Lessons Learned from A Three-Week Long User Study with post-SCI Patients using UCF-MANUS ARM

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Research Objectives

- Provide a sufficient quantitative and qualitative analysis to support the following statements.

    1. People with traumatic SCI will benefit from use of a UCF-MANUS.

    2. Novel interfaces being developed for subjects to use UCF-MANUS will vary in both ability to complete tasks as well as both rate of completion and subject experience.

Research Hypotheses

- **Hypothesis 1 (H1)**
  - Selection of specific user interface doesn't show any biased effect on the user's performance in the control.
- **Hypothesis 2 (H2)**
  - Compared with Cartesian interface, Auto interface is easy-to-use.
- **Hypothesis 3 (H3)**
  - Over a three-week long user study, the participants will undergo a significant improvement in their control performance.
- **Hypothesis 4 (H4)**
  - Tasks can be classified as easy and hard based on initial relative pose between object and robot.
- **Hypothesis 5 (H5)**
  - Baseline characteristics of subjects are correlated with the quantitative metrics.
- **Hypothesis 6 (H6)**
  - User's degree of satisfaction is correlated with performance metrics.

Selection Criteria

- Age: ≥ 21 (90 days post traumatic injury)
- Diagnosis level: C3-C6
- Powered wheelchair
- Baseline characteristics
  - MMSE: ≥ 22
  - FIM: ≤ 40

10 Subjects

Subject Grouping (in random)

- **Cohort A** (Auto interface)
    - 4 buttons for centering
    - 4 buttons for additive actions
    - 1-click initiation of automated grasping

- **Cohort C** (Cartesian interface)
    - 18 buttons for 3D translational/rotational commands
   - Fully manual control
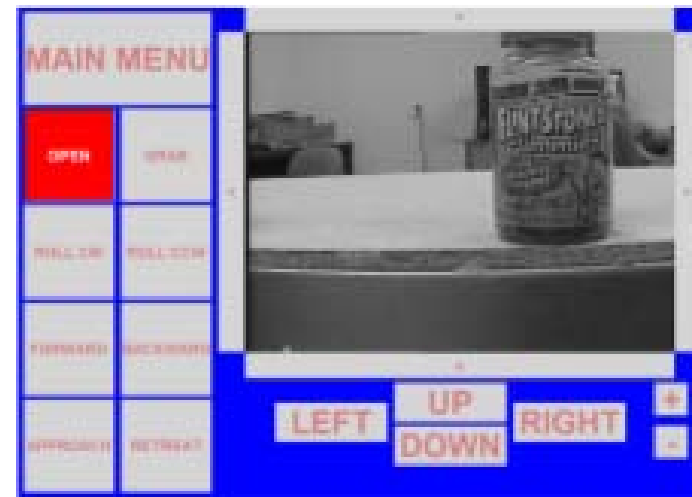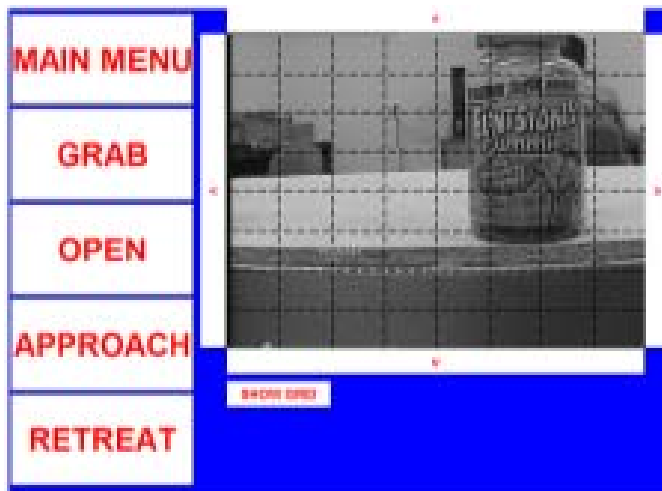
Robotic Platform

