 6.5).

The subjects were instructed to produce maximal thumb-tip force in 2 key postures and 1 opposition posture. The 2 key pinch postures were performed using the pad of the thumb and lateral aspect of the index finger (at the middle phalanx), first with the interphalangeal joint (IP) of the thumb extended and next with the IP joint flexed to approximately 80°. The third posture was opposition pinch, performed with contact between the tip of the thumb and the tip of the middle finger.

The stable task (Fig. 1A) consisted of producing maximal pinch force using a clinical pinch meter (Greenleaf Medical Systems, Palo Alto, CA). The contact surface of the pinch meter is a button with a concave surface to accommodate the pad of the thumb and to provide a secure, nonskid platform for generating maximal pinch forces. This concave, high-friction, soft-contact surface provided much latitude in the direction of thumb-tip force (approximately 60° before slipping occurs) even though the pinch meter only records the component of force perpendicular to the plane of the pinch meter. Subjects were allowed 10 seconds to produce a maximal isometric contraction in each posture while force magnitude and EMG data (see below) were collected simultaneously. A 1-minute rest was allowed between each contraction to avoid fatigue. The trial producing the greatest force was used for EMG analysis.

In the unstable task (Fig. 1B) subjects produced maximal isometric thumb-tip forces against a low-friction aluminum plate mounted to a force sensor. The force plate and sensor (6-axis force and torque sensor, Gamma F/T transducer; ATI Industrial Automation, Gardner, NC) were mounted on a robotic arm (Stäubli-Unimate Puma 260 programmable robot; Stäubli Corp, Duncan, SC) programmed to position and orient the force plate in opposition to the distal phalanx of the thumb in all 3 postures. A custom-molded thimble covering the distal phalanx had a 5-mm brass ball bearing embedded on its outer surface to define a low-friction point-contact between the force plate and the thumb-tip. The subjects were therefore required to produce a well-directed force, within 16° of the perpendicular to the surface, or else the bead would slip.[6] The subjects were seated with the right arm supported in elbow flexion and neutral forearm rotation. A forearm support maintained the subject's wrist in extension and ulnar deviation.

Thumb function was isolated from the other digits by fixing a horizontal plate on top of a vertical dowel around which the fingers were wrapped. Visual and auditory feedback motivated the subjects to produce maximal thumb-tip force in each posture. The subjects watched a computer screen programmed to display their maximal and 50% maximal force output



A

B

C

Figure 1. (A) Experimental setup for stable tasks using a pinch meter with a concave surface for soft-finger contact to record pinch force. (B) Experimental setup for unstable tasks using a robot-held force sensor and beaded thimble for point-contact to record pinch force. (C) Spring device combining strength and dexterity requirements for dynamic regulation of pinch force.

in a stair-step pattern. Subjects were instructed to randomly produce either a step or a ramp increase in force during a 10-second trial. For the step force the subjects targeted the 50% maximal level, proceeded to maximal force, and reduced the force to repeat the 50% level of force. For the ramp the subjects were permitted to increase force at their chosen speed. The order of pinch postures was randomized for each subject.

We introduce a new device for evaluating pinch function that combines pinch strength and dexterity measurements (patent pending, F.J. Valero-Cuevas, 2000). Pinch dexterity is defined in this article as the ability to dynamically regulate the 3-dimensional directional accuracy of opposing thumb and index finger forces by longitudinally compressing springs, each with a different propensity to buckle. The small devices consist of customized compression springs with attached end-caps (Fig. 1C). To compress the springs subjects need to produce forces of sufficient magnitude (ie, strength) and directional accuracy (ie, dexterity). The large-diameter spring requires less directional accuracy (similar to the stable task condition) and greater force to compress. The small-diameter spring requires greater directional accuracy to prevent the spring from buckling (similar to the unstable task conditions). Four subjects were instructed to compress 3 different spring devices with different strength or dexterity requirements. The EMG data for the experimental testing devices were selected based on when the subject reached the maximal level of compression, even if the spring was only partially compressed. Only the key pinch posture was tested with the spring devices. A summary of the device requirements is shown in Table 1.

