"Who's Minding the Store?" starring Jerry Lewis

Investigating the Dexterity of Multi-Finger Input for Mid-Air Text Entry

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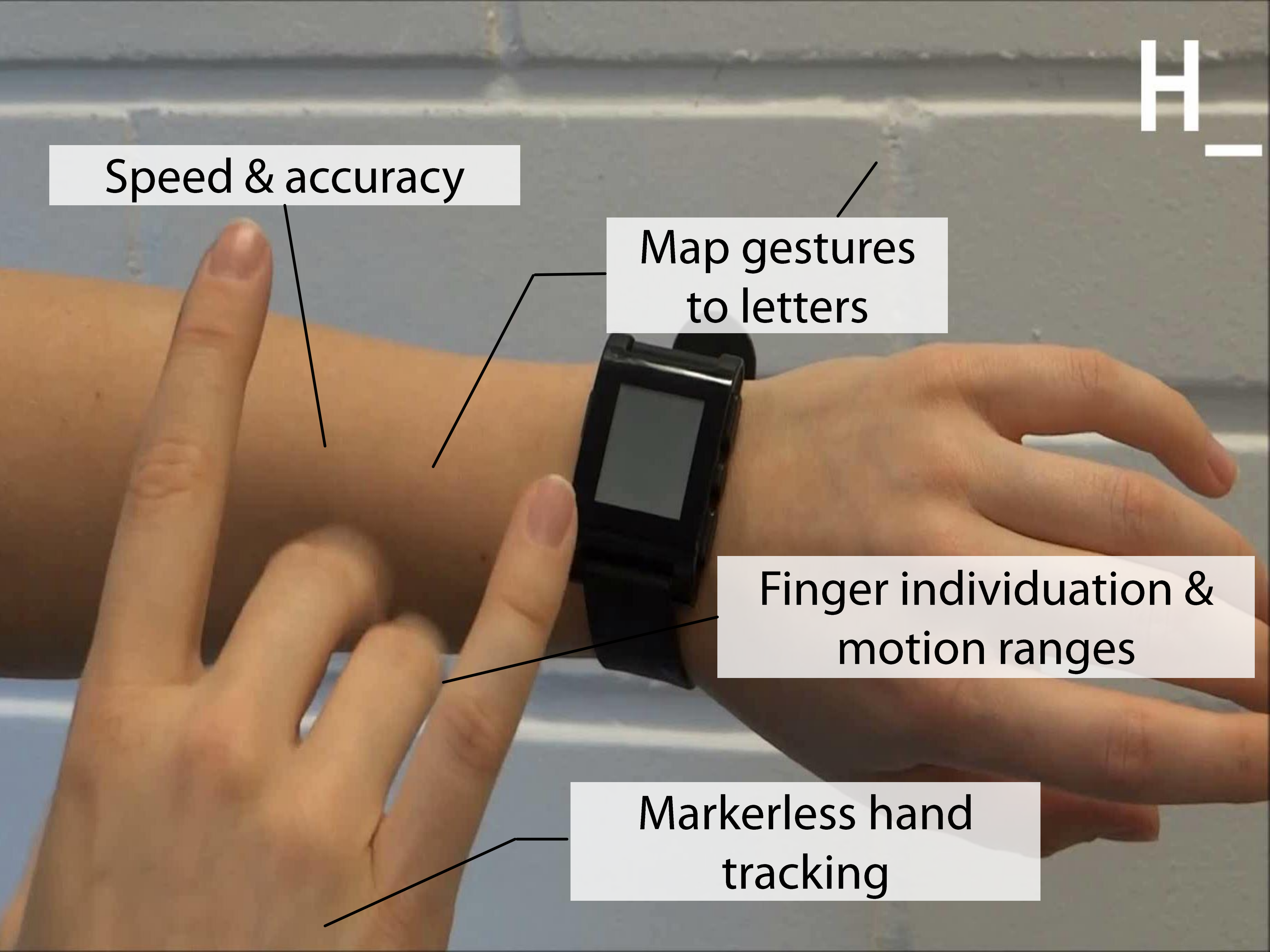
Christian Theobalt[1] Antti Oulasvirta[2]

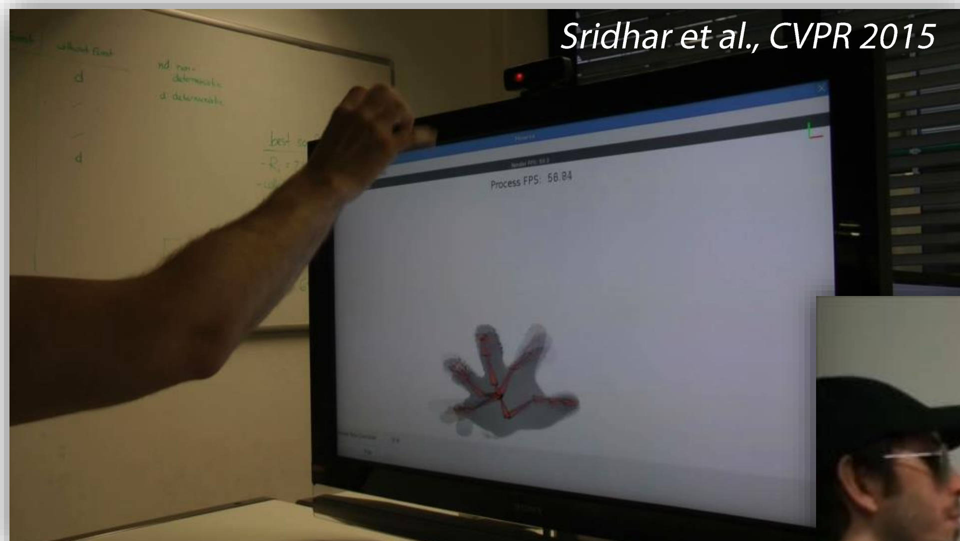
1 max planck institut informatik

2


MORE
THAN
OVER

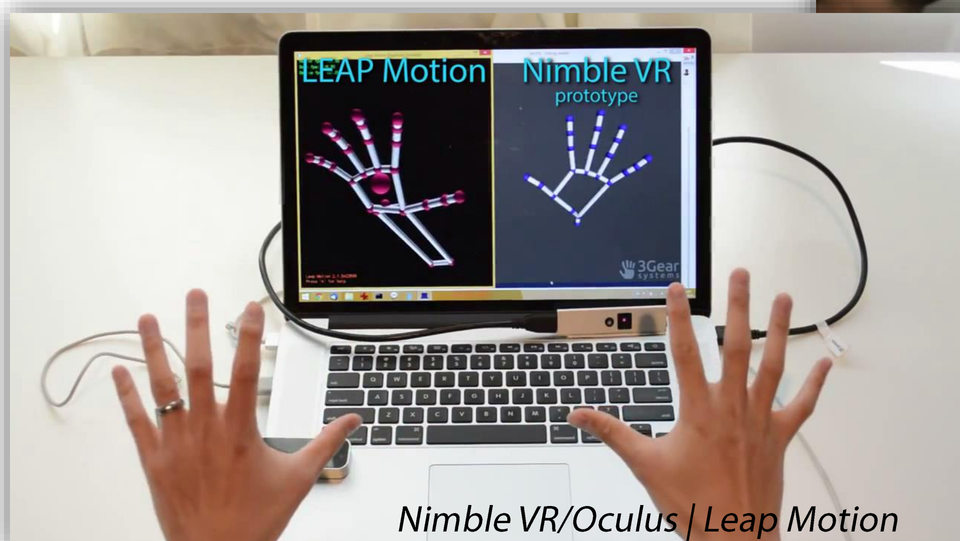

Speed & accuracy
Map gestures to letters
Finger individuation & motion ranges
Markerless hand tracking

Hand Tracking: State of the art



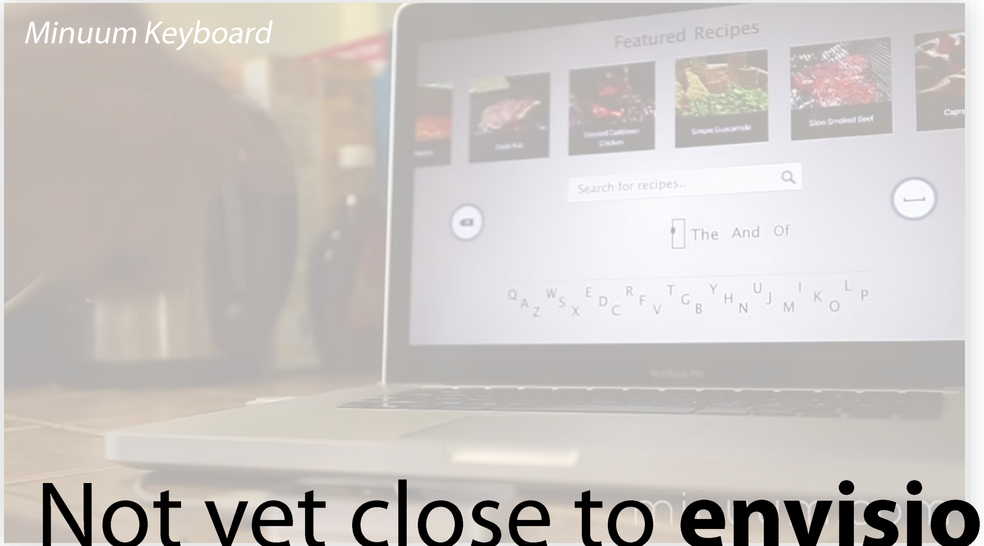
Sridhar et al., CVPR 2015

Sharp et al., CHI 2015



Nimble VR/Oculus | Leap Motion

Current State of Mid-Air Gestural Input



Limited use of **dexterity of fingers**.