- UCF-MANUS ARM
  - 6DOF MANUS ARM
  - Stereo camera for 2D & 3D visual perception
  - Force sensor for adaptive grasping (only in Auto interface)
  - Two hardware user interfaces
    - Trackball + Switch
    - Microphone + Switch
  - GUI for live video feedback
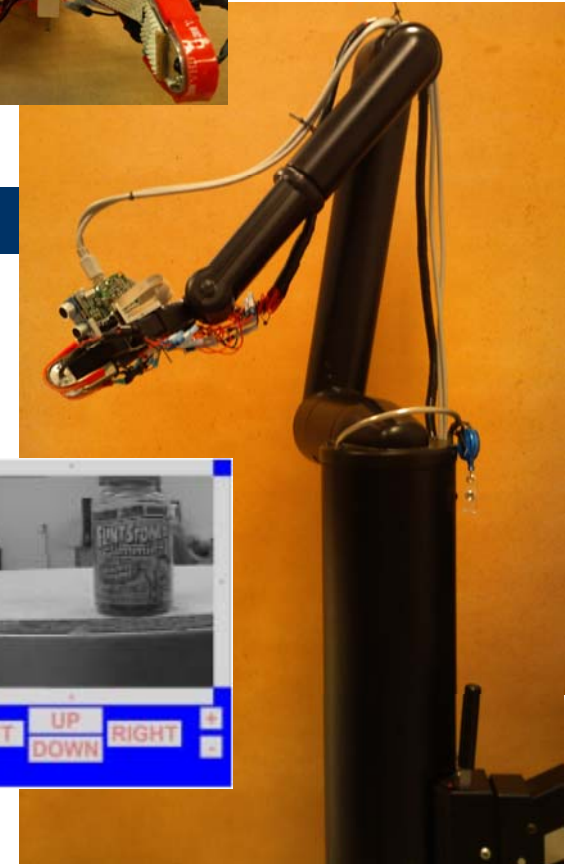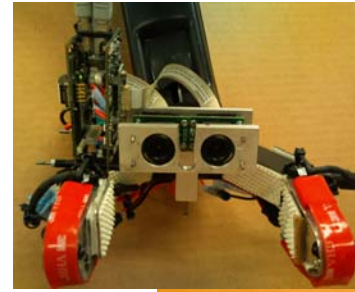
Testing Setup

- Bi-level Shelves
    - Easy level (30″ height)
    - Hard level (6″ height)
- Pick-and-place of Six ADL objects
    - Mini cereal box
    - Vitamins jar
    - Juice Bottle
    - Remote control
    - Toothpaste box
    - Soap box

7
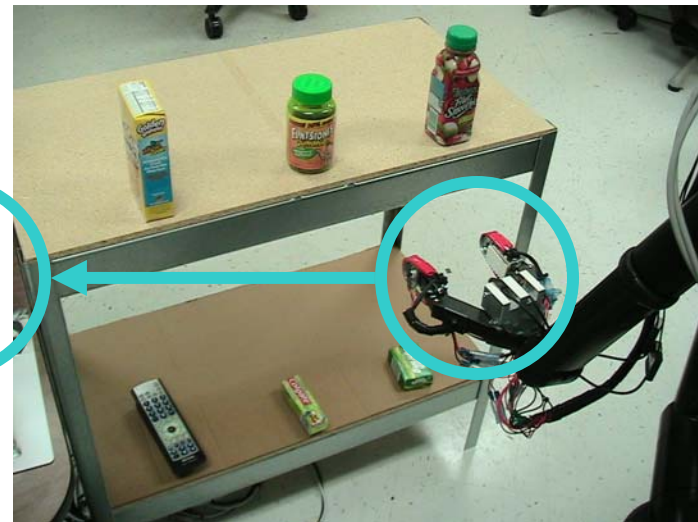
Outcome Measures

- Quantitative metrics
  - Time to task completion (TTC)
  - Number of user clicks (NOC)
- Psychometrics
  - Psychosocial Impact of Assistive Devices Scale (PIADS)
    - Competence, Adaptability, and Self-esteem
    - Ranged in [-3.0,+3.0]
- Semi-Structured Exit Interview

