HUMAN FINGER MOVEMENTS ARE NOT INDEPENDENT

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Introduction

Movements of the human fingers often are regarded as being independent of one another. Nevertheless, finger movements recorded during typing or piano playing typically show multiple fingers in simultaneous motion during each keystroke (e.g. Soechting & Flanders 1992). Even in such sophisticated tasks, however, subjects have no specific requirement to keep the other fingers still while one finger strikes a key, as long as the other digits do not strike other keys. This study addresses whether other digits move when normal humans attempt to move just one digit at a time. We quantified the independence of the digits with an Individuation Index (Schieber 1991) to compare: i) the different digits, ii) the right versus left hand, and iii) movements at a self-paced frequency versus externally paced movements at 3 Hz.

Experimental setup

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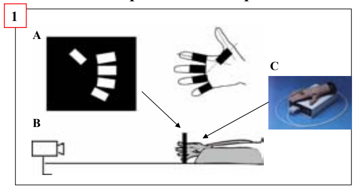

Methods

Ten right-handed subjects were instructed to perform cyclic flexion/extension movements of one finger at a time. The movements of their fingers were recorded in the plane of the 5 fingertips using an orthogonally mounted video motion analysis system (Peak Motus, Fig 1 B). In addition, motions of the individual joints of the hand were monitored by a CyberGlove (Virtual Technology, Fig 1 C) equipped with 22 sensors. Calibration of the Cyberglove sensors to each hand was achieved using a finger goniometer. The forearm and wrist were stabilized by a vacuum cast. The tips of the fingers were inserted in slots cut in a piece of cardboard mounted in a fixed frame (Fig. 1 A). The orientation and length of the slots were customized for each subject's hand. The slot for each finger was prepared so that the distance from the inner end (the point touched by flexing each digit) to the peripheral end (the point touched by extending each digit) was equal to the distance from that finger's MCP joint to its DIP joint. Upon verbal instruction the subjects flexed and extended the 'instructed' finger for 3.5 s between the edges of the slots while trying to keep the other fingers still. Two conditions were tested: 1) subjects moved at their own preferred movement frequency, and 2) subjects moved the fingers at a frequency of 3 Hz paced by a metronome. We recorded four 3.5 s periods of flexion-extension movements for each finger under each condition. Both right and left hands were tested using a right-handed and a left-handed Cyberglove, and the test order was varied between the subjects. Subjects were allowed to watch their finger movements since pilot experiments did not indicate any influence of visual feedback (Hayes & Schieber 1996).

Results

Two-dimensional motion of fingertips

The motion of the fingertips recorded by the video system in a plane parallel to the slotted cardboard was essentially linear, since abduction and adduction movements were restricted by the slots (Fig 2 A). Linear regression was used to compute a best fit line for each fingertip's motion, and all the data points were then projected onto this line. Data were normalized in order to compare the different fingers: the furthest extension equals 0 and furthest flexion corresponds to 1 (Fig 2 B).

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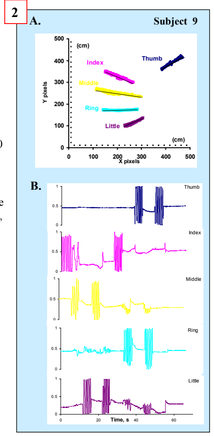

Individuation Index

To compare the independence of the digits we calculated an '*Individuation Index*' (Schieber, 1991). It quantifies the degree to which the j^{th} instructed digit is moved without movement of non-instructed digits. The Individuation Index was derived from data for each instructed finger movement as:

$$II_j = 1 - \left[\left(\sum_{i=1}^{n} |S_{ij}| \right) - 1 \right] \Big/ (n-1)$$

where II_j is the Individuation Index for instructed movement of the j^{th} digit; S_{ij} is the slope of the relative motion of the i^{th} digit during the j^{th} instructed movement (Fig 3); and n is the number of digits (here $n = 5$).

The Individuation Index will be close to 1 for an ideally individuated movement in which the instructed digit moves with no movement of non-instructed digits, and closer to 0 the more non-instructed digits move simultaneously with the instructed digit. Table 1. shows the slopes and Individuation Indexes calculated from the finger movement data illustrated in Fig. 2.

Table 1. **Subject 9**

	Finger instructed to move				
Slope of	Thumb	Index	Middle	Ring	Little
Thumb	1	-0.00068	-0.00032	0.009859	0.001362
Index	-0.04663	1	-0.17312	0.009814	-0.00703
Middle	0.00002	0.019211	1	0.144959	0.00641
Ring	-0.00596	0.002927	0.061239	1	0.093038
Little	-0.00195	-0.00971	0.021081	0.244312	1
Individuation index	0.98636	0.991868	0.9360597	0.897764	0.973039

Example of slopes of relative motion

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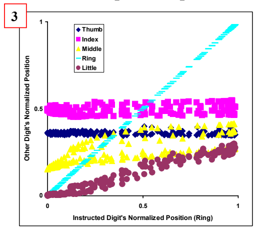

A major linear component was evident when the normalized position of each digit was plotted against the simultaneous normalized position of the instructed digit throughout flexion/extension movement cycles. Linear regression therefore was used to determine the slope of this linear component. This slope then quantified the relative motion of each digit during instructed movement of a given digit, being close to 0 if the digit did not move along with the instructed digit, and closer to 1 the more the digit moved. (Data from Subject 9 during ring finger movement, Fig 2).