Electromyographic data from the 9 muscles of the thumb were recorded simultaneously with force data (BAK model MDA-3 differential amplifiers; BAK Electronics Inc, Germantown, MD). Sterile, paired 50-μm wire electrodes with approximately 1-mm recording surface were inserted into flexors pollicis longus (FPL) and brevis (FPB), extensors pollicis longus (EPL) and brevis (EPB), abductors pollicis longus (APL) and brevis (APB), opponens pollicis (OPP), adductor pollicis (ADD), and the first dorsal interosseous (DIO) muscles. The muscle locations were identified by palpation or by using a monopolar electrode in a similar procedure described by Burgar et al.[13] Electrode placement was confirmed using mild electrical stimulation to the target muscle through the wires and by isolated contraction of each muscle. Raw and filtered signals were recorded (band-pass, 10–10,000 Hz) and amplified (gain, 500–2,000). Raw EMG was sampled at 2,000 Hz and displayed after each trial to review signals for noise before processing. Filtered signals were full-

Table 1. Experimental Spring Device Specifications

Device	*Free Length (mm)*	*Solid Length (mm)*	*Diameter (mm)*	*Compressed Force (N)*	*Spring Rate (N/mm)*
D1	25.4	7.62	25.4	30.47	1.714
D2	25.4	6.86	12.7	8.41	0.454
D3	25.4	5.59	6.4	7.98	0.419

wave rectified and smoothed (Paynter filter [Bak Electronics Inc, Germantown, MD], 50-millisecond time constant) to produce a linear envelope and sampled at 500 Hz.

Electromyography recordings during the pinch tasks were quantified by selecting a 750-millisecond window based on maximal force output for the unstable tasks recorded by the robot-mounted force sensor. For the stable tasks involving the pinch meter and the compression spring tasks we selected the region of maximal EMG levels recorded, assuming that this region represented the period of maximal force output. To control for differences in the EMG amplitude caused by electrode placement the EMG data were normalized to the highest EMG activity recorded for each muscle during a maximal voluntary contraction in manual muscle testing positions[14] or during the pinch tasks, whichever value was greater. Nonparametric statistical analyses (Friedman ANOVAs) were used to compare thumb-tip force magnitudes in all tasks, to determine significant differences in the activation levels of each muscle across pinch postures, and to compare the activation level of each muscle between stable and unstable tasks ($p < .05$). When significant differences were observed pairwise comparisons were performed using the nonparametric Wilcoxon matched pairs test, with $p < .05$ considered significant (Statistica, Statsoft Inc, Tulsa, OK). The EMG data from the compression springs were not included in the statistical analyses because of small sample size ($n = 4$); however, descriptive findings are reported.

Results

There were no statistical differences ($p < .05$) in the magnitudes of the thumb-tip forces produced in the stable condition (thumb pad on the concave surface of the pinch meter) versus the unstable condition (beaded thimble on the force plate). No statistical differences in force magnitude between the key and opposition postures were found using the same analysis. The mean force magnitude in each task is summarized in Figure 2.

When the muscle activation levels measured by EMG were compared for the same pinch tasks in the stable and unstable conditions, changes in the activation level of specific muscles were noted (Figs. 3–5). In the key posture with the IP joint extended (Fig. 3) the ADD was significantly more active in the stable condition. The APB and EPL were active at a significantly higher level in the unstable condition for both key postures (ie, with the IP joint extended or flexed; Figs. 3, 4). In the opposition posture (Fig. 5) EMG recorded from the DIO was significantly higher in the unstable condition. The significant increase in the activation of DIO in unstable opposition was most likely an artifact of the experimental setup and not a consequence of the muscle's role in accurately directing thumb-tip force. The activation of the DIO in this posture may be explained by subjects pushing upward against the plate with the radial side

