Applications in Hand-Focused Rehabilitation Therapy

TEAM #15
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Project Summary

- Hand fits in adjustable brace, secures to base
- Finger fits in silicon cup(s), force detected at base
- Force signals sent to computer and processed into usable information
- Increase digit count from two to five
  - 8 → 20 signal channels
- Properly calibrate force sensors with high sensitivity
- Modify mechanisms for easier component attachment and removal (brace, retention cups, etc.)

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Paper Selection

- Clinical background (1 paper)
  - **Jing Xu et al. — Recovery of hand function after stroke: separable systems for finger strength and control**
- Practical application (3 papers)
  - Dovat, L. et al. — HandCARE: a cable-actuated rehabilitation system to train hand function after stroke
  - Jean-Claude Metzger et al. — Assessment-driven selection and adaptation of exercise difficulty in robot-assisted therapy: a pilot study with a hand rehabilitation robot
  - N.S.K. Ho et al. — An EMG-driven Exoskeleton Hand Robotic Training Device on Chronic Stroke Subjects (if time permits)

Recovery of hand function after stroke

- Objective:
  - Isolate aspects of hand function (strength/individuation)
- Key Results:
  - Finger evaluation device
  - Involuntary passive finger movement correlates with active finger force
  - Strength/Individuation
    - Max improvement in first 3 months
    - Strong correlation up to 60% non-paretic strength

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Recovery of hand function after stroke

- Background
  - 2 components of hand motor function
    - Strength
    - Independent finger control
  - Existing metrics
    - Fugl-Meyer Assessment (Upper Extremity) http://www.gu.se/digitalAssets/1328/1328946_fma-ue-english.pdf
    - Action Reach Arm Test

FMA-UE

A. UPPER EXTREMITY	/36
B. WRIST	/10
C. HAND	/14
D. COORDINATION / SPEED	/ 6
TOTAL A-D (motor function)	**/66**

H. SENSATION	/12
J. PASSIVE JOINT MOTION	/24
J. JOINT PAIN	/24

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Recovery of hand function after stroke

- Methodology
  - Sampling
    - 3 medical centers (JH, Columbia, Zurich)
    - Inclusion criteria
    - 14 healthy age-matched control patients
  - Duration
    - 5 visits over 54 weeks
    - Strength – 2 x 2 sec / digit
    - Individuation – 4 x 4 levels x 0.5 sec / digit

Patient	Age at stroke	Gender	Paretic Side	Initial impairment (FMA)	Initial MoCA
1	57	M	R	48	27
2	24	M	L	35	23
3	67	F	R	16	23
4	74	F	R	39	17
5	61	F	L	48	26
6	59	F	R	60	28
7	57	M	R	54	27
8	66	M	L	65	25
9	42	F	R	5	18
10	65	M	L	30	25
11	66	F	L	60	19
12	51	M	L	34	25
13	63	F	L	57	26
14	55	M	L	0	26
15	56	M	L	38	25
16	56	M	L	64	24
17	64	F	R	20	16
18	60	F	R	55	21
19	64	M	L	63	25
20	25	F	L	42	29
21	39	F	L	47	20
22	46	M	L	9	27
23	53	F	L	4	29
24	66	M	L	59	24
25	71	M	L	4	26
26	52	M	L	53	24
27	46	M	R	4	21
28	46	M	L	49	30
29	71	M	L	6	24
30	47	M	R	57	10
31	45	M	L	8	27
32	55	F	L	19	25
33	68	F	L	61	NaN
34	65	M	L	32	28
35	51	F	L	63	26
36	42	M	R	54	25
37	58	M	L	4	24
38	41	F	L	4	23
39	35	M	L	4	29
40	68	M	L	52	27
41	76	M	L	53	18
42	86	M	L	54	20
43	48	M	L	16	25
44	74	M	R	5	25
45	80	F	R	9	24
46	64	F	L	58	19
47	22	M	R	63	27
48	88	F	R	55	28
49	22	M	R	63	27
50	87	F	R	50	28
51	84	M	R	30	26
52	53	M	R	30	29
53	54	M	L	59	21
54	58	M	R	61	23

Recovery of hand function after stroke

- Methodology
  - Human Interface
    - Keyboard glove
    - Monitor display
  - Metrics
    - MVF (Max strength averaged across all digits)
    - Individuation (Averaged regression b/t active, passive fingers)

