Understanding the Impact of Cognitive Reference Frames on Unmanned Aircraft Operator Workload and Performance

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Overview

- Motivation

- Experimental Methods
  - Independent Variables
  - Dependent Variables

- Prior Work

- Current Study

- Discussion
Motivation

“One of the largest cost drivers in the budget of DoD is manpower” [1]

[2] Reuters
Single Operator

- Navigation
- Aircraft
- Sensor
- Mission

- Coupling
- Information Only
- Feedback and Control
Reducing cognitive orientation time will improve multitask performance and workload during representative Unmanned Aircraft missions.
Experimental Methods

- Subjects control an aircraft and onboard video sensor
- Display configuration is varied to adjust several independent variables
Experimental Designs

Independent Variables
1. Reference Frame Alignment
2. Exocentric Orientation Aids
3. Display Integration
4. Target Movement
5. Aircraft Display Removal

Controlled variables
1. Subject
2. Image Rotation Angle
3. Subject Trial Number
4. Target

Dependent Variables

Performance
1. Target Acquisition Time (ONLY for STATIONARY TARGETS)
2. Combined Track Error
3. Orientation Time

Workload
1. Secondary Workload Measurement (Reaction Time)
2. Subjective Workload Rating
Independent Variables: Reference Frame Alignment

Misaligned

Aligned
Independent Variables:
Exocentric Orientation Aids

No Exocentric Orientation Aid
No “North Arrow”

Exocentric Orientation Aid Present
“North Arrow”
Independent Variables: Display Integration

Separate Displays

Integrated Display
Independent Variables: Target Movement

Stationary Target

Moving Target
Independent Variables: Removing Aircraft Display

**Aircraft Display**
- **“PFD”**
- **Aircraft Display Removed**

**Aircraft Display Removed**
- **No “PFD”**
Dependent Variables

Performance
1. Target Acquisition Time (ONLY for STATIONARY TARGETS)
2. Combined Track Error
3. Orientation Time

Workload
1. Secondary Workload Measurement (Reaction Time)
2. Subjective Workload Rating
Prior Work: Initial Simulator Study

- **Independent Variables**
  - Reference Frame Alignment
  - Exocentric Orientation Aids

- **Display Configurations**

<table>
<thead>
<tr>
<th>Display Configuration</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aircraft</td>
<td>Track-Up</td>
<td>Track-Up</td>
<td>Track-Up</td>
<td>North-Up</td>
</tr>
<tr>
<td>Navigation</td>
<td>North-Up</td>
<td>North-Up</td>
<td>North-Up</td>
<td>North-Up</td>
</tr>
<tr>
<td>Sensor</td>
<td>Sensor-View</td>
<td>North-Up</td>
<td>Sensor-View</td>
<td>North-Up</td>
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<tr>
<td>Mission</td>
<td></td>
<td></td>
<td></td>
<td>North-Up</td>
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<table>
<thead>
<tr>
<th># Reference Frames</th>
<th>3</th>
<th>2</th>
<th>3</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation Aid</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Integrated</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Prior Work: Initial Simulator Study
Pairwise Comparisons

- Independent Variables
  - Reference Frame Alignment
  - Exocentric Orientation Aids

- Results

<table>
<thead>
<tr>
<th>36 subjects</th>
<th>2-sided student t-test</th>
<th>Reference Frame (RF) Alignment</th>
<th>Exocentric Orientation Aid (OA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>t$_{crit}$ = 2.6</td>
<td>1-sided p-value</td>
<td>2 RF ≠ 1 RF</td>
<td>Disp B ≠ D</td>
</tr>
<tr>
<td>Orientation Time$^1$</td>
<td>t*</td>
<td>-0.620</td>
<td>13.21</td>
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<tr>
<td>p-value</td>
<td>0.73</td>
<td>1.8e-15</td>
<td>1.1e-16</td>
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<tr>
<td>Target Acquisition Time$^1$</td>
<td>t*</td>
<td>1.95</td>
<td>5.62</td>
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<tr>
<td>p-value</td>
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<td>1.2e-6</td>
<td>1.7e-7</td>
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<tr>
<td>Combined Track Error$^1$</td>
<td>t*</td>
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<td>p-value</td>
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<td>p-value</td>
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</table>

$^1$Transformed variables
Prior Work: Initial Simulator Study

- **Independent Variables**
  - Reference Frame Alignment
  - Exocentric Orientation Aids

- **Conclusions**
  - Demonstrated effectiveness of sensor video Reference Frame Alignment to improve each performance and workload measurement.
  - Demonstrated effectiveness of Exocentric Orientation Aids to improve Orientation Time.

- **Unexpected Observations**
  - Currently accepted practice (Exocentric Orientation Aids) did not improve target acquisition time
  - Aircraft display reference frame alignment did not improve performance or workload measurements
Current Experiment Design

**Independent Variables**

1. Reference Frame Alignment
2. Display Integration
3. Target Movement

**Controlled variables**

1. Subject
2. Image Rotation Angle
3. Subject Trial Number
4. Target

**Dependent Variables**

**Performance**

1. Target Acquisition Time (ONLY for STATIONARY TARGETS)
2. Combined Track Error
3. Orientation Time

**Workload**

1. Secondary Workload Measurement (Reaction Time)
2. Subjective Workload Rating
# Current Study Display Configurations

<table>
<thead>
<tr>
<th>Display Configuration</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display</td>
<td>Track-Up</td>
<td>North-Up</td>
<td>Track-Up</td>
<td>North-Up</td>
</tr>
<tr>
<td>Aircraft</td>
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<tr>
<td>Navigation</td>
<td>North-Up</td>
<td>North-Up</td>
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<tr>
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<td>Sensor-View</td>
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<tr>
<td>Mission</td>
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</table>