Extensions of **2D** gestures to **3D**.

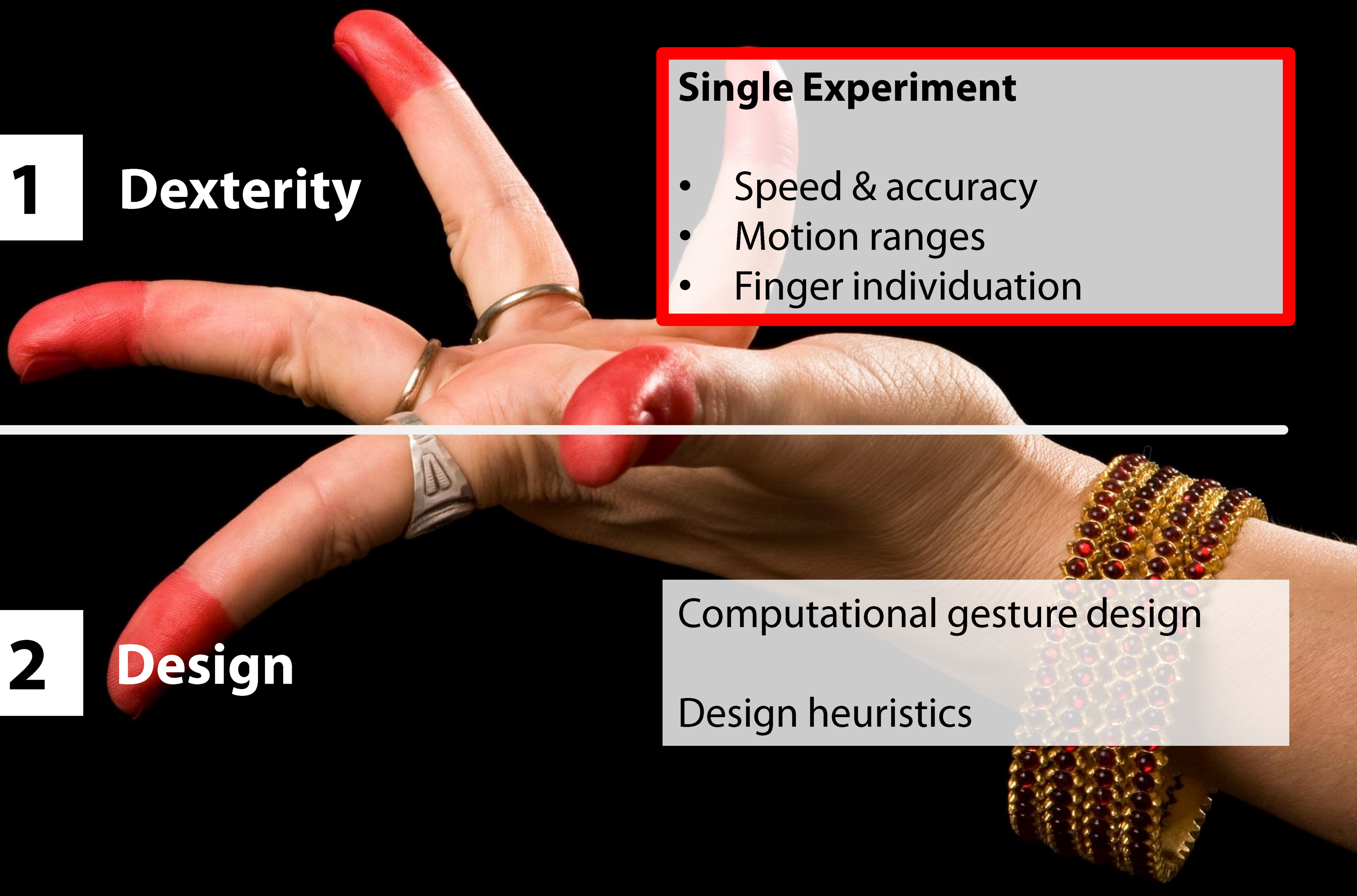
Not yet close to **envisioned performance goals!**

Limited vocabulary of gesture sets.

No guarantees on **usability, performance, or accuracy**.

Objectives and Approach

<u>Goal:</u> *Inform the design of high throughput mid-air gestures.*



1 Dexterity

Single Experiment

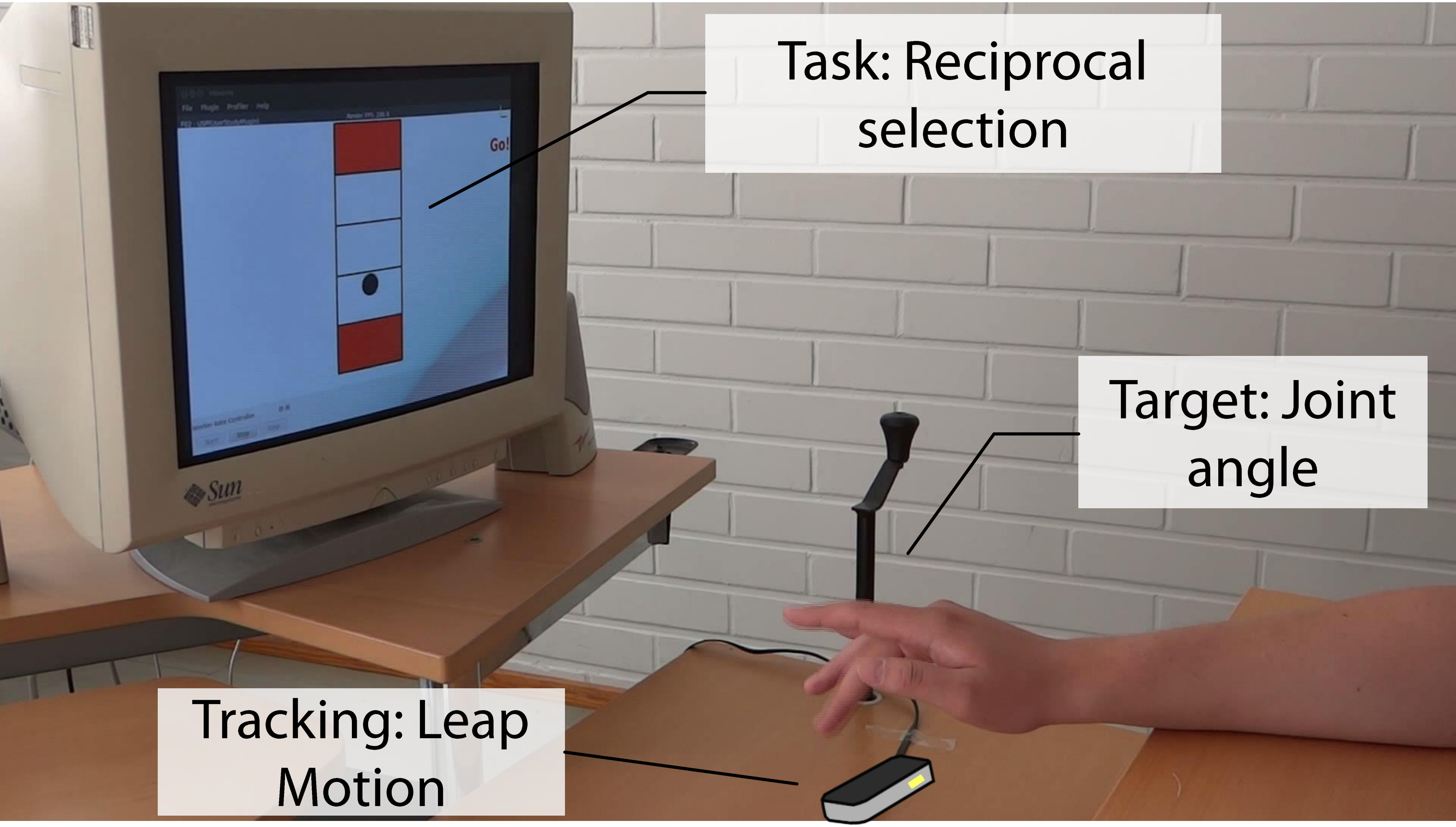
- Speed & accuracy
- Motion ranges
- Finger individuation