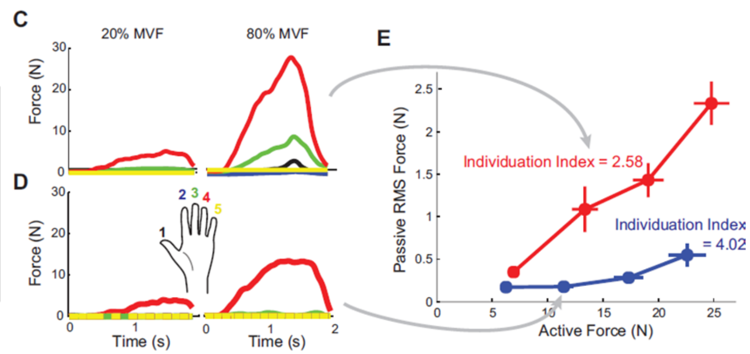
MVF Task

2 trials per digit

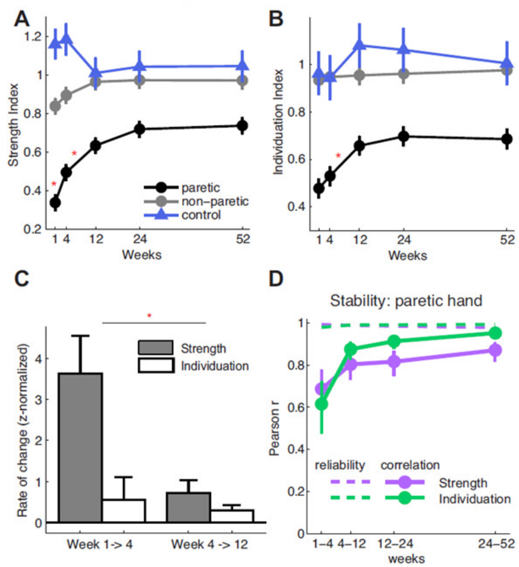
Individuation Task

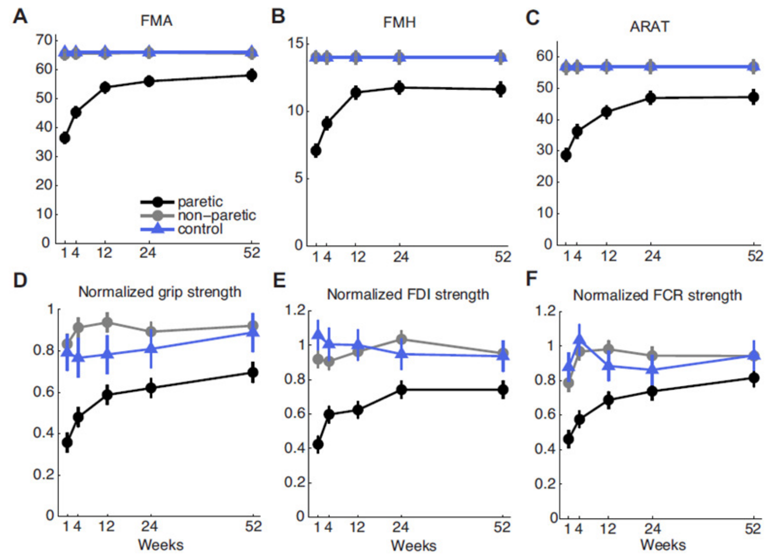
4 trials per level

4 levels (20% — 80%) per digit



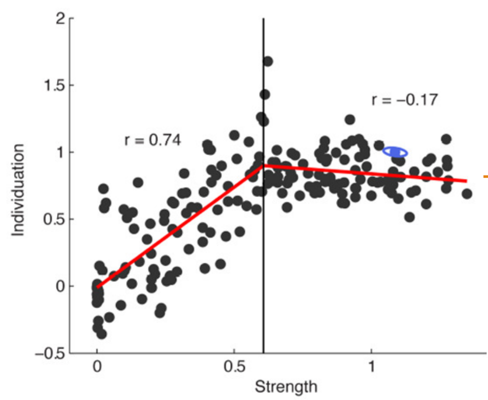
Recovery of hand function after stroke

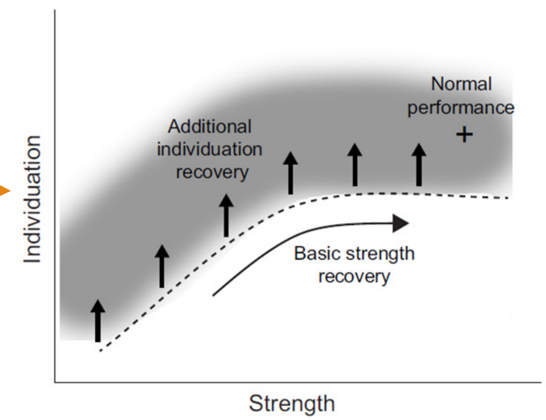




Recovery of hand function after stroke

- Highlights
  - Two independent metrics of motor control
  - Representative sampling
- Limitations
  - Averaging metrics overgeneralizes finger contributions
  - Single direction transducers
- Relevance
  - Evaluation device
  - Appropriate test and interface





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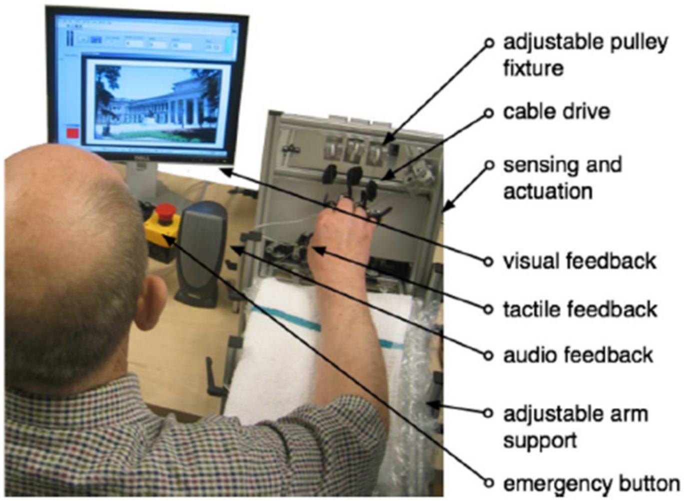
HandCARE cable-actuated rehabilitation system

- Objective:
  - Train fingers with elements of passive and active haptics
- Key Results:
  - Adjustable cable-driven training system
  - Individual control for each digit through clutch subsystem
  - Relatively large range of motion



HandCARE cable-actuated rehabilitation system

- Background
  - Active robotics
    - Bulky
    - Limited range
  - Nonactuated devices
    - No force control
  - Continuous passive motion (CPM)
    - No active movements

TABLE I
REVIEW OF DEVICES FOR HAND AND FINGER REHABILITATION

		Interface	Movement	DOF	Output Force, Torque	Workspace
Non actuated		Thera-Band Hand Exerciser [6]	hand opening/closing (fingers move together)	1○	45N	∞
Non actuated		Digi-Flex [6]	extension/flexion of the five fingers (fingers move individually)	5○	40N / finger	30–60°
Non actuated		Power-Web [6]	any movements of the five fingers (fingers move individually)	∞○	*	∞
CPM		Hand 8091 by VQ OrthoCare [13]	extension/flexion of the five fingers (fingers move together)	1⊕	*	0–90°
CPM		Amadeo System by Tyromotion [14]	extension/flexion of the five fingers (fingers move individually)	5⊕	*	0–70°
Active robotic devices	Additional hand module	Hand Robot Alpha-Prototype II [15]	extension/flexion of the five fingers (fingers move together)	1•	120N	-45–90°
Active robotic devices	Additional hand module	ARMin forearm extension [16]	forearm pronation/supination wrist extension/flexion	2•	4Nm 3Nm	±70° -30–75°
Active robotic devices	Additional hand module	Gentle/G Grasp Robot [17]	extension/flexion of four fingers (2 DOF) (fingers move together) thumb extension/flexion (1 DOF)	3• 3○	18N 12N	0–70° -10–60°
Active robotic devices	Robot dedicated to hand function	Rehabilitation Haptic Knob [18]–[20]	forearm pronation/supination extension/flexion of five fingers (fingers move together)	2•	1.5Nm 50N	±180° 0–60°
Active robotic devices	Robot dedicated to hand function	HWARD [21]	extension/flexion of four fingers (fingers move together) thumb extension/flexion wrist extension/flexion	3•	15N	25–90° 0–60° 0–20°
Active robotic devices	Glove and exoskeleton for individual finger	Rutgers Master II [22], [23]	extension/flexion of four fingers, without little finger (fingers move individually)	4•	16.4N / finger	0–40°
Active robotic devices	Glove and exoskeleton for individual finger	CyberGrasp, Immersion [24]	extension/flexion of five fingers (fingers move individually)	5•	12N / finger	-45–85°
Active robotic devices	Glove and exoskeleton for individual finger	Gifu Haptic Interface [25], [26]	extension/flexion of each finger (2 DOF) abduction/adduction of each finger (1 DOF) thumb extension/flexion (3 DOF) thumb abduction/adduction (1 DOF) forearm pronation/supination wrist extension/flexion	18•	5N 5N 5N 5N 3Nm 1.3Nm	0–90° 0–45° 0–80° 0–60° ±90° ±80°
Active robotic devices	Robot for 1-2 fingers	SPIDAR [27], [28]	extension/flexion of two fingers	6•	4N / finger	-45–90°
Active robotic devices	Robot for 1-2 fingers	HIFE [29]	extension/flexion of one finger	2•	10N / finger	-45–90°