Testing Protocol

	Purpose	Detail	Time
WEEK0	Pre-Evaluation	AROM/PROM assessment bilateral UE (goniometer)	120 min
		Manual Muscle Test bilateral UE from wheelchair level	
		Sensory Assessment/ASIA	
		MVPT to assess visual perception	
		Determine appropriate interface (Trackball/Switch or Mic/Switch)	
		Recommend location of jelly switch	
WEEK1	Initial Training	OT is manipulating the MANUS and providing verbal instruction.	60 min
		PT performs preliminary training with the MANUS with basic motions.	
		PT is set up and tests for reach and grasp of six items.	
WEEK2	Top Shelf Training	PT is able to actively practice with prompts picking up top shelf items.	60 min
		PT performs test with top shelf item placed in fixed testing positions.	
	Bottom Shelf Training	PT is able to actively practice with prompts picking up bottom shelf items.	60 min
		PT performs test with bottom shelf item placed in fixed testing positions.	
WEEK3	Final Training	Practice with the MANUS (no verbal cueing)	30 min
	Post-Evaluation	Final test for top and bottom shelves (no verbal cueing)	60 min
		PIADS assessment by OT	

Data Analysis

- Small sample size → Nonparametric tests

- Wilcoxon signed-rank test
  - Alternative to the paired Student's t-test
  - Statistical hypothesis test for quantitative metrics

- Pearson product-moment correlation coefficient (PMCC)
  - Correlation between quantitative metrics and psychometrics

10

Demographic Profile

- Age: 41.1 (9.9)
- Onset (y): 16.7 (11.8)
- 6 Males and 4 Females
- Diagnosed: C4-C6
  (PT#8: C7 → not fully
  functional as C7)

	Age	Sex	Diag.	Onset
PT#1	43	M	C4	22
PT#2	26	M	C4-5	10
PT#3	54	M	C5-6	34
PT#4	35	M	C6	5
PT#5	49	M	C5-6	4
PT#6	25	F	C5	9
PT#7	44	F	C4	21
PT#8	39	F	C7	3
PT#9	46	F	C6-7	6
PT#10	50	M	C5-6	33

Baseline Characteristics

- MMSE: 27.7 (1.64) > 22
- FIM: 18.6 (9.5) < 40
- MVPT-R: 57.2 (5.01)

	MMSE	MVPT-R	FIM^{TM}
PT#1	26	65	6
PT#2	29	58	17
PT#3	30	54	23
PT#4	27	63	15
PT#5	26	60	39
PT#6	30	52	23
PT#7	26	57	6
PT#8	27	54	21
PT#9	29	49	21
PT#10	27	60	15

H1. Choice of user interface

- Five able-bodied subjects were tested across different user interfaces
  - 1) Touch Screen (TS), 2) Trackball only (TO), 3) Trackball and Jelly Switch (TJ), and 4) Microphone and Jelly Switch (MJ).
- Randomly ordered selection of user interfaces
- TO performed significantly poorly than TS in TTC; $Z=-2.8925$, $p<0.05$; while other interfaces had no significant difference with TS.
- MJ is not significantly different with others.

- In consideration of the subjects' functional capability, our choice of two user interfaces (TJ and MJ) was fully supported by this preliminary test.

H2. Ease of use

- Cohort A is significantly efficient than Cohort C
  - TTC; Z=-2.5135, p<0.05
  - NOC; Z=-7.9615, p<0.05

14
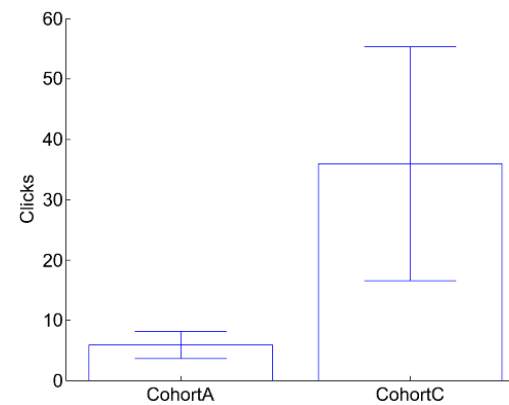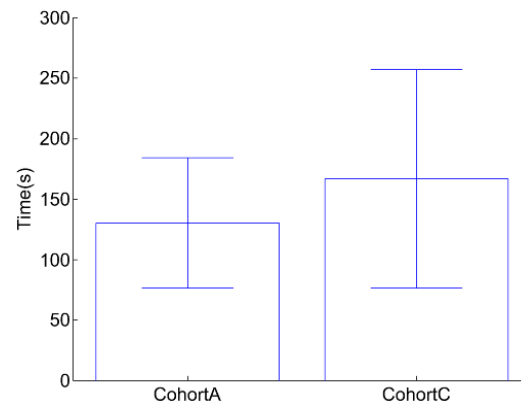
H3. Learning effect (in total)