2 Design

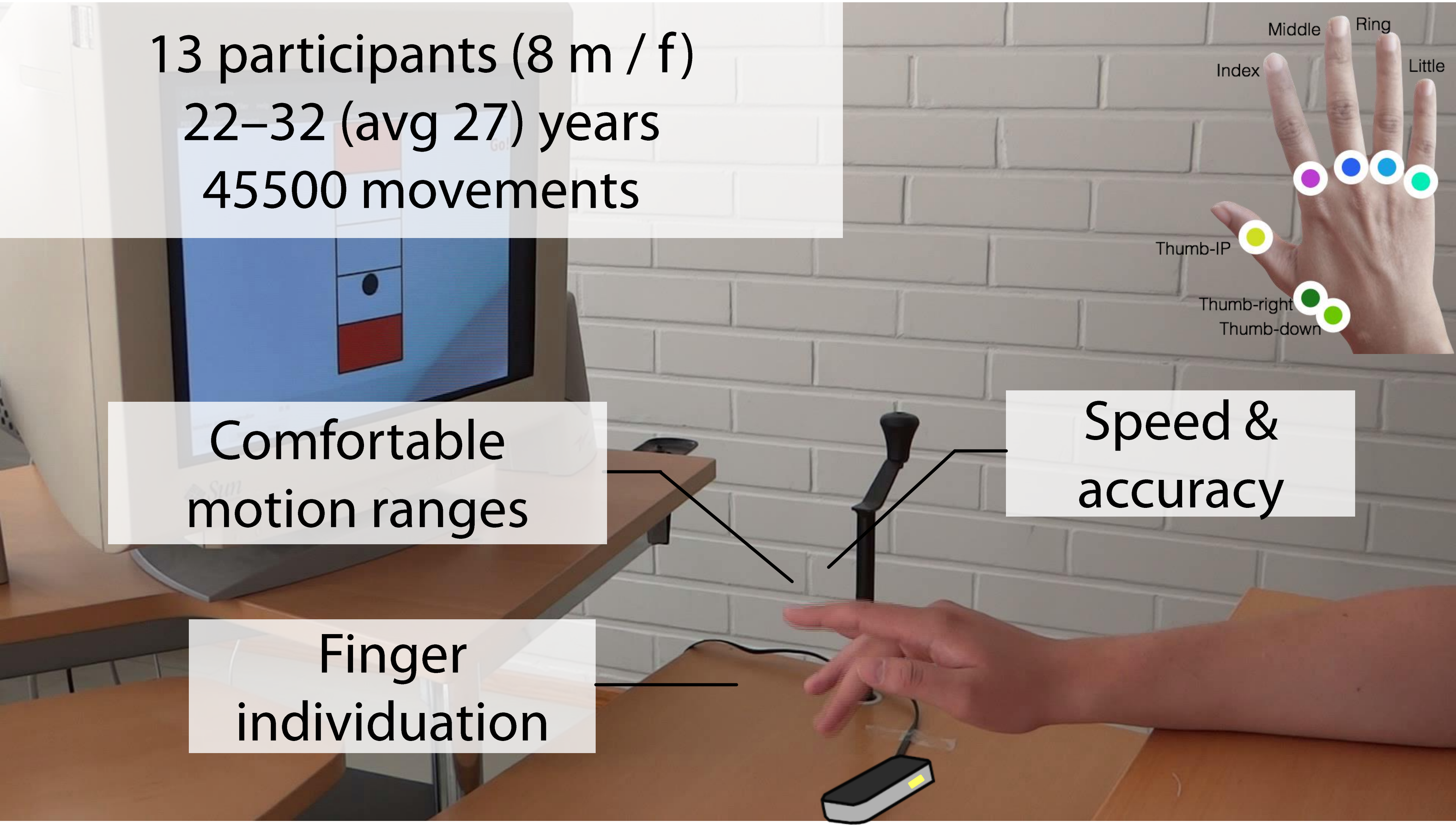
Computational gesture design

Design heuristics

Experiment


Task: Reciprocal selection
Go!
Target: Joint angle
Tracking: Leap Motion

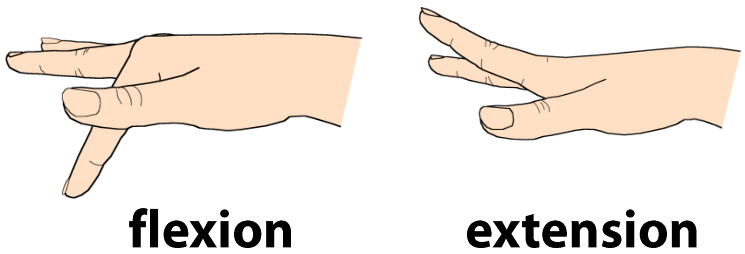
Experiment


13 participants (8 m / f)
22–32 (avg 27) years
45500 movements
Middle
Ring
Index
Little
Thumb-IP
Thumb-right
Thumb-down
Comfortable motion ranges
Speed & accuracy
Finger individuation

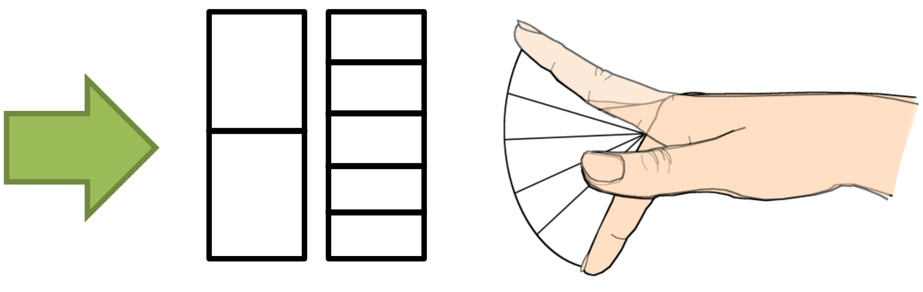
Performance Analysis

Joint-specific Fitts' Law models

Record movement ranges



Divide movement range into 2–5 bins, 4 ID conditions



Performance Analysis

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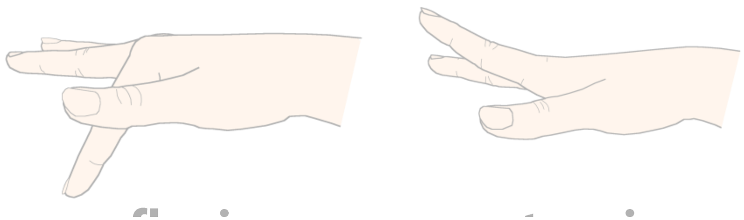

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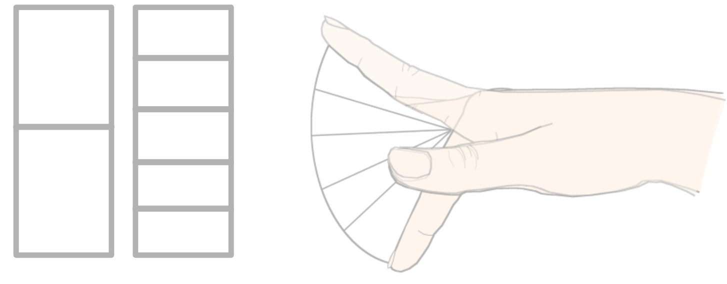
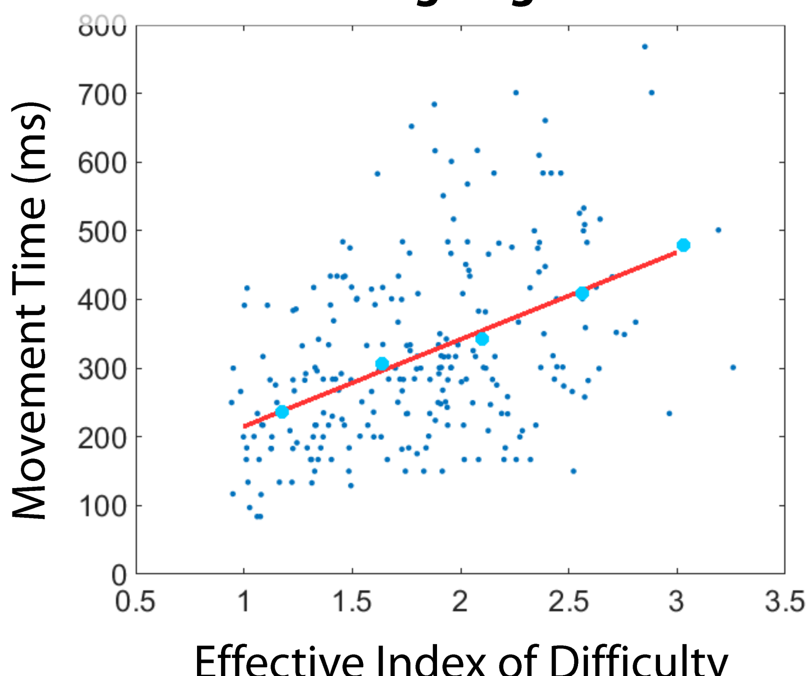