○ non actuated DOF ⊕ actuated and passive DOF • actuated and active DOF
* not available

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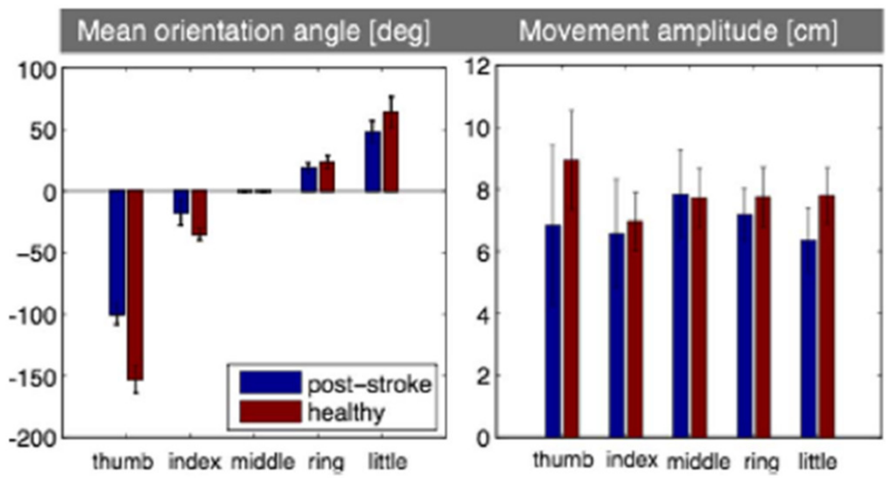
HandCARE cable-actuated rehabilitation system

- Biomechanical study
  - Sampling
    - 8 healthy participants
    - 5 chronic stroke patients (RH)
  - Measurements
    - Finger orientation
    - Finger amplitude
    - States: open and close



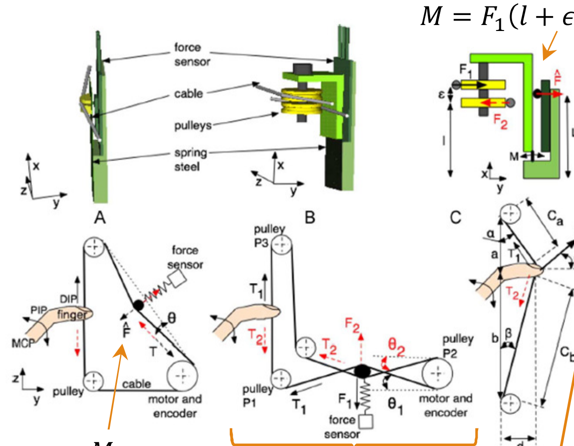
HandCARE cable-actuated rehabilitation system

- Construction
  - Multi-pulley system (POM)
  - Cables (steel)
    - Linear workspace $\Delta a = 8\text{cm}$
    - Open palm range
  - Force sensors
    - 1000 Hz sampling rate
    - Orthogonally anchored to cable
    - θ: Angular deflection of cable
    - $\hat{F}$: sensed force; F: applied finger force; $\rho = \frac{\hat{F}}{F}$
    - Sensor voltage $V = c\hat{F} + V_0 = cF\frac{l}{L}\sin\theta + V_0$
    - $V \in [-15, 15]\ N$ If $c = 0.2\frac{V}{N}$ and $V_0 = 1.9\ V$

TABLE II
FEATURES OF THE *HandCARE*

linear motion of each finger	8.5	*cm*
flexion of each finger	0 - 70	*deg*
maximal opening (between thumb and opposing fingers)	18.5	*cm*
minimal opening (between thumb and opposing fingers)	1.5	*cm*
maximal/minimal force generated at the ouput	± 75 ± 15	*N* *N* for each finger
force measuring range	± 15	*N* for each finger
force sensitivity	0.2	*N*
control frequency	100	*Hz*
sensor sampling frequency	1000	*Hz*
weight (with motor and control system)	5	*kg*
external dimensions	60 x 30 x 30	*cm*^{3}

$$M = F_1(l + \epsilon) - F_2 l$$



$$T_1 \cos\alpha = T_2 \cos\beta$$

$$\cos\alpha = \frac{a}{C_a} \quad \cos\beta = \frac{b}{C_b}$$

$$C_a = \sqrt{a^2 + d^2}$$

$$C_b = \sqrt{b^2 + d^2}$$

$$F = k[(C_a + C_b) - (a + b)]$$

$$k_{steel\ cable} = 40\frac{N}{mm}$$

$$\hat{F} = \frac{M}{L}$$

$$\hat{F} = (T_1 - T_2)\frac{l}{L}\sin\theta$$

$$\hat{F} = F\sin\phi$$

$$F_i = T_i \sin\theta_i,\ i = 1{,}2$$

$3.5\ cm < a < 21.5\ cm \rightarrow \Delta a = 8\text{cm}$

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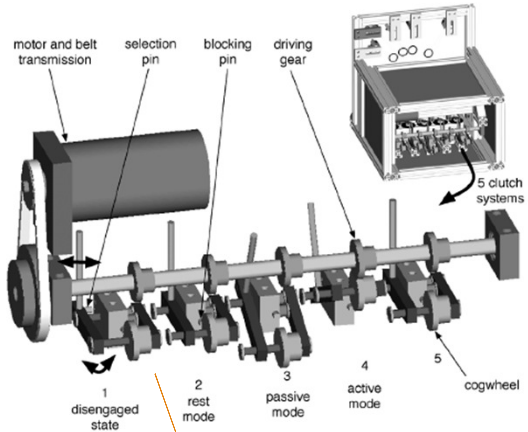
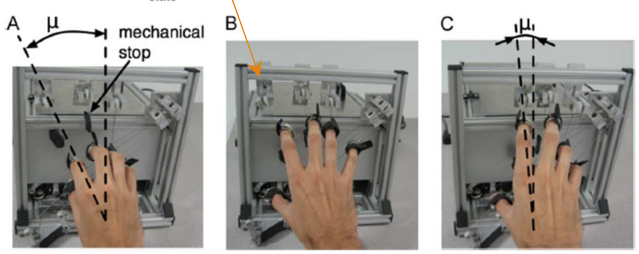
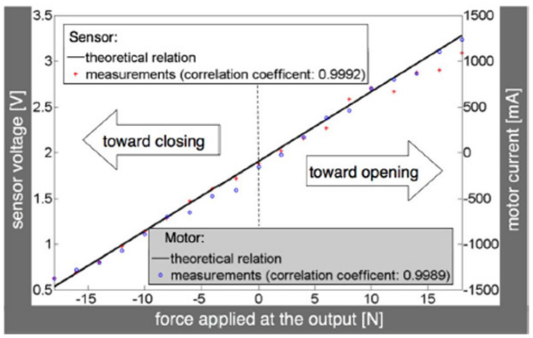
HandCARE cable-actuated rehabilitation system

