Effects of Type and Strength of Force Feedback on Movement Time in a Target Selection Task

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NextGen Flight Decks

- Future flight decks will require advanced onboard avionics
  - *E.g., the Cockpit Display of Traffic Information (or CDTI)*
    - Allows pilots to view surrounding airspace and manipulate routes in real time
    - Would require direct interaction from the pilot (e.g., item selection)
  - *There will be constraints on the implementation of these new tools onto the flight deck:*
    - The limited space in the cockpit will necessitate small interfaces
    - The instability of the cockpit will make traditional HCI input devices unlikely (e.g., mouse, touch screen)
Force Feedback

• Additional technologies may be necessary to ensure optimal performance
  • Force feedback has been found to enhance performance in difficult HCI tasks (Griffiths and Gillespie, 2005)
    • Force feedback works to actively assist or resist operator movement during a task (e.g., target selection)
      • An attractive or repulsive force will help pull or push an operator’s selection tool towards or away from a given target
      • Attractive forms of force feedback are commonly referred to as “virtual fixtures” or “gravity wells”
  • According to Ahlstrom (2005), force feedback reduces:
    • Task completion times
    • Operator musculoskeletal discomfort
    • Error rates
Akamatsu & MacKenzie (1996) and Hwang et al. (2003) divided target selection tasks into 2 primary components:

- **Approach Time & Selection Time**
  - Akamatsu and MacKenzie found that force feedback reduced Selection Time
    - Used a friction-based force feedback (only engaged once inside target)
  - Hwang et al. found that force feedback reduced Approach Time
    - Used an attractive force feedback (engaged before reaching target)

- **Neither study manipulated the strength or type of force feedback**
Force Feedback

- Rorie et al. (2012) examined the effect of force feedback and movement direction on overall movement time
  - Presented targets on a CDTI-like display
  - Manipulated direction, size and distance of target
    - The presence of force feedback was found to disproportionately improve the selection of small and close targets
      - Overall, force feedback reduced target selection times by 47%
  - Only 1 level and type of force feedback was utilized
Force Feedback

• Little research has been done to study the optimal level of force feedback for a given task
  • *i.e.*, what’s the ideal strength of the attractive or repulsive force?
• The primary criticism of the implementation of force feedback is the effect of “distractors”
  • Therefore, the goal should be to find the lowest level of force feedback that produces greatest benefits
Purpose

• To examine the effect of multiple levels and types of force feedback in a CDTI display environment
  • *Extension of Rorie et al. (2012):*
    • Examines multiple levels of two different types of force feedback:
      • Gravitational Force Feedback
        • Acts as an attractive force that pulls participant’s cursor towards the target when outside of it
      • Spring Force Feedback
        • Acts a rubber band-type force that makes it hard to leave the target once the participant is inside
    • Applies Akamatsu and MacKenzie’s (1996) movement time components:
      • Approach Time
      • Time in Target
Method

• **Subjects**
  • 12 participants (7 female, 5 male; M = 25.83 years old) from NASA Ames and San Jose State University
    • Right handed, normal or corrected-to-normal vision

• **Apparatus**
  • *Standard Logitech laser mouse*
  • *Novint Falcon force feedback device*
    • 4” x 4” x 4” operational workspace
    • Capable of providing up to 2lbs of force
Method

• Two force feedback models:
  • (Modified) Newton’s Gravitational Law Model:
    • \[ F = \left\{ \frac{K_1}{||d||^2} \right\} d (\text{when } ||d|| > r) \]
    • \( K_1 \) units = Newtons Pixels\(^2\) (NPS)
  • 3 Gain Levels of Gravitational Force Feedback Used
    • \( K_1 = 100 \text{ NPS}, 300 \text{ NPS}, \& 500 \text{ NPS} \)
  • Spring Force Model:
    • \[ F = \left\{ K_2 \right\} d (\text{when } ||d|| \leq r) \]
    • \( K_2 \) units = Newtons Per Pixel (NP)
  • 2 Gain Levels of Spring Force Feedback Used
    • \( K_2 = 0.1 \text{ NP} \& 0.3 \text{ NP} \)
Method