Ring finger



Soukoreff et al., 2004

Angular model

$$MT = a + b\log_2\left(\frac{\alpha_D}{\beta_W} + 1\right)$$

Kondraske,1994

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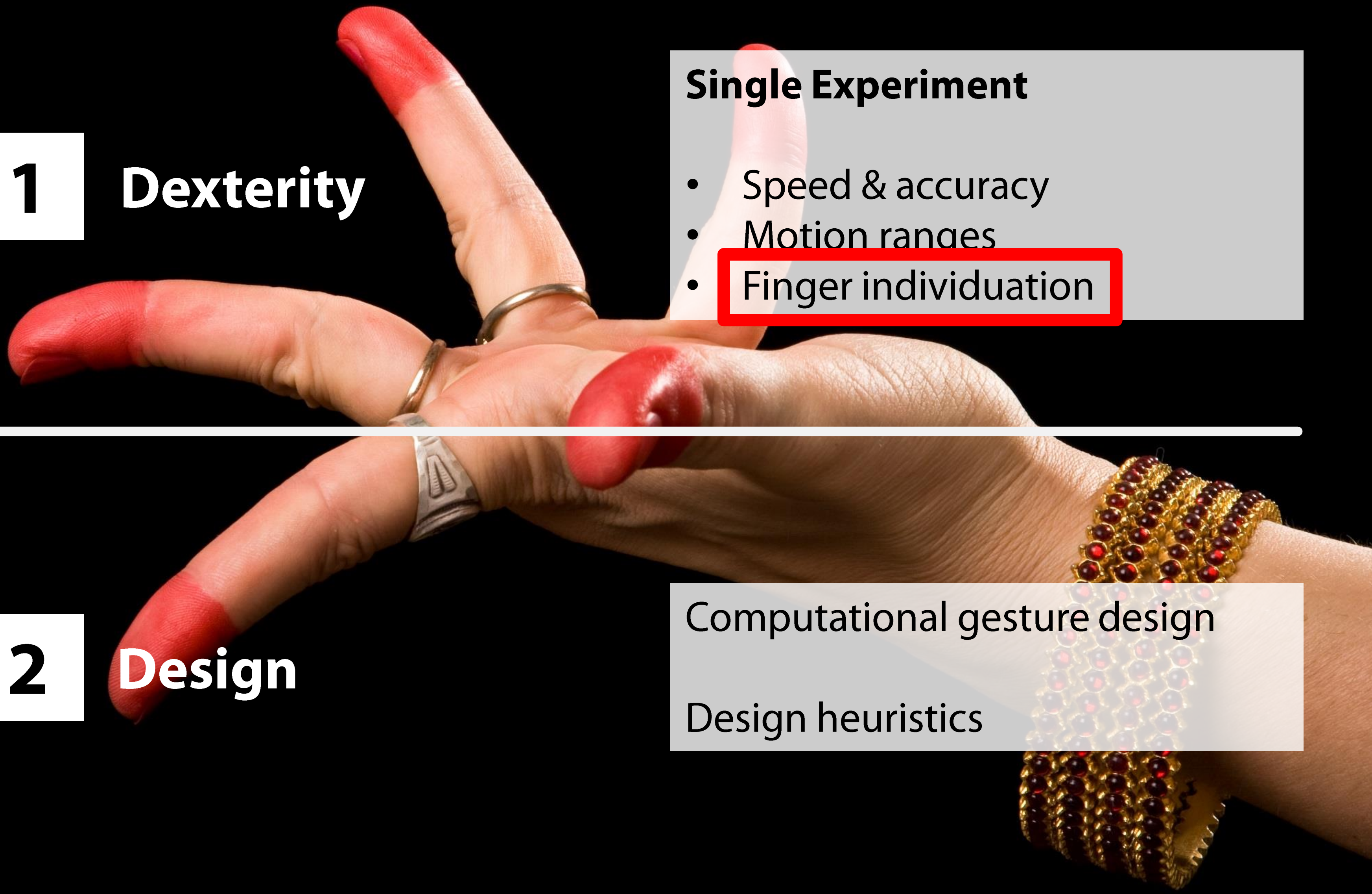

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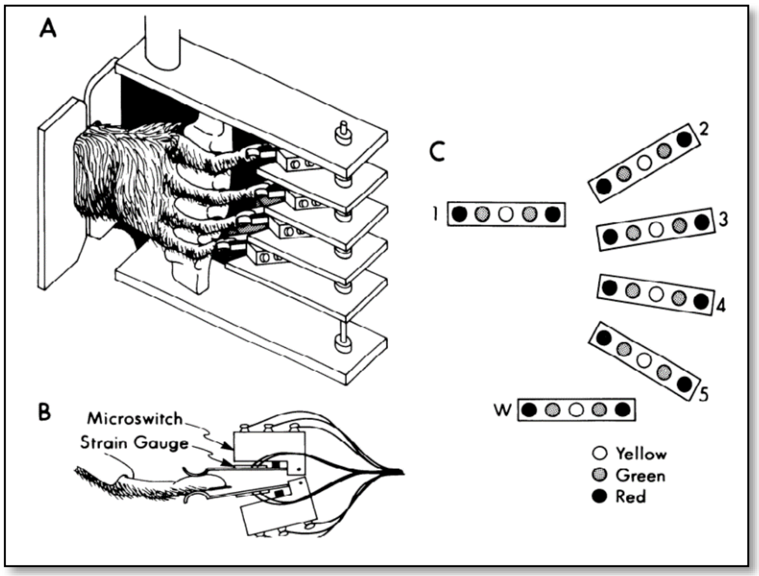
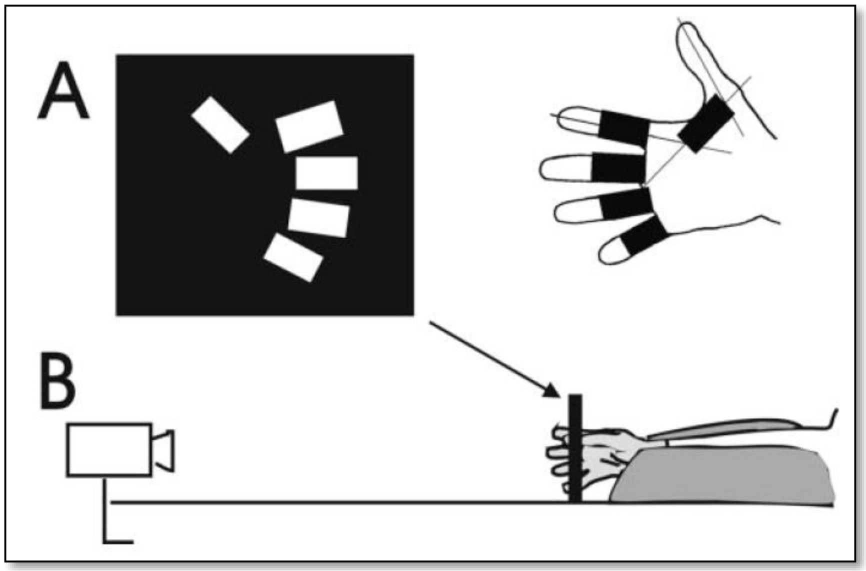
Individuation Analysis

Schieber Index

Quantify independence of uninstructed joints



Schieber, Jounal of Neurophysiology, 1991



Häger-Ross and Schieber, Journal of Neuroscience, 2000

Individuation Analysis

Schieber Index

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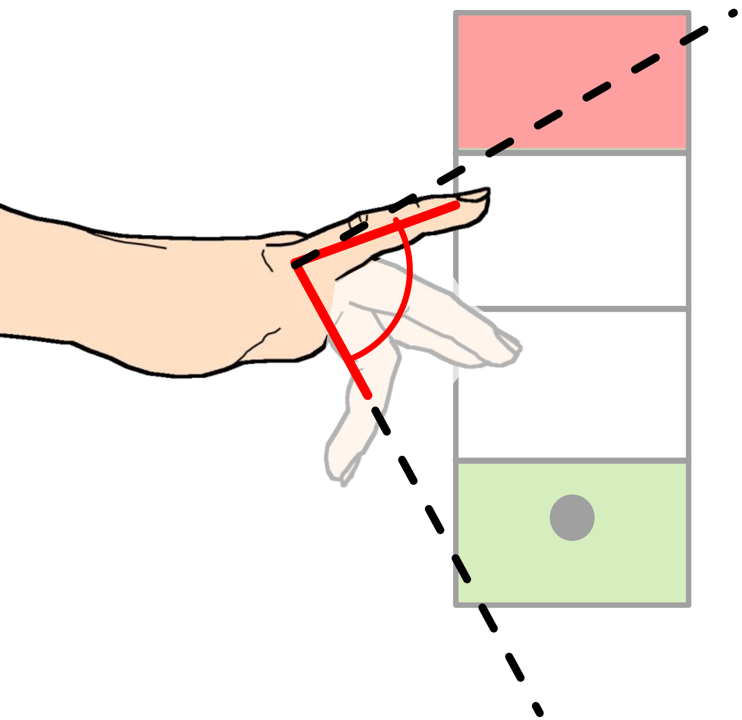