- Construction
  - Cogwheels (steel)
  - Clutch subsystem
    - Active mode (4) — driving gear
    - Fixed mode (2) — blocking pin
    - Free mode (1,3) — disengaged gear and pin
  - Actuation/control subsystem
    - 150 W motor; 500 counts/rev encoder
    - 100 Hz sampling from encoder; 100 Hz commands to motor
    - Able to record 2-7 Hz human motions
  - Safety subsystem
    - Mechanical stops
    - Emergency button

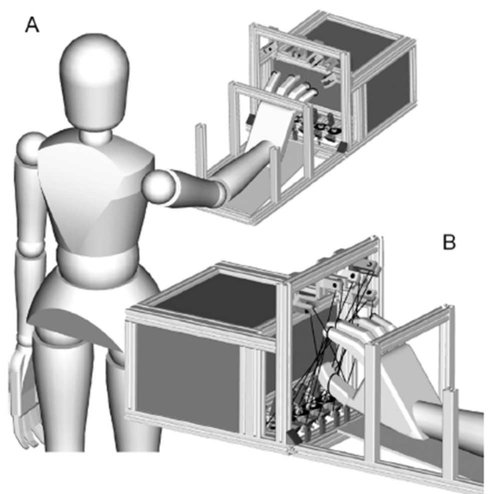






HandCARE cable-actuated rehabilitation system

- Advancements
  - Wide actuation workspace
  - Hybrid modes
- Limitations
  - Little detail about material selection
  - Human testing (detail and scale)
- Relevance
  - Passive actuation
  - Force transducing individual digits
  - Human signal sampling rate



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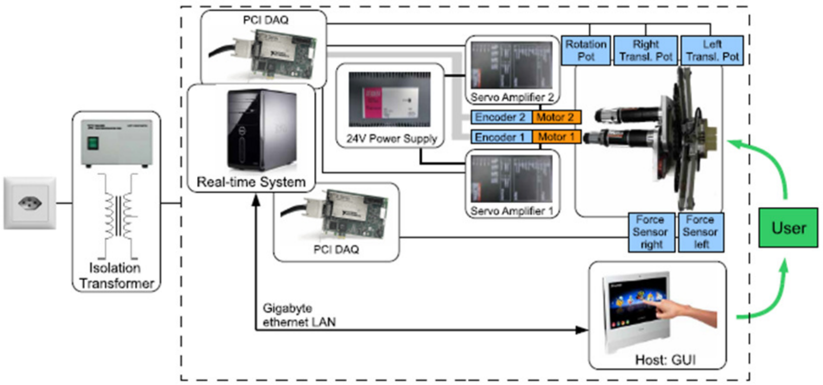
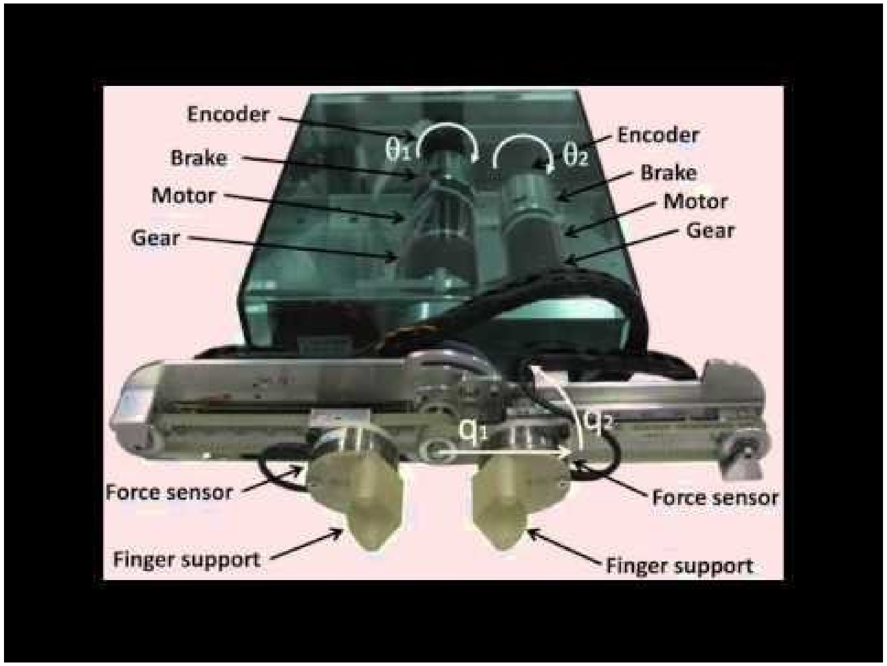
ReHapticKnob Pilot Study

- Objective:
  - Adaptive stroke therapy
- Key Results:
  - 2 DOF passive haptic device
  - Control over exercise performance with difficulty adjustment
  - Sensorimotor impairment characterization

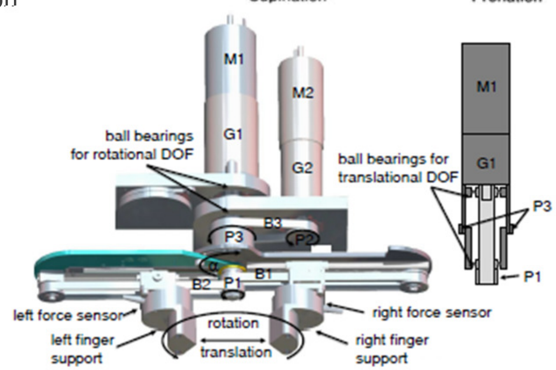


ReHapticKnob Pilot Study



ReHapticKnob Pilot Study

- Background
  - Relationship between engagement and difficulty
  - 2DOF range of motion
    - Pronation/supnation
    - Grip aperature