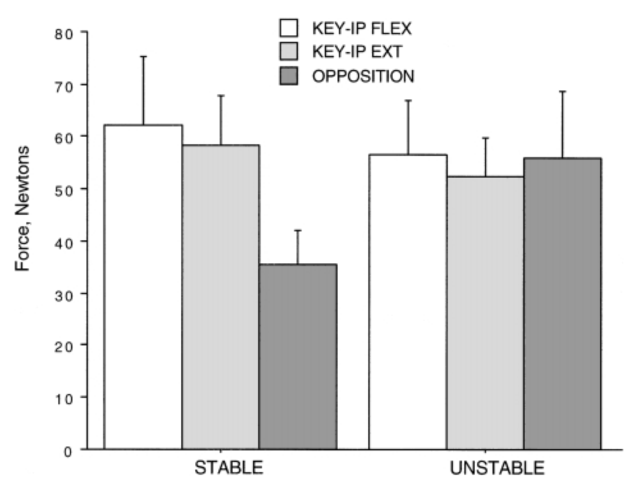


Figure 2. Comparison of pinch force in stable and unstable tasks. No significant differences ($p < .05$) in force magnitude were found in any of the tasks. KEY-IP FLEX, key pinch with IP flexion; KEY-IP EXT, key pinch with IP extension.

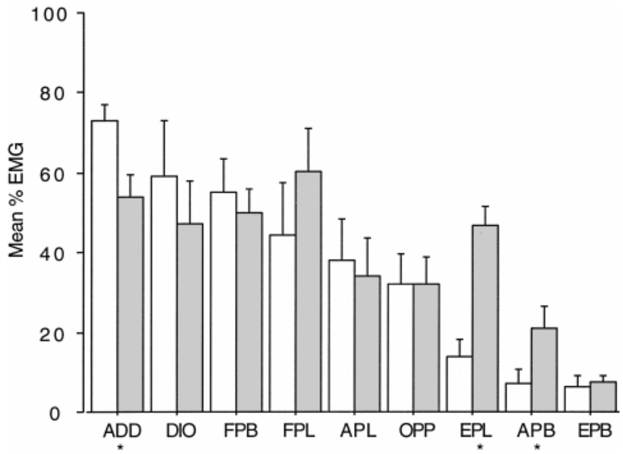


Figure 3. Comparison of key pinch with IP extension in stable (☐) and unstable (▩) conditions. The muscles are sequenced in descending rank order for stable key pinch with IP joint extension. Stable condition represents the findings using the pinch meter; unstable condition represents the findings using the thimble and robot-mounted force sensor (see Materials and Methods for muscle abbreviations.) *$p < .05$, a significant difference between the stable and unstable condition for that muscle.

of the index finger (Fig. 1B). In contrast, when subjects used the pinch meter the middle finger helped to oppose the thumb and the index finger was not in contact with any surface.

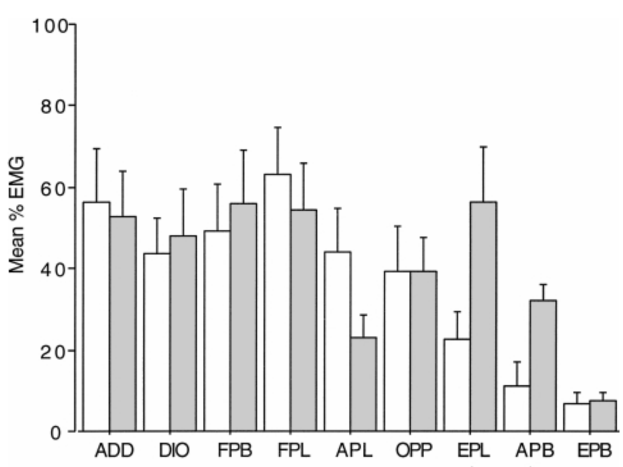


Figure 4. Comparison of key pinch with IP flexion in stable (☐) and unstable (▩) conditions. The muscles are sequenced in the same rank order as Figure 3 for visual comparisons. Stable condition represents the findings using the pinch meter; unstable condition represents the findings using the thimble and robot-mounted force sensor. *$p < .05$, a significant difference between the stable and unstable condition for that muscle.