- Significant improvement across a three-week training
  - Week1 to Week 2
    - TTC; $Z=-1.568$, $p>0.05$; and NOC; $Z=-1.7832$, $p>0.05$
  - Week2 to Week 3
    - TTC; $Z=-3.6636$, $p<0.05$; and NOC; $Z=-3.8078$, $p<0.05$
  - Week1 to Week 3
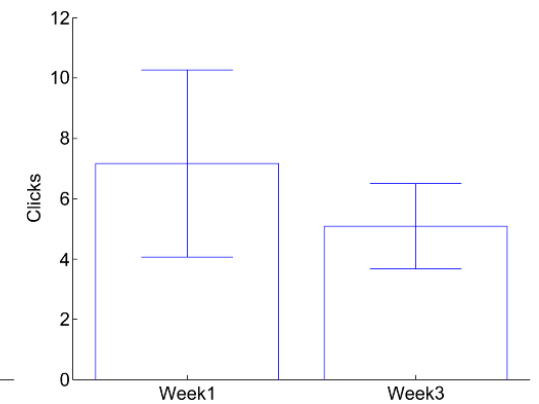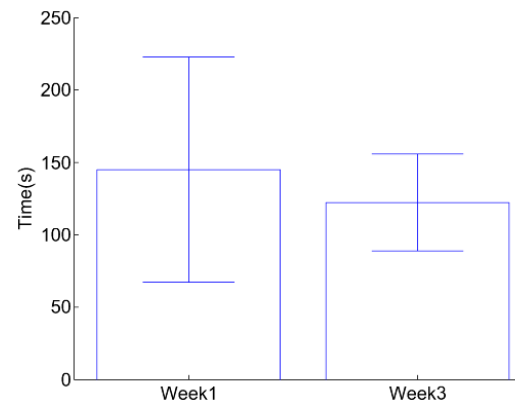   - TTC; $Z=-4.2664$, $p<0.05$; and NOC; $Z=-4.5576$, $p<0.05$

Progressive
Improvement

15
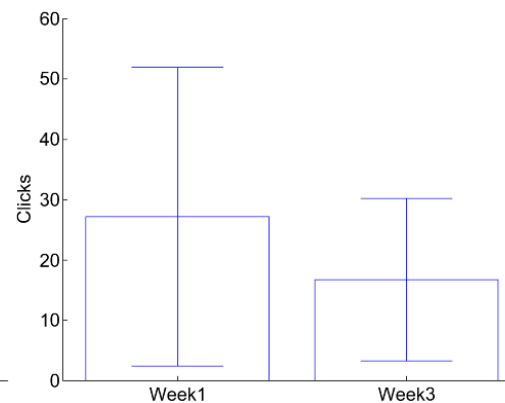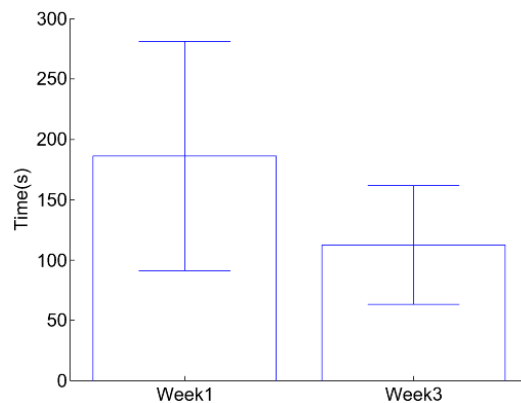
H3. Learning effect (Cohort A vs Cohort C)

- Cohort A
  - TTC; Z=-0.7714, p>0.05; NOC; Z=-3.0904, p<0.05
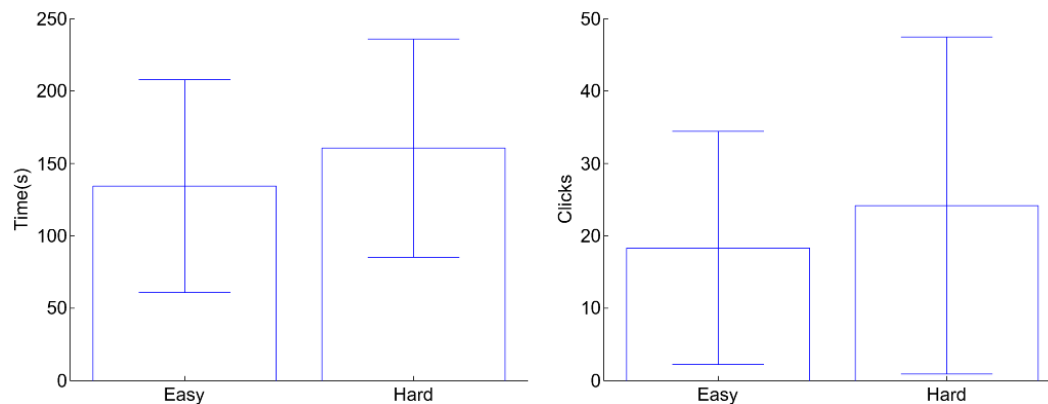 - Significant improvement in NOC