Performance measure DOF	*ReHapticKnob* translation	 rotation
Range of motion	30-200 *mm*	±159°
Position resolution (encoder)	0.0024 *mm/count*	0.009°/*count*
Velocity resolution (encoder) @ 1kHz	2.45 *mm/s*	9°/*count*
Maximum velocity	520 *mm/s*	4.8 *rotations/s*
Maximum acceleration	13.25 m/s^2	124 $rotations/s^2$
Static friction	6 *N*	<0.4 *Nm*
Maximum actuation force at end-effector (continuous)	1181 *N* (88 *N*)	12.18 *Nm* (0.98 *Nm*)
Force/Torque meas. in x,y direction (Resolution)	80 *N* (0.02 *N*)	4 *Nm* (0.0005 *Nm*)
Force/Torque meas. in z direction (Resolution)	240 *N* (0.04 *N*)	4 *Nm* (0.0005 *Nm*)
Closed-loop (PID) position bandwidth	6.6 *Hz*	7.6 *Hz*
Control frequency	1kHz	

$$ROM_{\varphi} = \varphi_{p,max} - \varphi_{s,max}$$

$$ROM_x = x_{max} - x_{min}$$

ReHapticKnob Pilot Study

- Methodology
  - Sampling
  - Robotic Assessment
    - ROM
    - Proprioception
    - Haptic perception
  - Neurocognitive Exercises
    - Proprioception
    - Haptic perception
    - Sensorimotor memory
    - Sensorimotor coordination
  - Difficulty adjustment
  - Impairment Evaluation
    - Fugl-Meyer Assessment
    - Upper Extremity (A-D) & Hand/Wrist (B,C)

Table 1 Patient demographics

Patient	Age [years]	Gender	Handed -ness	Impaired hand	Post lesion [weeks]	Initial FMA-UE[1]	Initial FMA[1] subscore (hand/ wrist)	Neurological disorder
P1	85	F	R	L	2	57	20	Ischemic stroke in the right corona radiata and frontal centrum semiovale
P2	67	M	R	L	2	55	20	Ischemic stroke in right thalamus
P3	80	M	R	L	5	59	19	Ischemic stroke in right ponto-cerebellar region
P4	70	M	R	R	6	52	16	Ischemic stroke in left parietal lobe
P5	53	M	R	L	4	52	17	Ischemic stroke in right pre and post-central gyrus and right parietal lobe
P6	82	M	R	L	3	61	20	Ischemic stroke in cortico-subcortical temporal-parietal lobe
Mean	72.8	-	-	-	3.7	56.0	18.7	-
(Std)	(12.0)	-	-	-	(1.5)	(3.7)	(1.8)	-

[1] Fugl-Meyer Assessment (FMA) [31]. FMA scores for the upper extremity (maximum score = 66) and hand/wrist (maximum score = 24) subsections are reported (lower scores indicate greater impairment).

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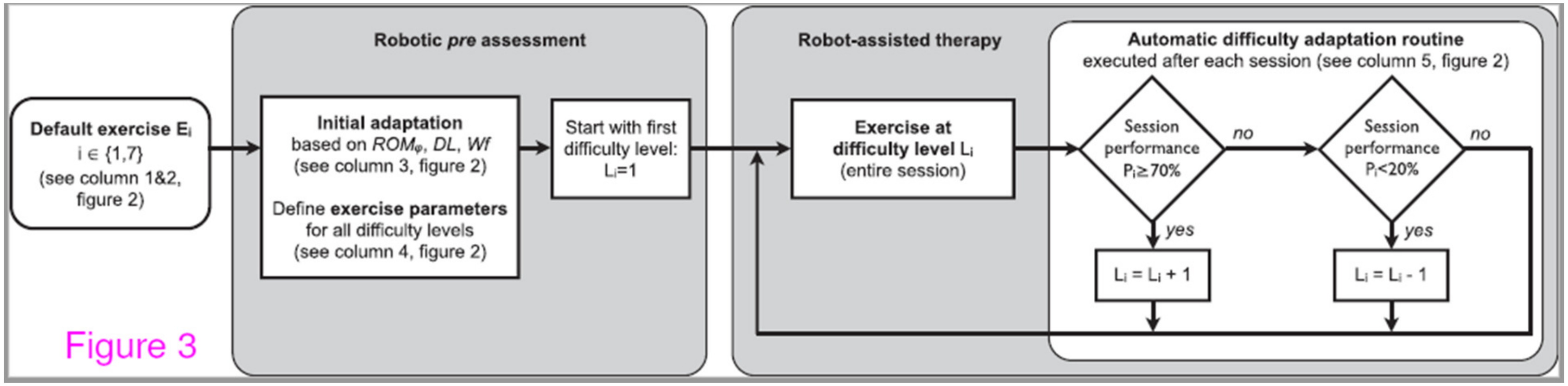
ReHapticKnob Pilot Study



$$L_i = \begin{cases} L_i + 1 & ,if\ P_i \geq 70\% \\ L_i & ,if\ P_i \in\ ]20,70[\ \% \\ L_i - 1 & ,if\ P_i \leq 20\% \end{cases}$$

