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
Force Feedback

- 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
• 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:
    • $F = \{K_1 / \|d\|^2\} \cdot \hat{d}$ (when $\|d\| > r$)
      • $K_1$ units = Newtons Pixels$^2$ (NPS)
    • 3 Gain Levels of Gravitational Force Feedback Used
      • $K_1 = 100$ NPS, $300$ NPS, & $500$ NPS
  • Spring Force Model:
    • $F = \{K_2 \cdot \|d\|\} \cdot \hat{d}$ (when $\|d\| \leq r$)
      • $K_2$ units = Newtons Per Pixel (NP)
    • 2 Gain Levels of Spring Force Feedback Used
      • $K_2 = 0.1$ NP & $0.3$ 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.
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?