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: $\geq 21$ (90 days post traumatic injury)
- Diagnosis level: C3-C6
- Powered wheelchair
- Baseline characteristics
  - MMSE: $\geq 22$
  - FIM: $\leq 40$

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
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

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Detail</th>
<th>Time</th>
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| WEEK0 Pre-Evaluation | AROM/PROM assessment bilateral UE (goniometer)  
|                    | Manual Muscle Test bilateral UE from wheelchair level                                    | 120 min |
|                    | 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.  
|                  | PT performs preliminary training with the MANUS with basic motions.                    | 60 min  |
|                  | 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.    
| Bottom Shelf Training | PT performs test with top shelf item placed in fixed testing positions.                | 60 min  |
|                    | PT is able to actively practice with prompts picking up bottom shelf items.             |        |
|                    | 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 $\rightarrow$ 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
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)

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<td>C5-6</td>
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Baseline Characteristics

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

|    | MMSE | MVPT-R | FIM
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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; $Z=-7.9615$, $p<0.05$
H3. Learning effect (in total)

- Significant improvement across a three-week training
  - Week 1 to Week 2
    - TTC; $Z=-1.568$, $p>0.05$; and NOC; $Z=-1.7832$, $p>0.05$
  - Week 2 to Week 3
    - TTC; $Z=-3.6636$, $p<0.05$; and NOC; $Z=-3.8078$, $p<0.05$
  - Week 1 to Week 3
    - TTC; $Z=-4.2664$, $p<0.05$; and NOC; $Z=-4.5576$, $p<0.05$
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**

- 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

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<thead>
<tr>
<th>MVPT-R</th>
<th>Time (s)</th>
<th>Clicks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cohort A</td>
<td>0.4</td>
<td>-0.2</td>
</tr>
<tr>
<td>Cohort C</td>
<td>-0.7</td>
<td>-0.6</td>
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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.
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