- **2 x 2 x 2 x 3 x 12** Within-Subjects Design
  - **144 trials (i.e., target selections) per experimental block**
    - 20 experimental blocks with the Novint Falcon
    - 2 experimental blocks with Mouse
  - = 3,168 total target selections per participant

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Size</td>
<td>0.5cm &amp; 1cm</td>
</tr>
<tr>
<td>Target Distance</td>
<td>3.5cm &amp; 8.5cm</td>
</tr>
<tr>
<td>Spring Force Level</td>
<td>0.1 NP &amp; 0.3 NP</td>
</tr>
<tr>
<td>Gravitational Force Level</td>
<td>100 NPS, 300 NPS &amp; 500 NPS</td>
</tr>
<tr>
<td>Target Direction</td>
<td>0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300°, &amp; 330°</td>
</tr>
</tbody>
</table>
Method

- Procedure
  - *Point-and-Click task*
    - Start icon remained constant size (0.75cm) and location (center)
    - All independent variables were manipulated randomly within each experimental trial
  - *Dependent Variables*
    - Overall Movement Time (ms)
      - Approach Time (AT)
      - Time Inside Target (TI)
Results

• **Approach Time**
  • *Main Effect of Gravitational Force Level*
    • 300 & 500 NPS both resulted in significantly faster approach times than the 100 NPS Gravitational Force Level
  • *Gravitational Force X Spring Force*
    • 0.3 NP Spring Force Level only had an effect at the lowest Gravitational Force Level
Results

• Approach Time
  • Main Effect of Target Distance
  • Smaller approach times for closer targets
  • Compared to performance with the mouse:
    • 100 NPS significantly worse
    • 300 and 500 NPS Gravitational Force Levels were equal or better
Results

• Time in Target
  • Main Effect of Spring Force Level
    • The 0.3 NP Spring Force Level led to significantly less time spent inside the target than the 0.1 Spring Force Level
  • No Main Effect of Gravitational Force Level, Target Distance or Target Size
Results

- **Time in Target**
  - *Gravitational Force Level x Spring Force Level x Target Size*
  - For the 300 & 500 NPS Gravitational Force Levels, Spring Force Level only had a significant effect for *large* targets.

![Graphs showing mean time in target for small and large targets.](image)
Discussion

- Approach Time was shown to be a negatively accelerating function of Gravitational Force Level
  - 300 NPS reduced approach times by 14% when compared to the 100 NPS Gravitational Force Level
  - 500 NPS, by contrast, only reduced approach times by 18% when compared to the 100 NPS Gravitational Force Level
    - A slight improvement over the 300NPS level
- 300 NPS and 500 NPS were both shown to produce Approach Times similar to the computer mouse
  - Note that participants had no prior experience with the Novint Falcon
Discussion

• Spring Force Level was found to only have a main effect on Time Inside Target
  • Consistent with Akamatsu and MacKenzie (1996), the stronger Spring Force Level reduced selection times
  • The stronger Spring Force Level also reduced Time Inside Target to a level comparable to the mouse for large targets at the higher Gravitational Force Levels
    • Suggests higher Gravitational Force Levels may need a stronger Spring Force Value to keep the participant within the target’s boundaries
Design Implications

• Results suggest future CDTI designs can utilize a lower level of gravitational force (i.e., 300 NPS)
  • *Will allow for more operator control over the device*
    • May mitigate the negative effects of target distractors
  • *The 300 NPS level did not require the higher spring force level (as seen with 500 NPS)*

• Lack of training with Spring & Gravitational force levels highlights the substantial benefit of force feedback
  • *Led to comparable performance to the much more familiar computer mouse*
Limitations

• Novint Falcon is not intended for use in commercial cockpits
  • *Future studies will need to incorporate a greater number of input devices*

• No baseline condition (i.e., no force feedback) for Novint Falcon
  • *Rorie et al. (2012) demonstrated ineffectiveness of Falcon without force feedback*
Questions?