<table>
<thead>
<tr>
<th># Reference Frames</th>
<th>3</th>
<th>1</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Orientation Aid</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Integrated</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Integration Effect:
A vs. C and B vs. D

### Reference Frame Alignment Effect:
A vs. B and C vs. D
Current Study Results

- **Data quantity**
  - 16 Subjects
  - 2.5 hours per subject
  - Nov - Dec 2015

- **Dependent Variables**
  - Performance
    - Orientation Time
    - Target Acquisition Time
    - Combined Track Error
  - Workload
    - Bedford Scale (Subjective)
    - Reaction Time (Secondary)

- **Independent Variables**
  - Display Configuration
    - Reference Frame Alignment
    - Display Integration
  - Subject
  - Image Rotation Angle
  - Subject Trial Number
  - Target
  - Target Movement

- **Box-Cox Transformation to Normalize Data [16]**

\[
TAT' = \frac{(TAT - 3.9279 - 1)}{-3.9279}
\]

[16] Kutner et al
## Linear Regression Model

<table>
<thead>
<tr>
<th>Multi-Factor Linear Regression</th>
<th>Orientation Time</th>
<th>Tgt Acq Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Frame Alignment</td>
<td>F(503), p(2.86e-102)</td>
<td>F(14.7), p(1.60e-4)</td>
<td>Hypothesis: Alignment will affect human performance</td>
</tr>
<tr>
<td>Display Integration</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Hypothesis: Display Integration will affect human performance</td>
</tr>
<tr>
<td>Subject</td>
<td>F(152), p(0)</td>
<td>F(13.5), p(1.38e-24)</td>
<td>Pairwise within subjects</td>
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<tr>
<td>Image Rotation Angle</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Contrary to literature</td>
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<tr>
<td>Subject Trial #</td>
<td>F(7.58), p(5.93e-3)</td>
<td>F(9.13), p(2.78e-3)</td>
<td>Counterbalanced</td>
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<tr>
<td>Target</td>
<td>Not significant</td>
<td>F(39.1), p(1.09e-20)</td>
<td>Counterbalanced</td>
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<td>Target Movement</td>
<td>F(52.8), p(4.73e-13)</td>
<td>n/a</td>
<td>Secondary Hypothesis</td>
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<tr>
<td>Alignment*Subject</td>
<td>F(4.63), p(7.62e-9)</td>
<td>Not significant</td>
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<tr>
<td>Subject*Subject Trial #</td>
<td>F(2.43), p(0.00163)</td>
<td>Not significant</td>
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</table>
Results Summary:
Target Acquisition Time

Target Acquisition Time vs. Alignment

Target Acquisition Time vs. Integration

Transformed Target Time (×10^5-25450)

Error %

Alignment

Integration
Results Summary: Orientation Time

Orient Time vs. Alignment

Orient Time vs. Integration
Subjective Observations

Subjective Display Rankings
1 is best, 4 is worst

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
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<tr>
<td>2</td>
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<td>4</td>
<td>3</td>
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</table>
Pairwise Comparisons

<table>
<thead>
<tr>
<th>Performance</th>
<th>Reference Frame Alignment</th>
<th>Display Integration</th>
<th>Interaction Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sep. A ≠ B</td>
<td>Integr. C ≠ D</td>
<td>misAlign A ≠ C</td>
</tr>
<tr>
<td><strong>Orientation Time</strong></td>
<td>t*</td>
<td>8.63</td>
<td>10.8</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>1.67e-7</td>
<td>8.50e-9</td>
</tr>
<tr>
<td><strong>Target Acquisition Time</strong></td>
<td>t*</td>
<td>1.66</td>
<td>4.26</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.0593</td>
<td>3.40e-4</td>
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<tr>
<td><strong>Combined Track Error</strong></td>
<td>t*</td>
<td>-0.015</td>
<td>-0.292</td>
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<tr>
<td></td>
<td>p-value</td>
<td>0.506</td>
<td>0.613</td>
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<tr>
<td><strong>Subjective Workload Rating</strong></td>
<td>t*</td>
<td>-0.593</td>
<td>-0.273</td>
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<td>p-value</td>
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<td><strong>Reaction Time</strong></td>
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<td></td>
<td>p-value</td>
<td>0.188</td>
<td>9.40e-3</td>
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</tbody>
</table>

1 Transformed variables
2 For all dependent variables smaller numbers are desirable
Preliminary Conclusions

- Reference Frame Alignment improved performance on orientation time and target acquisition time.
- Display Integration did not have a significant impact on performance.
- Display integration had a negative impact on workload with one significant measurement of secondary workload and other workload measurements trending towards significance.
- Display Integration was more effective with aligned displays.
Discussion

- **Integrated Display Effect**
  - Changing crosscheck pattern

- **Aircraft Display (PFD)**
  - Subjects all stated they didn’t use PFD
  - Complete reliance on flight path predictor

- **Control Errors**
  - Right-left bank errors when aircraft heading South on misaligned displays (tilting left to bank right)
  - Different control methods (tilt vs. twist) for left and right hands avoided confusion (limited observation ~ 2 subjects)

- **Future Work**
  - Examine aircraft display impact, given integrated flight path predictor information on navigation display
  - Continue to test reference frame alignment effect during increasingly realistic simulations
    - Squint angle
    - More complex navigation tasks
    - Datalink latency
Questions