ReHapticKnob Pilot Study

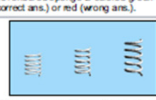
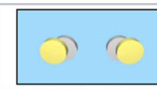
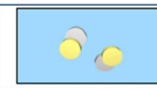
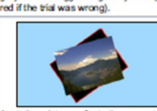
Exercise description	Visual feedback	Initial adaptation	Exercise parameters	Performance metric
E_1: Proprioception (Passive grip aperture identification) The robot closes the hand from an initial grasping aperture d_i (adjustable in the range [102, 122] mm based on hand size) to one out of N target apertures. The N target apertures differ by δ_d and are centered around d_i-22 mm.	 N sticks indicate the N grasping apertures. *Identification feedback*: a green check mark (correct ans.) or a red cross (wrong ans.) is displayed next to the correct (target) stick.	The difference between target apertures is a function of the assessed distance *DL*: δ_d = *f*(distance *DL*) The assessed distance *DL* (assessment A_2) is limited to the range [2, 10] mm	5 difficulty levels: Number of target apertures N = {3,4,5,5,5} Target aperture difference δ_d = {2,1.6,1.2,1.1,1} × (distance *DL*)	Percentage of correct identification trials
E_2: Proprioception (Passive pronosupination angle identification) The robot rotates the hand from an initial angle (-60°, i.e. counterclockwise) to one out of N target angles. The N target angles differ by δ_φ and are centered around 0°.	 N triangles indicate the N target angles. *Identification feedback*: a green edge (correct ans.) or a red edge (wrong ans.) is displayed around the correct (target) angle.	none	5 difficulty levels: Number of target apertures N = {3,4,5,6,7} Target aperture difference δ_φ = {30,25,20,15,10}°	Percentage of correct identification trials
E_3: Haptic perception (Stiffness identification during grasping) The robot renders N sponges (spring-damper combinations) which have to be identified based on their viscoelastic resistance during squeezing. Rendered stiffness and damping pairs vary by η percent from one to another and are centered around K_{medium} = 550 N/m and B_{medium} = 35 N/(m/s).	 All N sponges are displayed and animated during squeezing. *Identification feedback*: the rendered sponge is colored green (correct ans.) or red (wrong ans.).	The relative difference between the visco-elasticities is a function of the assessed stiffness *Wf*: η = *f*(stiffness *Wf*) The assessed stiffness *Wf* (assessment A_5) is limited to the range [7.5, 45] %	10 difficulty levels: Number of sponges N = {3,3,4,4,5,5,5,5,5,5} Relative difference between viscoelasticities η = {2,1.9,1.8,1.7,1.6,1.5, 1.4,1.3,1.2,1.1} × (stiffness *Wf*)	Percentage of correct identification trials
E_4: Haptic perception (Stiffness identification during pinching) The robot renders N springs (spring-damper combinations) which have to be identified based on their viscoelastic resistance during vertical index finger pinching. Rendered stiffness and damping pairs vary by η percent from one to another and are centered around K_{medium} = 300 N/m and B_{medium} = 20 N/(m/s).	 All N springs are displayed and animated when compressed. *Identification feedback*: the rendered spring is colored green (correct ans.) or red (wrong ans.).	The relative difference between the visco-elasticities is a function of the assessed stiffness *Wf*: η = *f*(stiffness *Wf*) The assessed stiffness *Wf* (assessment A_5) is limited to the range [7.5, 45] %	5 difficulty levels: Number of springs N = {3,4,5,5,5} Relative difference between viscoelasticities η = {2,1.8,1.6,1.4,1.2} × (stiffness *Wf*)	Percentage of correct identification trials
E_5: Sensorimotor memory (Grip aperture) *Teach*: the robot closes the hand from an initial grasping aperture d_i (adjustable in the range [102, 122] mm based on the hand size) to a randomly selected target grasping aperture d_t in the range [70, d_i-2] mm. After 2 seconds the hand is moved back to d_i. *Reproduce*: the patient is asked to move to the „taught" target grasping aperture and hold this position for 2 seconds (position logging). A trial is correct if the logged position lies within the error band [d_t-δ_e/2, d_t+δ_e/2]. A damped force field helps to smoothen the movement of the patient: B=β × 50 N/(m/s).	 No visual feedback is provided during „teach" and „reproduce" phases. After trial completion a green check mark is shown if the trial was correct. Additionally, the target position is shown in grey and the registered position in yellow (or in red if the trial was wrong).	The error band is a function of the assessed distance *DL*: δ_e = *f*(distance *DL*) The assessed distance *DL* (assessment A_2) is limited to the range [2, 10] mm	5 difficulty levels: Error band δ_e = {1.2,1.1,1,0.9,0.8} × (distance *DL*) Reduction of damping support: β={1,0.75,0.5, 0.25,0} **Exercise parameters:** Par = {val1,val2,val3,val4,val5} level 1 level 2 level 3 level 4 level 5	Percentage of correct reproduced trials
E_6: Sensorimotor memory (Pronosupination angle) *Teach*: the robot rotates the forearm from an initial angle (-60°, i.e. counter-clockwise) to a target angle φ_t randomly selected from a range R. After 2 seconds the hand is returned to φ_i. *Reproduce*: the patient is asked to rotate to the „taught" target angle and hold this angle for 2 seconds (angle logging). A trials is correct if the logged angle lies within the error band: [φ_t-δ_e/2, φ_t+δ_e/2]. A damped force field helps to smoothen the movement of the patient: B=β × 50 Nm/(°/s).	 No visual feedback is provided during „teach" and „reproduce" phases. After trial completion a green check mark indicates if the trial was correct. Additionally, the target angle is shown in grey and the logged angle in yellow (or in red if the trial was wrong).	Assessed rotational ROM_φ (assessment A_1) defines the range R from which the target angle is randomly selected: R=*f*(ROM_φ) The range R is limited to [-60, 60] °	5 difficulty levels: Range from which φ_t is randomly selected R = {1,1.05,1.1,1.15,1.2} × ROM_φ Reduction of damping support: β={1,0.75,0.5, 0.25,0} Error band δ_e = {10,8,6,4,2} °	Percentage of correct reproduced trials
E_7: Sensorimotor coordination (Haptically cued forearm rotation) The patient is asked to explore the rotational DOF in order to find a target angle φ_t which is indicated haptically by means of a small haptic valley/gap with amplitude *A* along the translational DOF. The robot has to be held in [φ_t-2°, φ_t+2°] for 2 seconds to register and verify the correctness of the current robot angle φ. A rotational damping field with damping constant B smooths the patient's movement. A trial is successful when the target angle is found within 60 seconds. Otherwise the rob… the patient passively to φ_t.	 A rotating picture reflects the current robot angle φ. A green frame is drawn around the picture when the target angle has been found successfully. Only during task familiarization the target angle φ_t is visualized by a black square.	Assessed rotational ROM_φ (assessment A_1) defines the range R from which the target angle is randomly selected: R=*f*(ROM_φ) The range R is limited to [-60, 60] °	10 difficulty levels: Applicable range of target angles: R = {1,1.02,1.04,1.06,1.08, 1.1,1.12,1.14,1.16,1.18} × ROM_φ Reduction of damping support: B={0.9,0.8,0.7,0.6, 0.5,0.4,0.3,0.2,0.1,0} e-3 [Nm/(°/s)] Haptic valley amplitude: *A*={1.8,1.65,1.5,1.35,1.2,1.05,0.9, 0.75,0.6,0.45} [mm]	Number of successful trials within exercise time. 20 trials (or more) in 15 min corresponds to 100%.