Individuation varies among the digits

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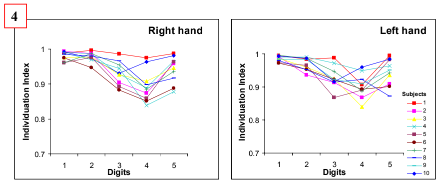

The thumb typically is the digit with the highest Individuation Index, followed by the index finger and the little finger. The middle finger and especially the ring finger have the lowest Individuation Index (see also Table 2). This was true for both the dominant and non-dominant hand. The human Individuation Indexes presented here are generally higher than those reported for rhesus monkeys (Schieber 1991).

Table 2.

	Right hand		Left hand	
Digit	*Individuation Index ± SD*	*Range*	*Individuation Index ± SD*	*Range*
Thumb	0,983012 ± 0,012894	0,947069 -0,999004	0,990654 ± 0,005897	0,976247 - 0,998473
Index	0,981879 ± 0,012984	0,950694 - 0,994652	0,974337 ± 0,021582	0,927538 - 0,998854
Middle	0,937313 ± 0,033743	0,860015 - 0,991987	0,934643 ± 0,039054	0,851109 - 0,995321
Ring	0,907469 ± 0,046227	0,809294 - 0,985282	0,898315 ± 0,059701	0,734771 - 0,985295
Little	0,943091 ± 0,042042	0,824569 - 0,993567	0,944949 ± 0,039881	0,836092 - 0,996029

Averages and ranges for the Individuation Indexes across subjects.

There was no difference in independence of the digits between the right and left hand.

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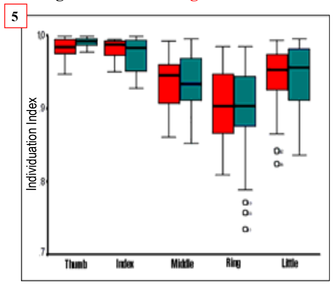

Although some subjects showed slightly lower Individuation Indexes for their non-dominant left hand (cf. Fig.4), there was no statistical difference between the hands ($p > 0.05$; Wilcoxon matched). Each box shows the median, quartiles, and extreme values within a category.

Most angular motion occurred at the PIP joints

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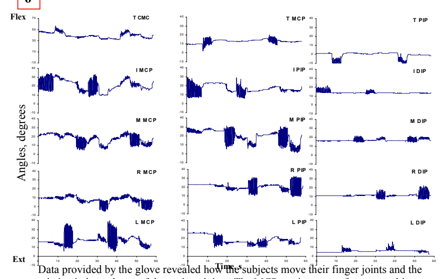

Data provided by the glove revealed how the subjects move their finger joints and the relative independence of the various joints. The MCP motions were for some subjects more pronounced than for others. Least angular motion took place in the DIP joints. Fig. 6 shows data from 15 sensors of the glove for subject 5 during two 3.5 periods of flexion-extension movements for each digit.

Distribution of angular motion over the finger joints

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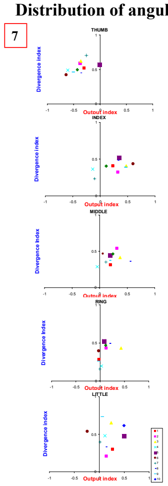

To illustrate how subjects distributed motion over the MCP, PIP or DIP joints of a given finger we calculated an *'Output Index'* (OPI). It ranged from +1 to - 1 with +1 representing the majority of the motions at the most proximal joint (MCP), 0 representing motions primarily around the PIP joints or evenly distributed across all joints, while -1 represents all the motion occurring at the most distal joint (DIP). In addition, a '*Divergence Index'* (DIV) quantified the extent to which the movements occurred in all the three joints of each finger (DIV=1) versus being focused on one joint (DIV=0). Fig. 7 shows these indexes for all subjects (data from subject 5 shown in Fig. 6 are indicated by a ■).

The Output Index (OPI) is calculated as:

$$OPI = \sum_{i=1}^{n} \tau_i * w_i$$

where τ_i is the fraction of the total slope coefficients given by the i^{th} finger joint, n is the number of finger joints within a finger (=3), and w_i is a constant that provides a rank-ordered weighting of the joints: $w_i = (2i - n - 1) / (n - 1)$.

The Divergence Index (DIV) is calculated as:

$$DIV = s * \sum_{i=1}^{n} \tau_i * (OPI - w_i)^2$$

Finger independence was less during 3 Hz than during self-paced movements

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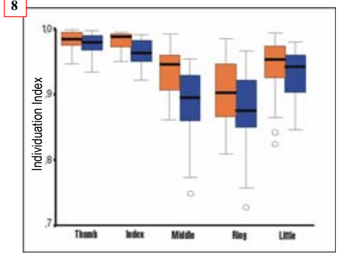

The Individuation Indexes were significantly lower when the movement frequency was paced to 3 Hz than for the self paced frequency (mean ~2 Hz). Each box shows the median, quartiles, and extreme values within a category.

Conclusions

- Even when asked to move just one finger, normal human subjects produce motion in other digits. Movements of the middle and ring fingers were the least independent while the thumb, index finger, and little finger were more independent. Simultaneous motion of non-instructed digits may result in part from passive mechanical connections between the digits, in part from the organization of multitendoned finger muscles, and in part from distributed neural control of the hand.
- Fingers of the dominant right hand were **not** more independent than those of the non-dominant left hand.
- Movements made at a slower self-paced frequency were more highly individuated than externally paced movements at 3 Hz. This suggests viscous and inertial forces coupling the fingers, and/or differences in neuromotor control between the two conditions.

Acknowledgments

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References

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