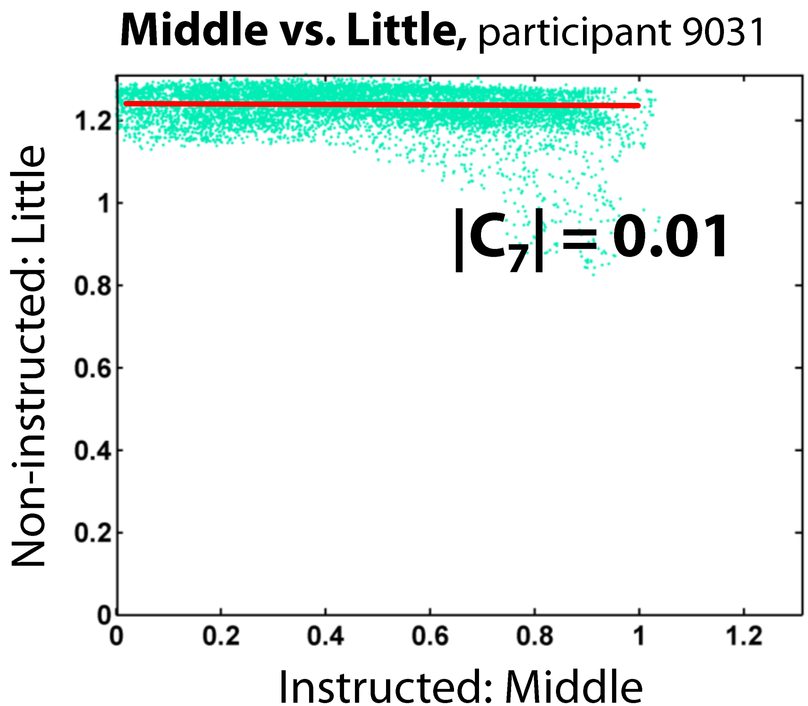

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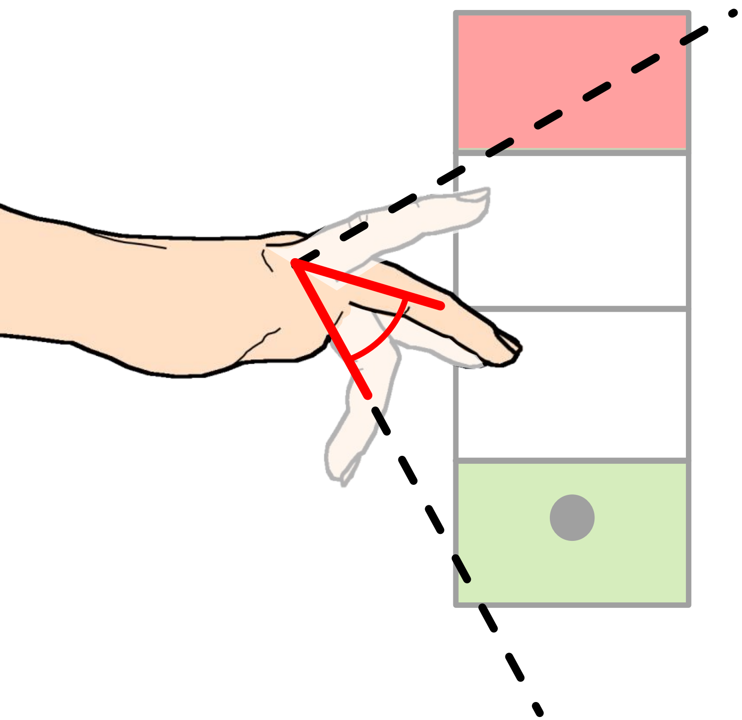
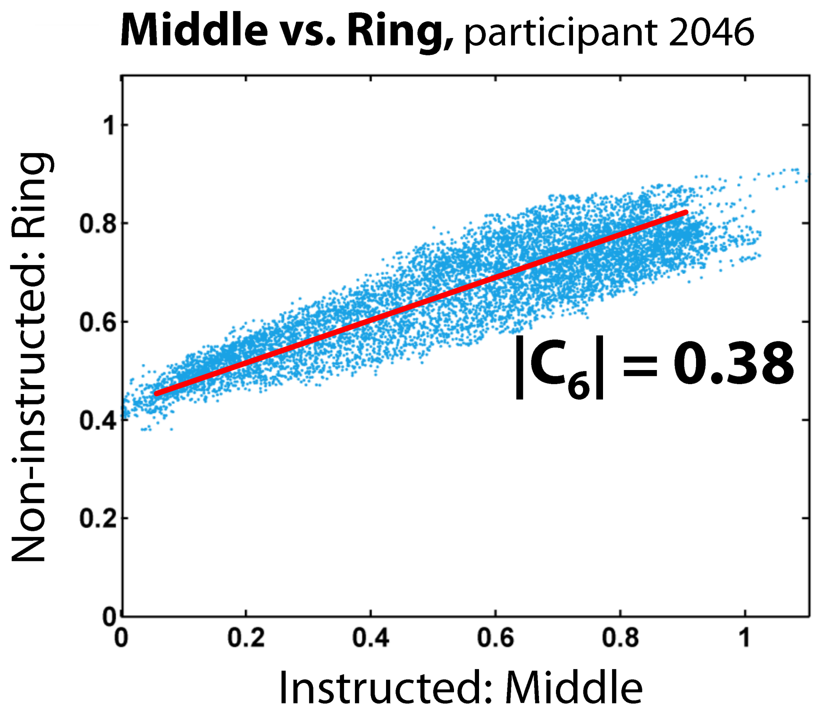




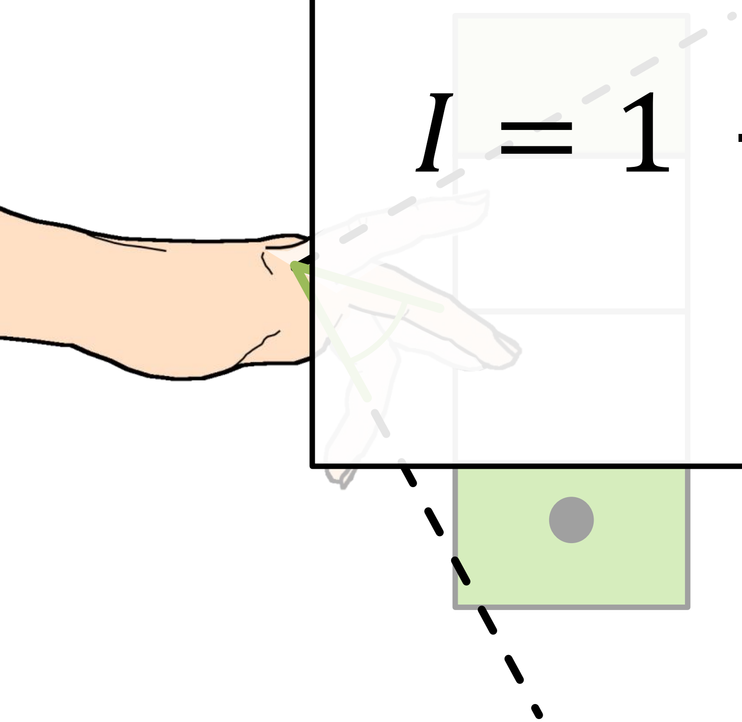
Individuation Analysis

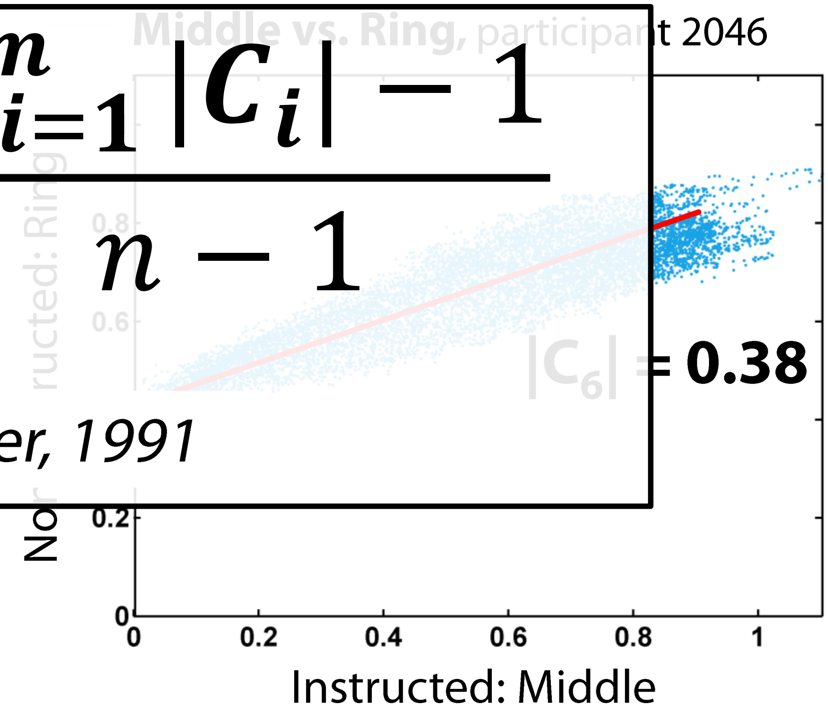
Schieber Index

Quantify independence of uninstructed joints

$$I = 1 - \frac{\sum_{i=1}^{n} |C_i| - 1}{n - 1}$$

Schieber, 1991





Results

Models of **individuation**

Instructed Joint	Index of Individuation	Relative Coactivation						
		Index	Middle	Ring	Little	Thumb-Down	Thumb-Right	Thumb-IP
Index	0.819	1	0.24	0.20	0.19	0.29	0.11	0.06
Middle	0.817	0.16	1	0.41	0.14	0.20	0.11	0.07
Ring	0.808	0.16	0.20	1	0.36	0.15	0.22	0.06
Little	0.806	0.18	0.35	0.29	1	0.14	0.12	0.08
Thumb-Down	0.792	0.12	0.12	0.10	0.08	1	0.69	0.14
Thumb-Right	0.853	0.07	0.09	0.10	0.09	0.27	1	0.26
Thumb-IP	0.889	0.11	0.13	0.11	0.09	0.12	0.12	1