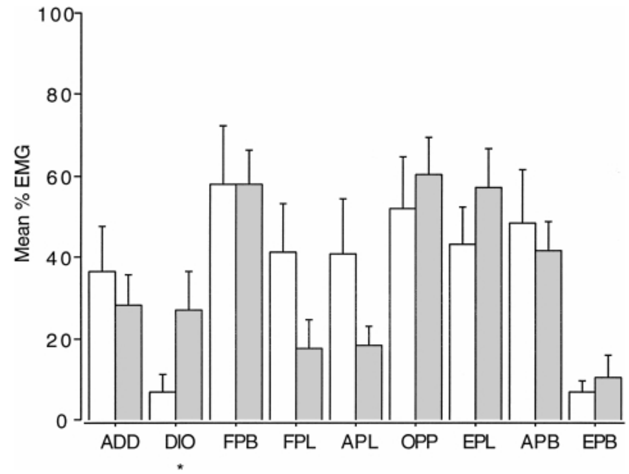


Figure 5. Comparison of opposition pinch in stable (☐) and unstable (▩) conditions. The muscles are sequenced in the same rank order as in Figure 3 for visual comparisons. Stable condition represents the findings using the pinch meter; unstable condition represents the findings using the thimble and robot-mounted force sensor. *$p < .05$, a significant difference between the stable and unstable condition for that muscle.

We also found that the EMG level of some muscles differed across tasks. These differences are primarily a result of changing from the key to the opposition posture. The FPL was significantly less active during unstable opposition pinch than any other task, yet its activity was not significantly different between the 2 key pinch postures. The ADD was also least active in stable and unstable opposition pinch compared with all key pinch tasks. The APB and EPL had significantly more activity during stable and unstable opposition pinch compared with all key pinch tasks, in addition to higher level activation during all key pinch tasks in unstable conditions. There were no significant differences in the EMG magnitudes recorded from the OPP, FPB, EPB, or APL in any of the pinch tasks. In all pinch tasks the lowest activity level was recorded from the EPB.

Spring D1, the widest (most stable) device requiring the most force to achieve full compression, produced EMG activation patterns similar to the key pinch task recorded in the stable condition (Fig. 6). Although the small number of subjects ($n = 4$) does not permit statistical analysis, the ADD, DIO, FPB, FPL, APL, and OPP were active at the highest levels and the APB, EPL, and EPB were at the lowest levels. The general trend was to decrease activation level when the D2 and D3 devices were compressed;

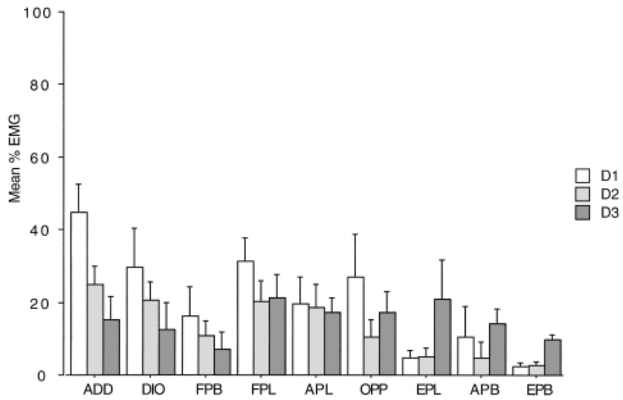


Figure 6. Muscle activation recorded during compression of spring device. For D1 and D3, 2 of the 4 subjects achieved only partial compression. (See Table 1 for D1-D3 specifications.)

these devices required lower pinch forces to compress. In contrast, when the D3, the narrowest (most unstable) device requiring the greatest directional accuracy of force between the index finger and thumb, was compressed, the EPL, APB, and EPB increased their level of activation compared with spring D1. When spring D3 was compressed we noted increased activation of the EPL and APB similar to what the subjects produced in performing the unstable (beaded thimble on the force plate) task. The EPB, which showed very little or no activity in any of the postures, was activated at a higher level when D3 was compressed.

Discussion

Our results confirm the hypotheses that muscle activation patterns recorded from thumb musculature are different between key and opposition pinch postures and between stable and unstable pinch tasks. The data suggest that specific muscles are more important for directing thumb-tip force. That is, the APB and EPL muscles are necessary to accurately direct thumb-tip forces in functional pinch, independently of pinch force magnitude. When more accurate control of the force direction was required, for example in unstable key pinch, the APB and EPL were recruited at a higher activation level. This finding occurred independent of the IP joint configuration or magnitude of thumb-tip force. In the opposition pinch posture the APB and EPL were also significantly more active than in key pinch for both stable and unstable tasks, presumably to both maintain the thumb in an opposition posture and contribute to the directional accuracy.

