Human Finger Independence:
Limitations due to Passive Mechanical Coupling versus Active Muscle Control

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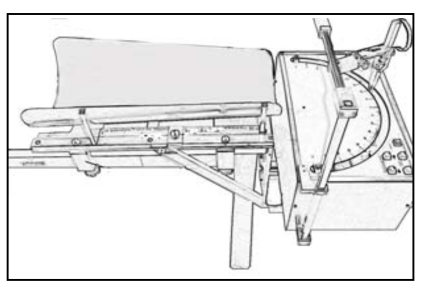
1. Introduction

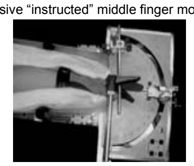
Humans can move their fingers almost, but not completely independently. Limitations to completely independent individuated finger movements likely come from both the anatomical structure of the hand and the neuromotor system that controls it. Anatomical structures such as the multitendoned extrinsic hand muscles, the juncturae tendinum, and the finger web space mechanically couple the fingers, such that passive movement at one finger produces passive movement at another finger. The neuromotor system that controls the hand may limit finger independence via common corticospinal input to spinal motorneuron pools controlling muscles that move more than one finger (e.g. short-term synchrony), and via incomplete neuromuscular compartmentalization of the multitendoned extrinsic finger muscles, such that active movement at one finger produces active movement at another finger. The purpose of this study was to determine the extent to which passive mechanical coupling and active muscle control limit finger independence in humans.

2. Methods

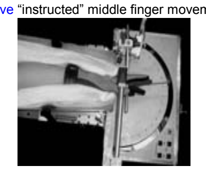
We studied 10 neurologically intact, right-handed control subjects (6 females and 4 males) between the ages of 19-45 years. For each subject, individuated flexion/extension finger movements at each metacarpophalangeal joint (MCP) were studied during passive and active conditions. For the passive condition, subjects sat relaxed while each finger was rotated into flexion and extension by a computer-controlled, custom-built device (see below). For the active condition, subjects moved each finger into flexion and extension while attempting to keep the other, non-instructed fingers still.



Passive "instructed" middle finger movement



Active "instructed" middle finger movement

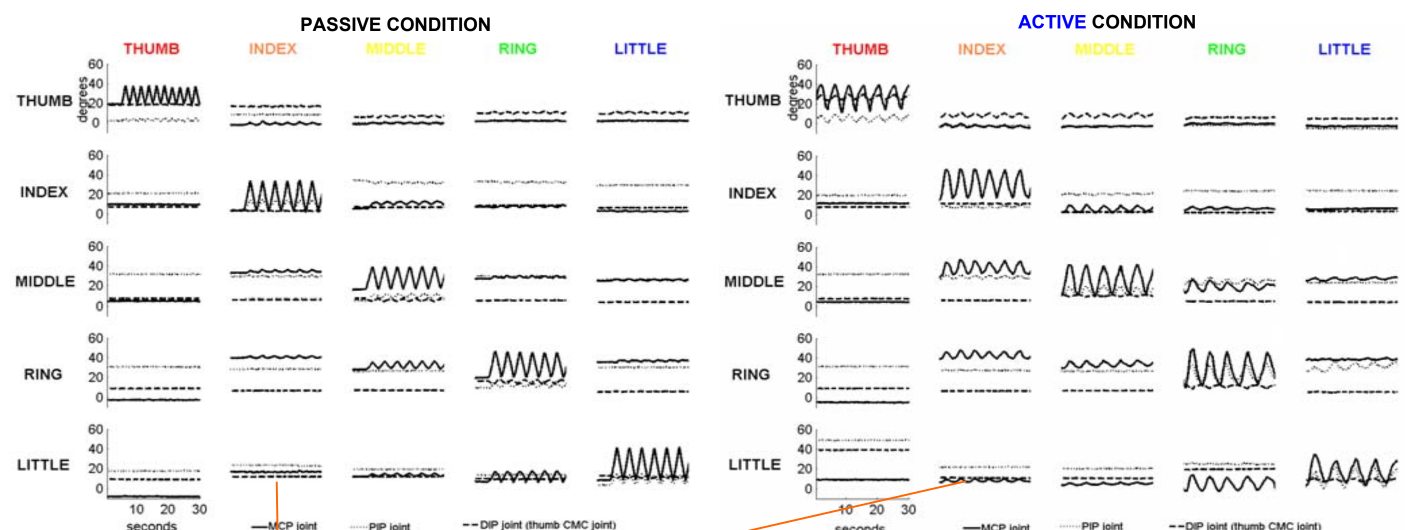


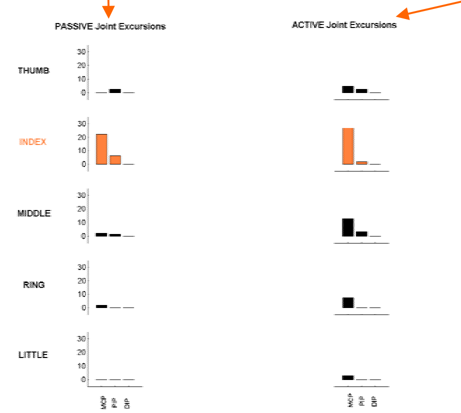
Movements under the passive and active conditions were performed through two ranges, a small-arc and a large-arc, where the range of the small-arc was one half the range of the large arc. The specific ranges used for the small- and large-arc trials were adjusted somewhat for each finger and for each subject to ensure that the range in the passive condition matched the range through which that finger could move actively (see panel to left for mean ranges during small- and large-arc movements). In the passive condition, the finger was rotated at 20º/second. In the active condition, subjects matched this speed to the best of their ability. Joint movement at all 5 fingers was recorded using an instrumented glove during both conditions.