Table 2. Individuation index and relative coactivation describe the involuntary motion of joints. The individuation index is an aggregate that describes the independence of a finger when averaged over all other fingers (1 = perfect individuation). Relative coactivation denotes the movement of an non-instructed joint when the instructed joint (each row) is moving. A value of 1 denotes that the two joints always move together.

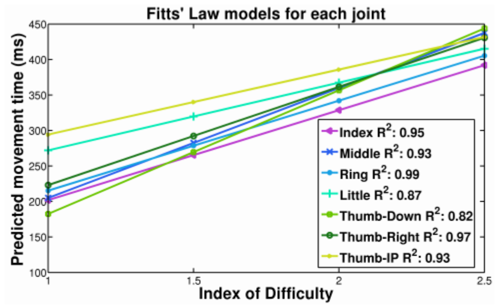


Figure 4. Performance models for each joint as given by Fitts' law. Overall, Index is the fastest, while Thumb and Little finger are the slowest.

Joint	Intercept a	Slope b	R^2
Index	75.140	126.77	0.95
Middle	49.940	155.03	0.93
Ring	88.450	126.79	0.99
Little	176.52	95.510	0.87
Thumb-Down	8.1900	174.26	0.82
Thumb-Right	84.590	138.44	0.97
Thumb-IP	202.73	91.590	0.93

Table 1. Fitts' Law models for each joint, given by intercept and slope.

Joint	Min° (SD)	Max° (SD)	Range (SD)
Index	48.39 (12.25)	−21.19 (8.70)	69.58 (11.81)
Middle	37.58 (11.95)	−18.69 (8.02)	56.27 (12.54)
Ring	44.66 (8.320)	−12.24 (7.70)	58.90 (11.46)
Little	39.47 (15.78)	−20.81 (8.64)	60.28 (14.89)
Thumb-Down	27.31 (1.680)	−6.280 (6.54)	33.58 (7.130)
Thumb-Right	22.18 (10.53)	−11.99 (8.43)	31.32 (12.59)
Thumb-IP	62.97 (12.94)	−27.41 (4.37)	90.38 (13.93)

Table 3. Angular limits and movement range of each joint. The table shows values averaged over all users together with standard deviations.

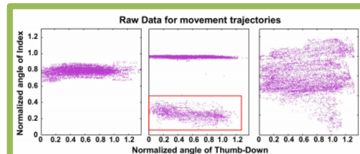


Figure 5. Raw data for movement of Index relative to instructed movement of Thumb-Down. Left (a): Example of high individuation, Middle (b): Tracking errors (red box), and Right (c): "drifting finger".

Movement **ranges**

Joint-specific **performance** models

shows the coactivation of Index relative to Middle. Movement strategies vary too, resulting in a positive slope (moving along with the instructed joint) or even a negative slope (moving opposite to the instructed joint). If a joint could not be kept static, users either moved it along with the instructed joint or opposite to it. Attempts at "counteracting" movement like this were also observed in the original work by Schieber [33]. It may represent a strategy for preventing non-instructed fingers from moving along instructed digits. This suggests that these strategies are applied unconsciously.

We also observed what we denote as the *drifting finger effect*: the position of non-instructed fingers may change gradually over time for some users, as they "forget" to keep the finger still. For some users, this poses no problem, they are able to produce the exact same movement over and over (Figure 5 (a)). We show raw data of this "drifting finger" problem in Figure 5 (c). Due to user-specific differences like this, the linear model of Schieber does not always fit to a user's motion. On average, an R^2 of 0.77 (SD 0.14) was found, ranging from 0.5 to excellent fits of 0.99. As discussed above, we excluded the data where no sufficient linear relationship could be found. On average, this amounted to excluding data from 4 users per joint-joint condition.

Finally, despite our efforts to ensure the ergonomics of the posture and to provide enough breaks, some users complained about fatigue, especially with their wrist or arm getting tired. This suggests that these motions are tiring even if they do not require the use of large forces.

APPLICATION TO TEXT ENTRY

The results of the study offer a nuanced picture of the two characteristics of finger motions. The performance and independence of fingers differ and are inter-connected in sub-

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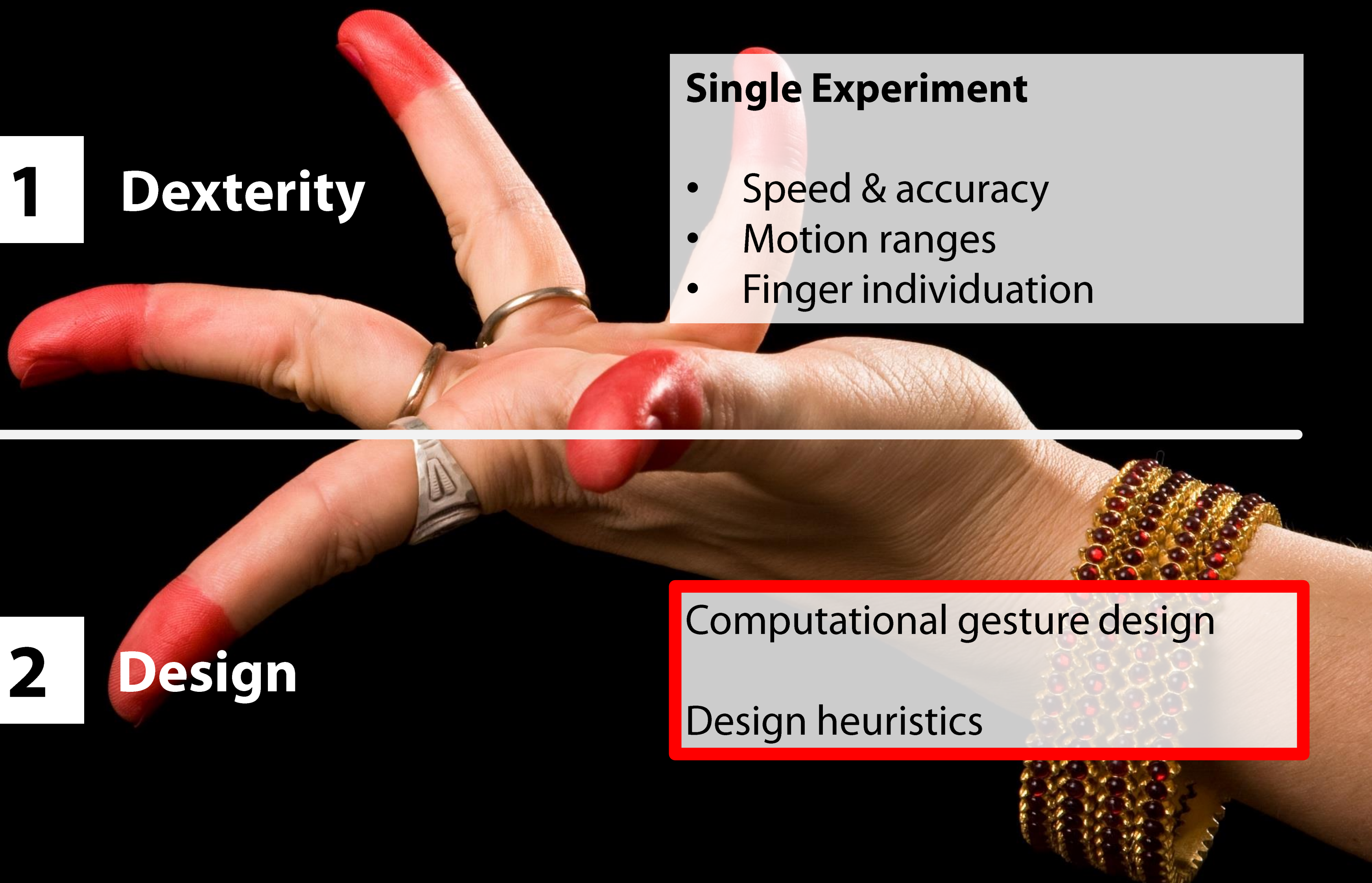