- Cohort C
  - TTC; Z=-4.0828, p<0.05; NOC; Z=-3.684, p<0.05
  - Significant improvement in TTC&NOC
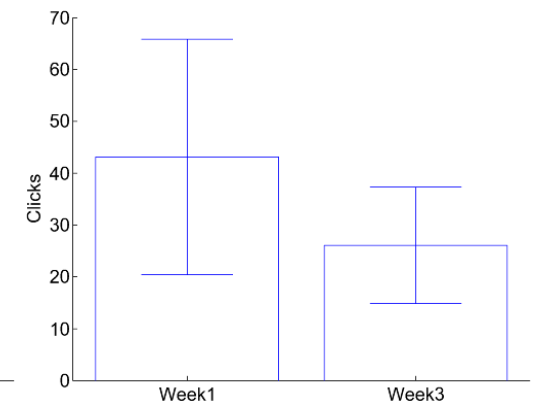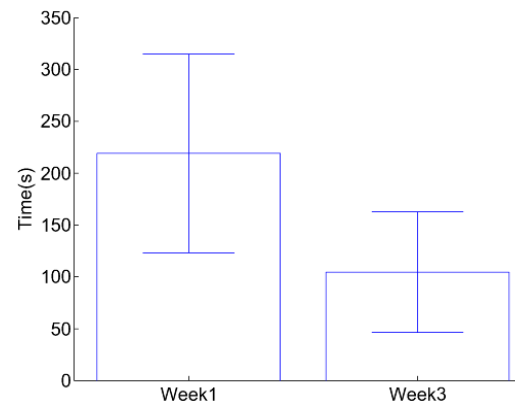
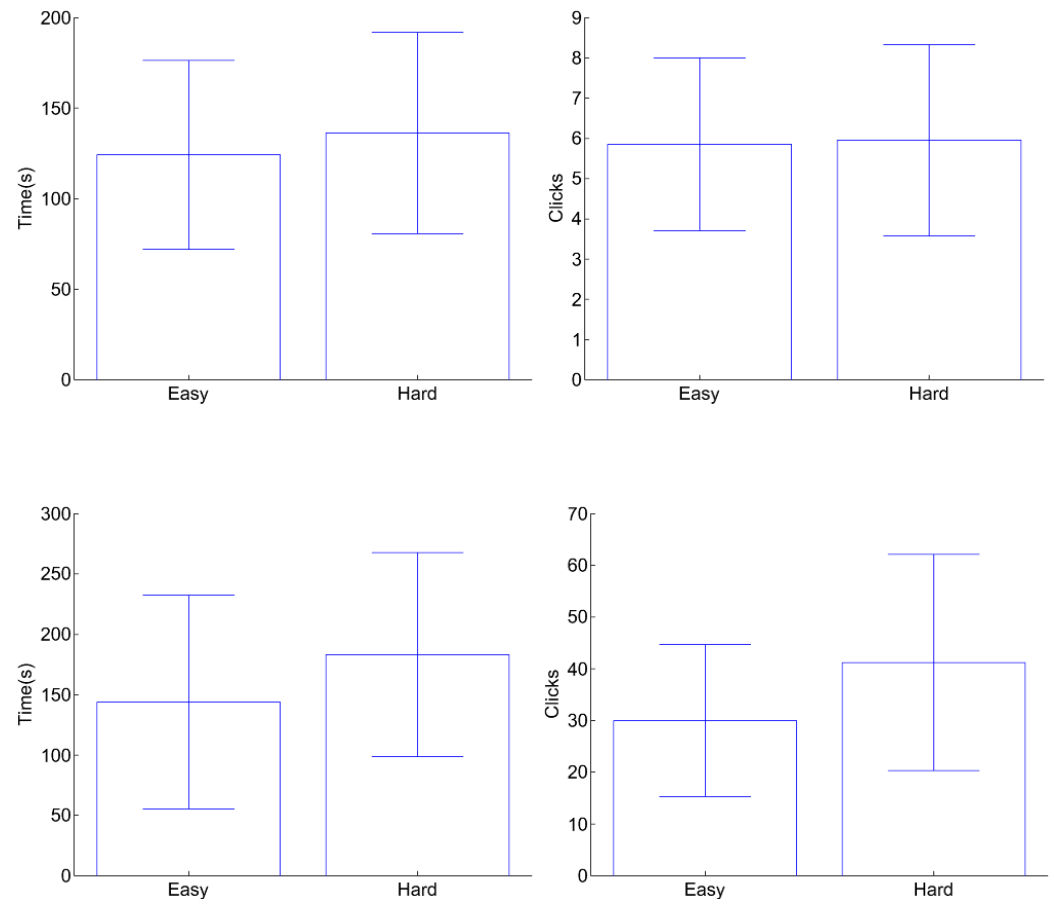# H4. Task categorization (in total)