Figure 2

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ReHapticKnob Pilot Study

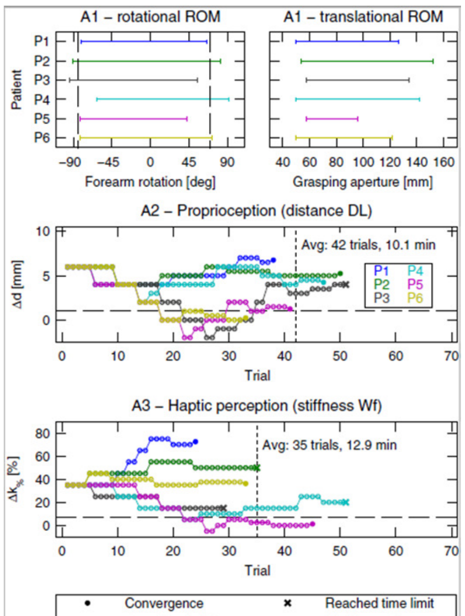


Figure 4

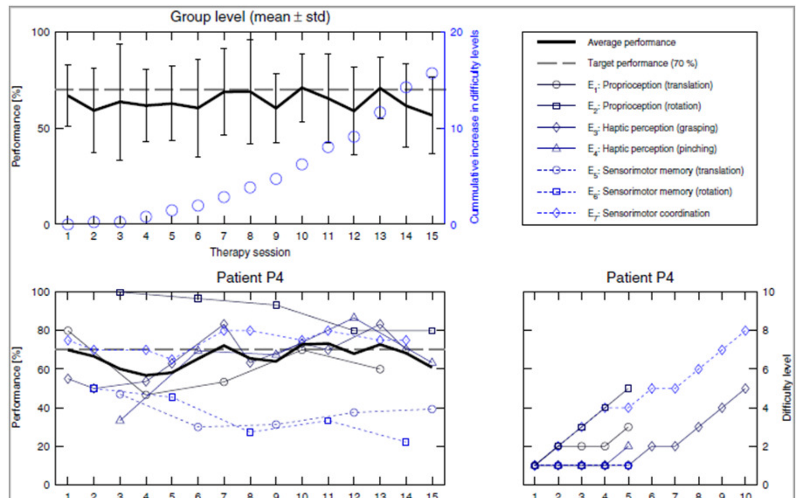


Figure 5

ReHapticKnob Pilot Study

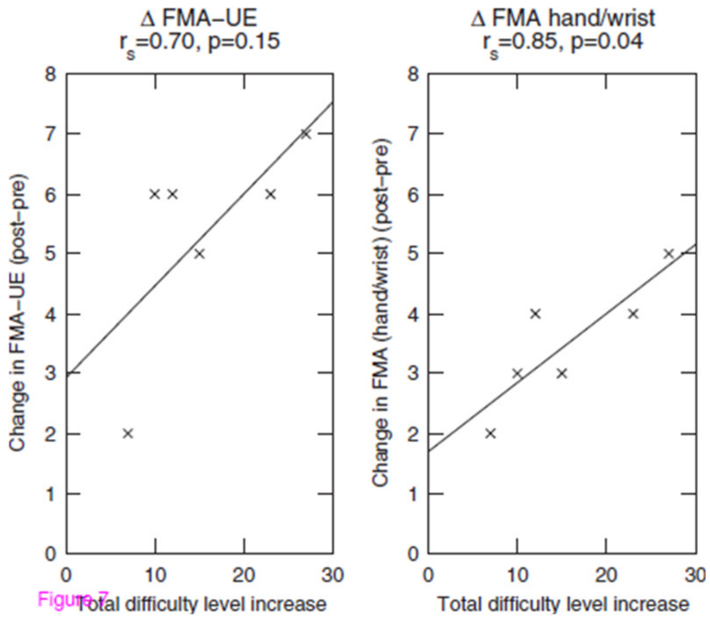


Figure 7

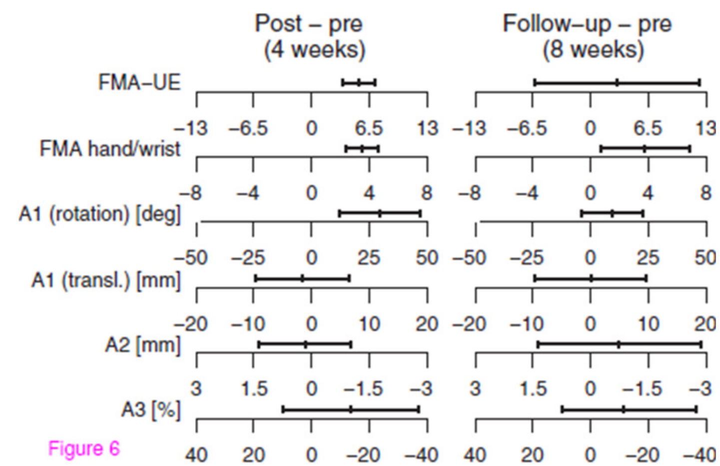
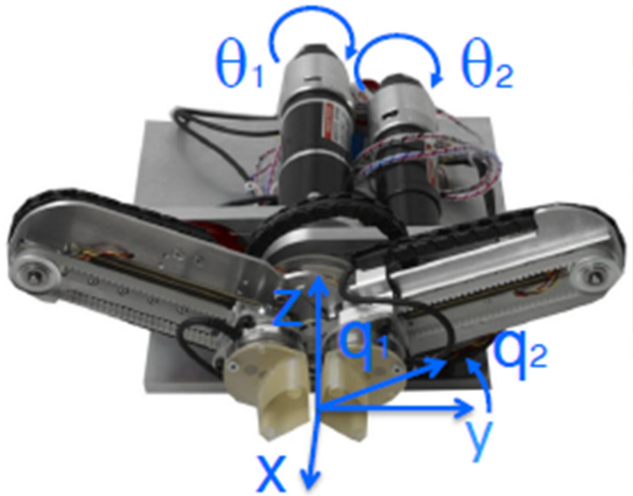


Figure 6

ReHapticKnob Pilot Study

- Advancements
  - System of adjusting difficulty
  - Plenty of detailed tests
- Limitations
  - High variability in performance
  - Small subject pool / limited control
- Relevance
  - Modifying force level difficulty
  - Mechanical adjustment of actuators



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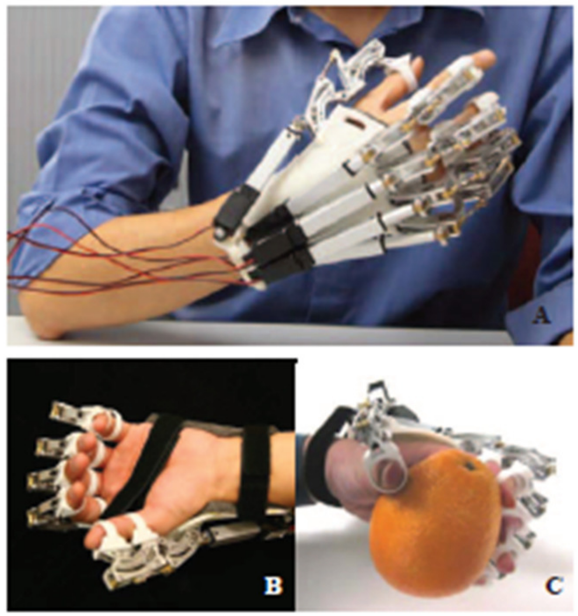
Paper Selection

- Clinical background (1 paper)
  - Jing Xu et al. — Recovery of hand function after stroke: separable systems for finger strength and control
- Practical application (3 papers)
  - Dovat, L. et al. — HandCARE: a cable-actuated rehabilitation system to train hand function after stroke
  - Jean-Claude Metzger et al. — Assessment-driven selection and adaptation of exercise difficulty in robot-assisted therapy: a pilot study with a hand rehabilitation robot
  - **N.S.K. Ho et al. — An EMG-driven Exoskeleton Hand Robotic Training Device on Chronic Stroke Subjects**

EMG-driven Exoskeleton Hand Robotic Training

- Objective:
  - Develop active rehab exoskeleton driven by EMG
- Key Results:
  - Exoskeleton deliverable
  - Portable by design