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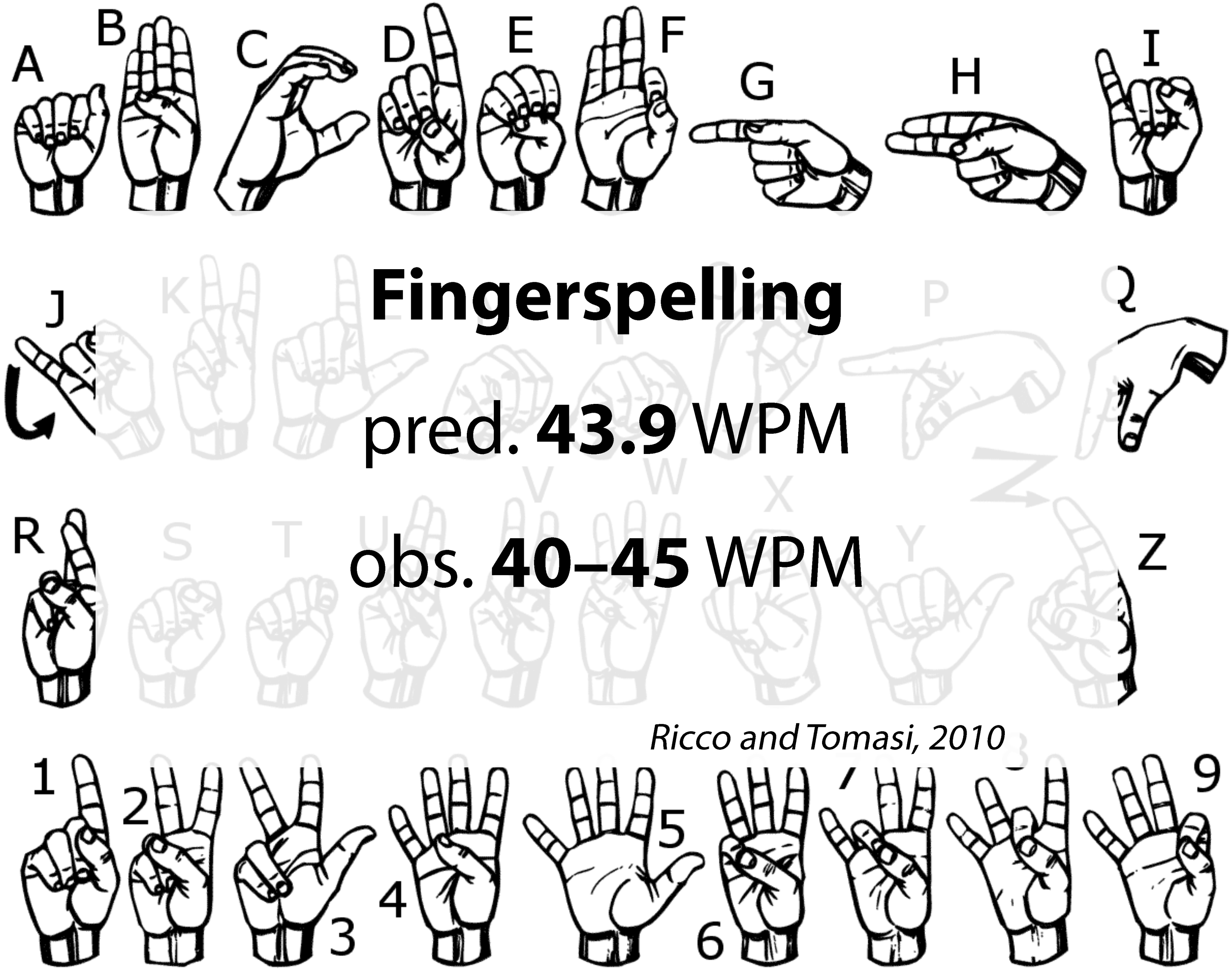
Performance Prediction



Fingerspelling

pred. **43.9** WPM

obs. **40–45** WPM

Ricco and Tomasi, 2010

Letter assignment problem

<u>Goal:</u> *Find the best letter–posture mapping.*

27 letters

A

B

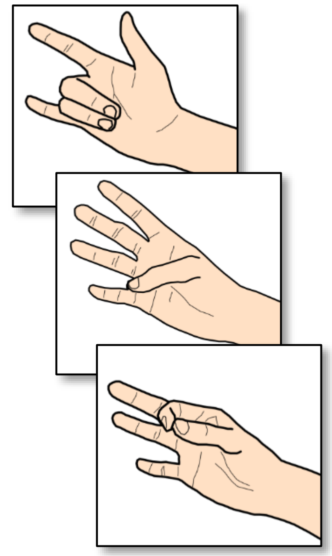
C

…

Z

?

10^{33} mappings



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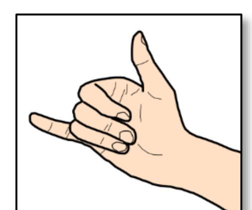


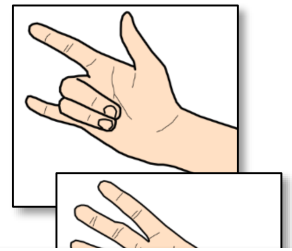
32 gestures

[e.g. Dunlop and Levine 2012, Zhai et al. 2000]

Letter assignment problem

Goal: Find the best letter to gesture mapping

A



27

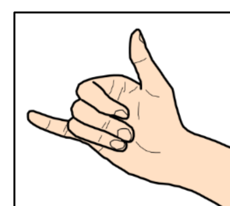
Maximize:

$$\boldsymbol{U} = w_P \cdot \boldsymbol{P} + w_A \cdot \boldsymbol{A} + w_L \cdot \boldsymbol{L} + w_M \cdot \boldsymbol{M}$$