- Our task discrimination into easy and hard levels seems appropriate.
  - TTC; Z=-3.0854, p<0.05; and NOC; Z=-3.4327, p<0.05

H4. Task categorization (Cohort A vs Cohort C)

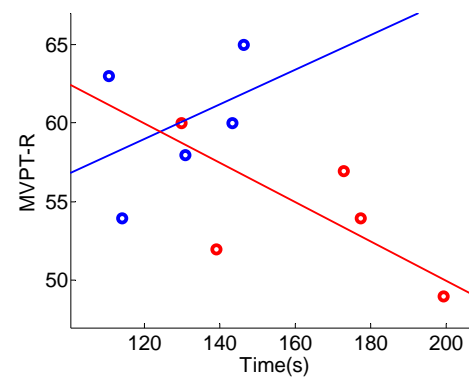- Cohort A
  - TTC; Z=-1.4067, p>0.05;
    NOC; Z=-0.0514, p>0.05
  - No significant improvement

- Cohort C
  - TTC; Z=-2.8275, p<0.05;
    NOC; Z=-3.8366, p<0.05
  - Significant improvement

H5. Quantitative metrics vs. Baseline characteristics

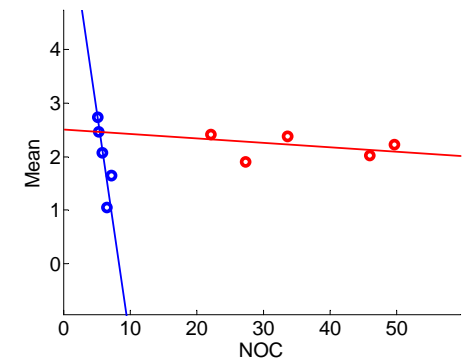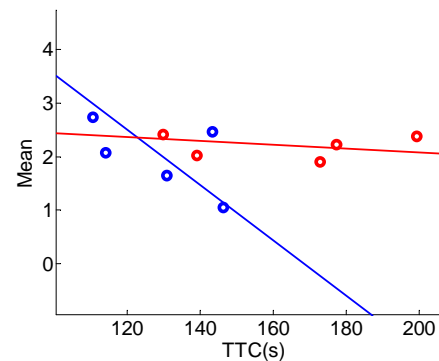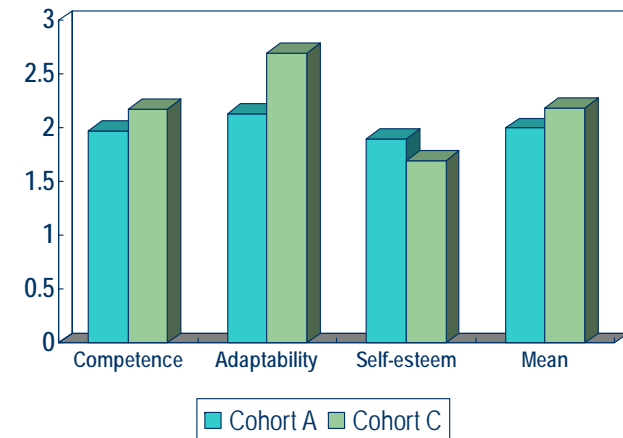| MVPT-R	Time (s)	Clicks
Cohort A	0.4	-0.2
Cohort C	-0.7	-0.6