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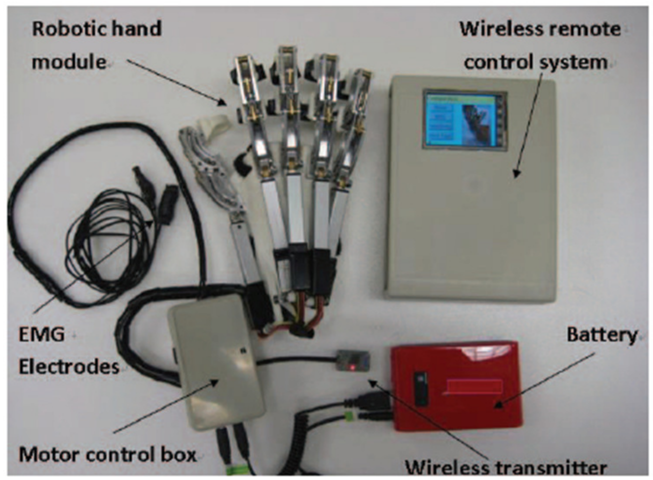
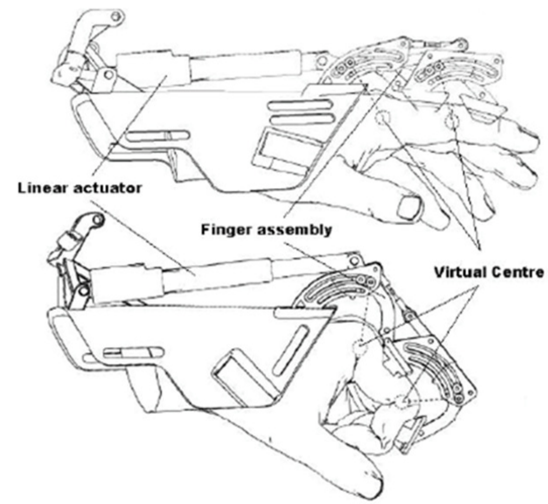
EMG-driven Exoskeleton Hand Robotic Training

- Background
  - Shoulder/elbow function recover faster than hand/wrist
  - Surface EMG from residual muscle
  - Exoskeleton design
    - 2DOF with linear actuator
    - 55 degree ROM for metacarpophalangeal (MCP) joint
    - 65 degree ROM for proximal interphalangeal (PIP) joint
    - 2 second zero-load close/open duration





EMG-driven Exoskeleton Hand Robotic Training

- Methodology
  - Sampling
    - Eight chronic stroke patients
    - Presumably convenience sampling
  - Duration
    - Three to five sessions / week
    - Two 10-minute tasks
      - Move block 50 cm (horizontal)
      - Move block 20 cm (vertically)
    - Five min rest in between

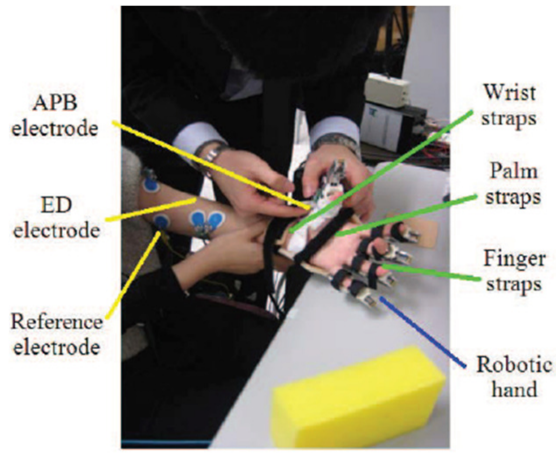
TABLE I. DEMOGRAPHIC INFORMATION

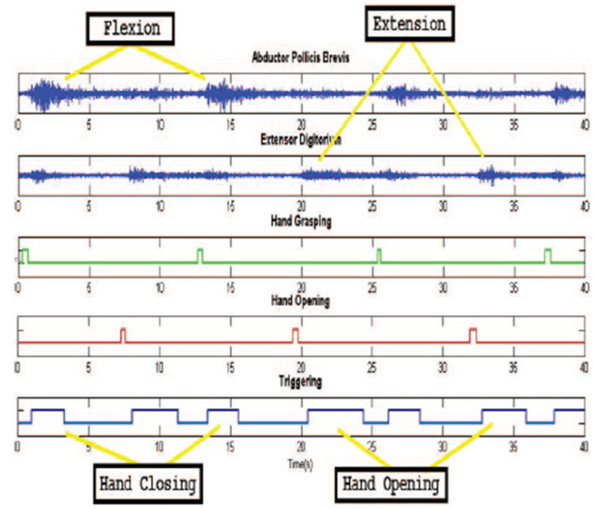
Subject	Gender	Age	Stroke Type	Affected Limb Side	Time after Stroke
Chronic					
1	F	28	Hemo.	Left	4 years
2	M	42	Hemo.	Right	14 years
3	F	63	Isch.	Left	4 years
4	M	67	Hemo.	Right	14 years
5	M	49	Isch.	Left	8 years
6	M	58	Isch.	Left	3 years
7	M	64	Isch.	Right	4 years
8	M	51	Isch.	Left	10 years

Female (F); Male (M); Hemorrhage (Hemo); and Ischemia (Isch).

EMG-driven Exoskeleton Hand Robotic Training

- Methodology
  - 1 kHz EMG from two muscle groups
    - Abductor pollicis brevis (closing)
    - Extensor digitorum (opening)
    - Mode select focuses action
  - Trigger at 20% max voluntary contraction EMG
  - Baseline and MVC EMG measured at beginning
  - Metrics
    - FMA-UE – Motor function
    - ARAT – Common daily tasks





EMG-driven Exoskeleton Hand Robotic Training

- Advancements
  - 2 DOF lightweight exoskeleton
  - Improvement in hand function scores
- Limitations
  - Lack of portability verification
  - Limited patient group
- Relevance
  - Mobility & weight
  - Human signal sampling rate
  - Secure hand via Velcro

TABLE II. STATISTICAL SUMMARY

Assessments (max. score)	Mean ± SD Pre	Mean ± SD Post	Paired t-test
FMA-S&E (42)	21.50±2.59	28.00±7.40	**0.0426***
FMA-W&H (24)	7.83±5.11	11.83±5.85	**0.0035***
ARAT (57)	21.833±8.66	29.67±9.14	**0.0121***

* Mean value changes with statistical significance (P<0.05, paired t-test).

Laboratory for Computational Sensing + Robotics, The Johns Hopkins University

Recap and Going Forward

- Finger Eval. Device
  - Motor function metrics (MVF, Individuation)
- HandCARE
  - Passive actuation
  - Force transduction and sampling
- ReHapticKnob
  - Engagement through dynamic difficulty
  - Actuator adjustment
- EMG Exoskeleton
  - Mobility, hand securing, sampling

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[5] Metzger, J. C., Lambercy, O., Califfi, A., Dinacci, D., Petrillo, C., Rossi, P., ... & Gassert, R. (2014). Assessment-driven selection and adaptation of exercise difficulty in robot-assisted therapy: a pilot study with a hand rehabilitation robot. Journal of neuroengineering and rehabilitation, 11(1), 154.

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