…

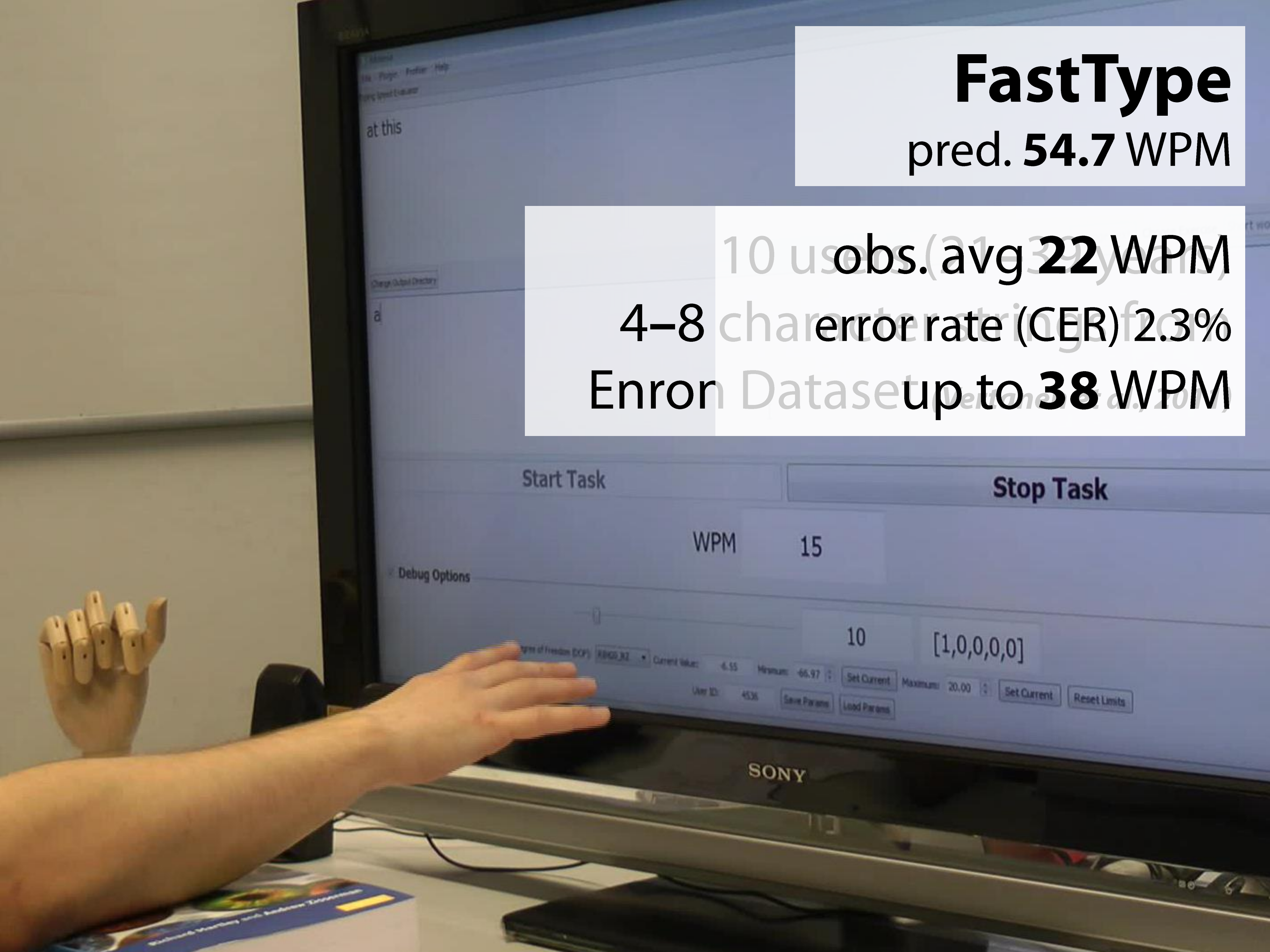
10^{33} mappings

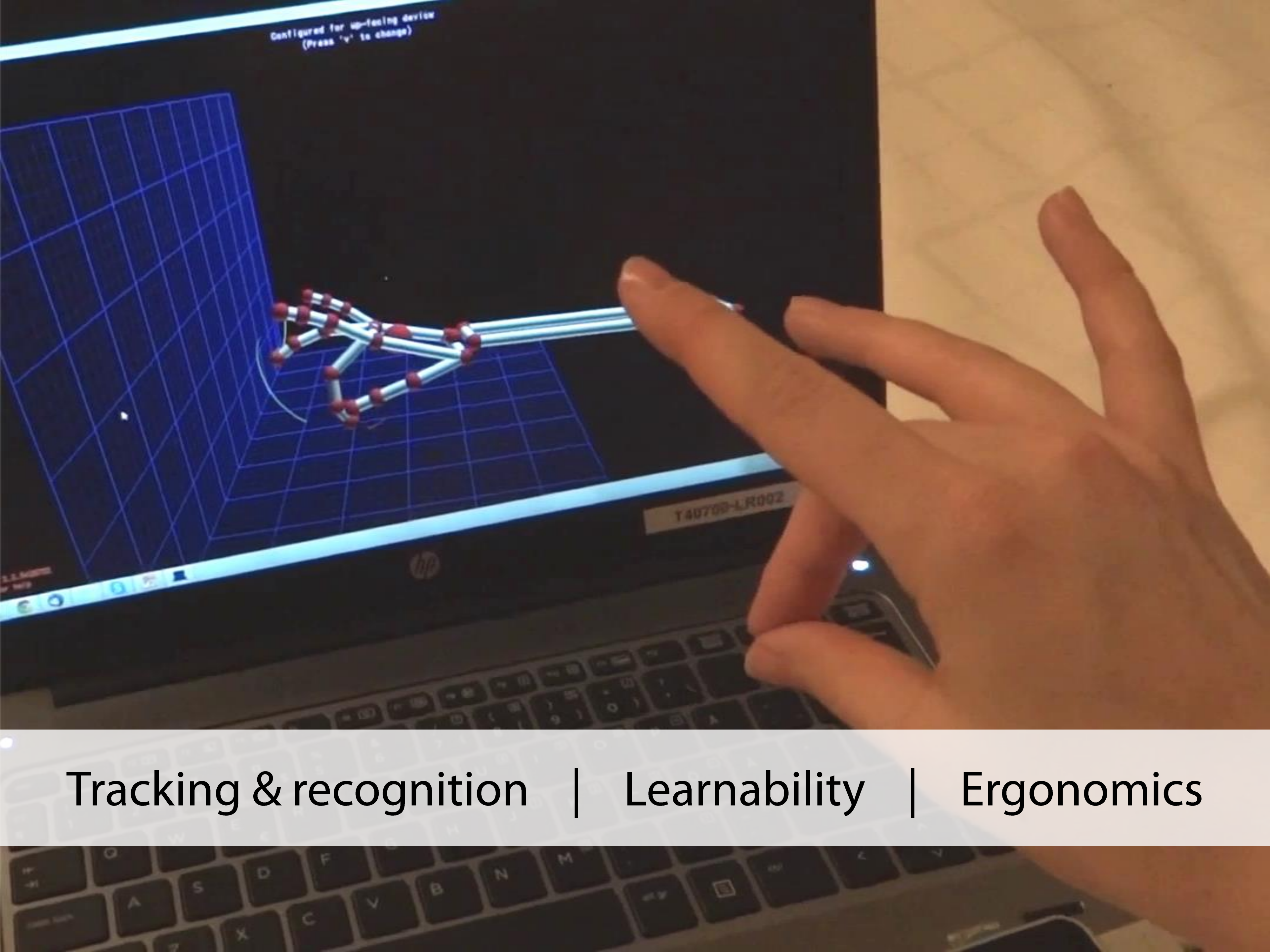
…



Z

[e.g. Dunlop and Levine 2012, Zhai et al. 2000]

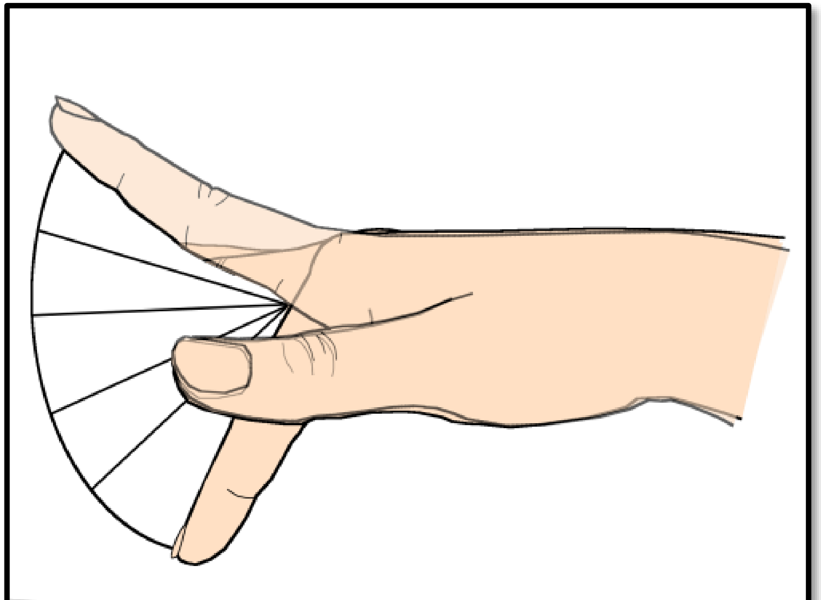

FastType
pred. **54.7** WPM
obs. avg **22** WPM
error rate (CER) 2.3%
up to **38** WPM
at this
Start Task
Stop Task
WPM
15
Debug Options
10
[1,0,0,0,0]
SONY



Tracking & recognition | Learnability | Ergonomics

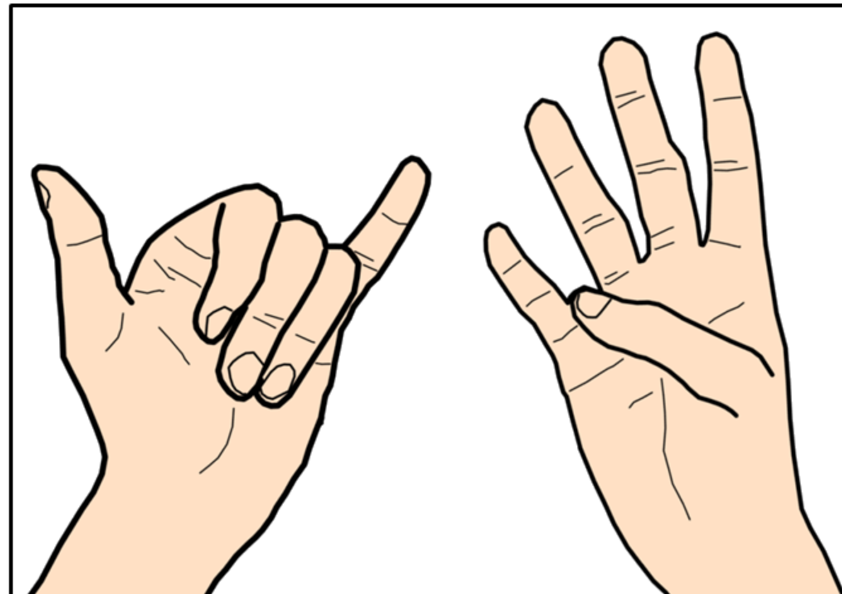
Further Predictions

65 WPM



More levels per joint

70–85 WPM



Two hand input


DRAGON
guide
all apps
8:00PM
Mon, Oct 17


Design of mid-air gesture is hard, but our data makes it easier.

1. Joint specific models for **dexterity**
2. Directly **applicable** to **design**
3. **Methodology** applicable in other settings

Thank you!

handtracker.mpi-inf.mpg.de

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Acknowledgments

ERC Starting Grant projects **CapReal** and **COMPUTED**, and the **Academy of Finland**