We found no statistical differences between thumb-tip force magnitude in opposition versus key pinch or in stable versus unstable tasks. This finding indicates that normally even the highest levels of force can be directed accurately. The force measured in the stable opposition task may be lower (not significantly) because of the discomfort of contacting the pinch meter with the unprotected thumb-tip.

To secure small, slippery, or rounded objects in either key or opposition pinch postures opposing forces must be accurately directed between the thumb and index finger. In all unstable conditions APB and EPL were among the most activated muscles and could provide directional accuracy to the task. Because the increases in activation levels were independent of the thumb-tip force magnitude, it is likely the APB, an abductor of the thumb, and the EPL, an extensor and adductor of the thumb, were recruited to direct the force. This action may represent a strategy to increase lateral stability in tasks in which the thumb has the potential for slipping medially or laterally or pronating and supinating as external force is applied. This tendency can be observed in grasping long objects that tend to twist out of the grasp, such as typing sticks, writing instruments, or eating utensils. The use of specific muscles to control force direction may also be applicable when dynamic control is necessary to manipulate a rounded object that can be unstable in all directions, such as a marble or thumb tack.

The novel spring devices represent a promising clinical tool that may be useful in evaluating and quantifying an individual's ability to control the magnitude and direction of force between the thumb and index finger. These 2 parameters are essential for functional pinch tasks and are not tested using a traditional pinch meter. Compression of the most unstable device (D3) resulted in activation of the same muscles identified when the beaded thimble was used to simulate an unstable task, whereas compressing the pinch meter did not.

When well-directed forces are required between the thumb and fingers, the APB and EPL are important to control the resulting force, not just to position the thumb. Previous reports suggest that individuals increase the force between the thumb and index finger when an object is perceived to be slipping from their grasp. Individuals increase the force measured between the index finger and thumb in response to unexpected pulling and pushing loads,[15] unexpected slips of an object,[16] and imposed tangential forces and torques.[17] In our study when the subjects wore a beaded thimble to produce maximal pinch force in the unstable condition, the magnitude of the force was not affected by the potential for slipping from the force plate. Instead, the subjects changed the muscle activation pattern to better direct the force in response to the unstable point-contact nature of the task. Controlling thumb-tip force direction seems to be an important factor in the strategy individuals need to secure small or slippery objects in the hands.

The lower activation of the FPL during opposition pinch than during key pinch is notable because of its functional importance and surgical relevance. If the FPL is permitted to excessively flex the IP joint of the thumb (Froment's sign), the thumb-tip will not contact the opposing digit and securing an object will be more difficult. In key and opposition postures the moment at the IP joint must be resisted by the balanced activity of the interphalangeal flexor (FPL) and extensors (EPL, ADD, APB) or the pinch force will be directed inappropriately. This explains the need to consider stabilizing the thumb's IP joint when function is to be surgically restored to the FPL in the circumstances of paralysis or weakness of the thumb's intrinsic muscles, for example in ulnar nerve palsy or tetraplegia. In these clinical conditions, characterized by absence of activity of the other thumb flexors such as ADD or FPB, surgical procedures such as arthrodesis or split FPL tenodesis are performed at the thumb's IP joint in conjunction with tendon transfer to the FPL.[18] Both procedures convert the FPL into a flexor of the carpometacarpal and metacarpophalangeal joints, making the FPL function as the FPB. In this study the FPB was consistently active at a high level in all of the pinch tasks, indicating its functional importance.

Our findings may explain some of the differences in muscle activation patterns from other investigations of maximal key pinch force. Previous reports concluded that the APB has a secondary role in lateral pinch[11,19] because it is active at a low level during pinch tasks. Kaufman et al[12] concluded that the APB is an antagonist to thumb flexion. Our findings suggest that the APB is an important muscle for lateral pinch when the pinch force must be well directed, as in performing an inherently unstable task. Testing subjects in different functional postures in our study resulted in different coordination patterns. Therefore, the findings from studies of thumb musculature obtained in alternative thumb postures not related to pinch functions, even though the same force direction is reported,[12] may not be generalized to functional pinch tasks.