- Cohort C was affected by MVPT-R.
  → Low MVPT-R scores
  → Inefficient or incorrect visual perception
  → Less efficient in TTC/NOC
  → Inverse correlation (r<0)
- MMSE and FIM subscale
  → no significant observation

(A)   (B)   (C)   (D)
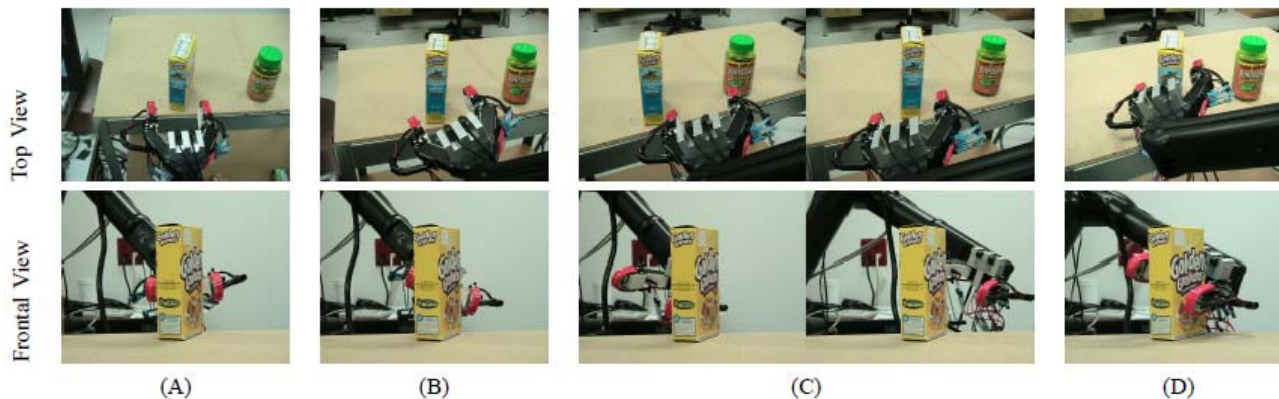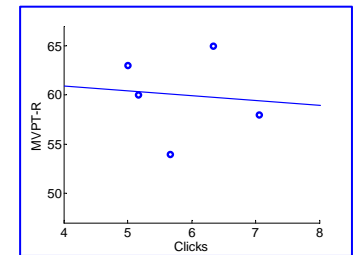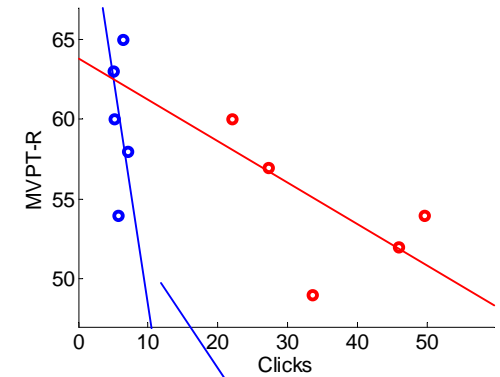
H6. Quantitative metrics vs. Psychometrics

- Overall satisfaction is good.

- Cohort C is more satisfied than Cohort A even with less efficient performance!

- Cohort C reveals similar satisfaction while Cohort A has a strong inverse relationship.
  → Auto interface is not sufficiently fast and convenient as Cohort A expected.

Mean	Time (s)	Clicks
Cohort A	-0.7	-0.9
Cohort C	-0.1	-0.3

Lessons Learned

- UCF-MANUS can greatly help the subjects with novel computer-based robot control interfaces.

- Auto interface is definitely required to resolve visual perception issues caused by low MVPT-R scores.

- Cartesian interface enables the subjects to be more active and satisfactory even with less efficient performance.

- Additional degree of freedom (mobility of wheelchair/mobile base platform) is always mentioned to fulfill more challenging tasks.

Future work

- Extension of testing setup
  → Tri-level shelves

- More complicated tasks
  → involving multiple objects at a time

- Elaborated user feedback
  → touch/haptic/3D visualization/etc.

- Mixture of Auto and Cartesian interfaces
  → More natural and comfortable HRI