Using joint excursions, we quantified finger independence by computing an individuation index for each finger, for each range, and for each condition (modified from methods of Schieber 1991, Lang & Schieber 2003). The individuation index shows the extent to which a finger is able to move independently, i.e. without the other fingers moving. The individuation index will be close to 1 for a finger that moves alone and close to 0 when the non-instructed fingers move with the instructed finger.

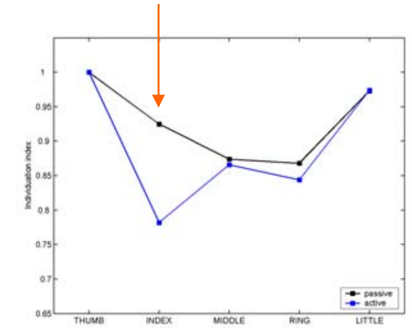
Constraints on finger independence due to passive mechanical coupling were determined from the individuation indices calculated from the passive condition data, while constraints on finger independence due to active motor control were determined by subtracting the passive from the active test conditions.

3. Finger joint movements, joint excursions, and individuation indices during small-arc passive and active conditions for a single subject.



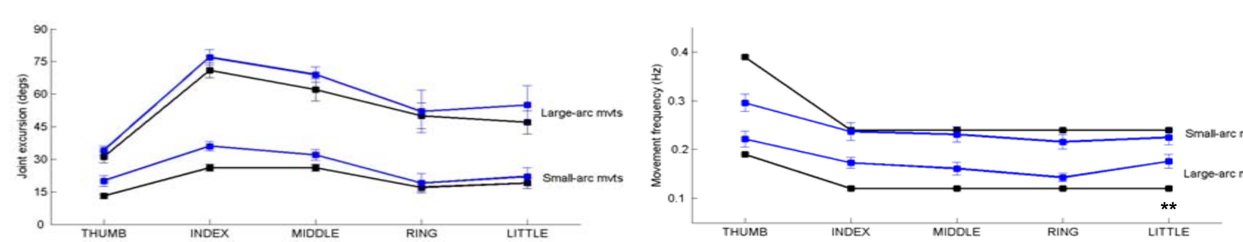


Individuation Index = 1 – (Ave joint excursion$_{\text{non-instructed joints}}$ / Ave joint excursion$_{\text{instructed joints}}$)



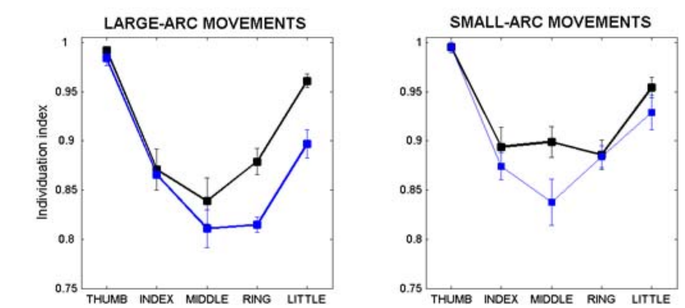
Individuation indices for a single subject during passive and active conditions. The orange arrow highlights the individuation indices calculated from the "instructed" index finger joint excursions shown on the left.

4. "Instructed" joint excursions and movement frequencies were similar between the two conditions.



Group means ± SE for joint excursion and movement frequency of the "instructed" fingers during the passive and active conditions.

5. Group individuation indices during passive and active conditions

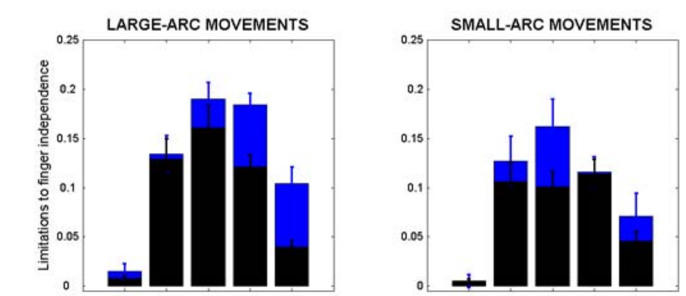


Group means ± SE for all "instructed" large-arc and small-arc movements.

6. Passive and active limitations to finger independence.

Passive limitations = Ave joint excursion$_{\text{non-instructed jts}}$ / Ave joint excursion$_{\text{instructed jts}}$ during the passive condition.

Active limitations = (Ave joint excursion$_{\text{non-instructed jts}}$ / Ave joint excursion$_{\text{instructed jts}}$ during the active condition) – (Ave joint excursion$_{\text{non-instructed jts}}$ / Ave joint excursion$_{\text{instructed jts}}$ during the passive condition).



Group means ± SE for all "instructed" large-arc and small-arc movements. Note: 1) the thumb has negligible limitations to independent movement, 2) the passive limitations are greatest for the index, middle, and ring fingers, 3) the passive limitations are generally greater than the active limitations, and 4) the passive limitations are not different for the large-arc and small-arc movements.

• Summary and conclusions

Passive mechanical coupling and active motor control place negligible limitations on the independence of the thumb.

For the other four fingers: 1) passive mechanical coupling limits independence to the greatest degree in the index, middle, and ring fingers, 2) passive mechanical coupling places greater limitations on finger independence than does active muscle control, and 3) passive mechanical coupling places similar limitations on finger independence during large-arc movements as during small-arc movements.

Our data show that while both the anatomical structure of the hand and the neuromotor system that control the hand restrict the independence of human finger movements, the anatomical structure generally limits finger independence to a greater degree.

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