From the clinical standpoint the ability to strengthen pinch force may not necessarily improve pinch function unless the force can be also be properly directed. Our data indicate that the key muscles involved in directing force are the EPL and the APB. The data suggest that when these muscles are paralyzed, for example in tetraplegia, one should consider restoring their action by tendon transfer whenever possible if restoration of forceful pinch is being considered.

Measuring the ability to produce thumb-tip force in stable and unstable conditions may be a more comprehensive indicator of impairment and disability than our current practice of measuring static, stable forces with pinch meters. Pre and postoperative treatment programs for muscle re-education and rehabilitation of the hand may also benefit from including both static, stable and dynamic, unstable force production tasks. Our new compressible devices provide a simple and economic method for measuring an individual's ability to dynamically produce grasp with different combinations of strength and dexterity.

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References

1. Brand PW, Hollister AM. Clinical mechanics of the hand. 3rd ed. St Louis: Mosby, 1999:88–91.
2. Stanley JK. Soft tissue surgery in rheumatoid arthritis of the hand. Clin Orthop 1999;366:78–90.
3. Hentz VR, House J, McDowell C, Moberg E. Rehabilitation and surgical reconstruction of the upper limb in tetraplegia: an update. J Hand Surg 1992;17A:964–967.
4. Waters RL, Sie IH, Gellman H, Tognella M. Functional hand surgery following tetraplegia. Arch Phys Med Rehabil 1996;77:86–94.
5. Murray RM, Li Z, Sastry SS. Grasp statics. In: A mathematical introduction to robotic manipulation. Boca Raton, FL: CRC, 1994:214–222.
6. Valero-Cuevas FJ, Zajac FE, Burgar CG. Large index-fingertip forces are produced by subject-independent patterns of muscle excitation. J Biomech 1998;31:693–703.
7. Johanson ME, Skinner SR, Lamoreux LW. Phasic relationships of the intrinsic and extrinsic thumb musculature. Clin Orthop 1996;322:120–130.
8. Forrest WJ, Basmajian JV. Functions of the human thenar and hypothenar muscles: an electromyographic study of twenty-five hands. J Bone Joint Surg 1965;47A:1585–1594.
9. Maier MA, Hepp-Reymond M-C. EMG activation patterns during force production in precision grip. II. Muscular

synergies in the spatial and temporal domain. Exp Brain Res 1995;103:123–136.
10. Maier MA, Hepp-Reymond M-C. EMG activation patterns during force production in precision grip. I. Contribution of 15 finger muscles to isometric force. Exp Brain Res 1995; 103:108–122.
11. Cooney WP III, An K-N, Daube JR, Askew LJ. Electromyographic analysis of the thumb: a study of isometric forces in pinch and grasp. J Hand Surg 1985;10A:202–210.
12. Kaufman KR, An K-N, Litchy WJ, Cooney WP III, Chao EYS. In-vivo function of the thumb muscles. Clin Biomech 1999;14:141–150.
13. Burgar CG, Valero-Cuevas FJ, Hentz VR. Fine-wire electromyographic recording during force generation: application to index finger kinesiologic studies. Am J Phys Med Rehabil 1997;76:494–501.
14. Kendall HO, Kendall FP, Wadsworth GE. Muscles: testing and function. 2nd ed. Baltimore: Williams & Wilkins, 1971:66–73.
15. Macefield VG, Hager-Ross C, Johansson RS. Control of grip force during restraint of an object held between finger and thumb: responses of cutaneous afferents from the digits. Exp Brain Res 1996;108:155–171.
16. Macefield VG, Johansson RS. Control of grip force during restraint of an object held between finger and thumb: responses of muscle and joint afferents from the digits. Exp Brain Res 1996;108:172–184.
17. Kinoshita H, Backstrom L, Flanagan JR, Johansson RS. Tangential torque effects on the control of grip forces when holding objects with a precision grip. J Neurophysiol 1997; 78:1619–1630.
18. Mohammed KD, Rothwell AG, Sinclair SW, Willems SM, Bean AR. Upper-limb surgery for tetraplegia. J Bone Joint Surg 1992;74B:873–879.
19. Long C II, Conrad PW, Hall EA, Furler SL. Intrinsic-extrinsic muscle control of the hand in power grip and precision handling: an electromyographic study. J Bone Joint Surg 1970;52A:853–867.