King Saud University

College of Engineering

IE – 341: “Human Factors Engineering”

Fall – 2016 (1st Sem. 1437-8H)

Chapter 10. Human Control of Systems – Tracking (Part 2)

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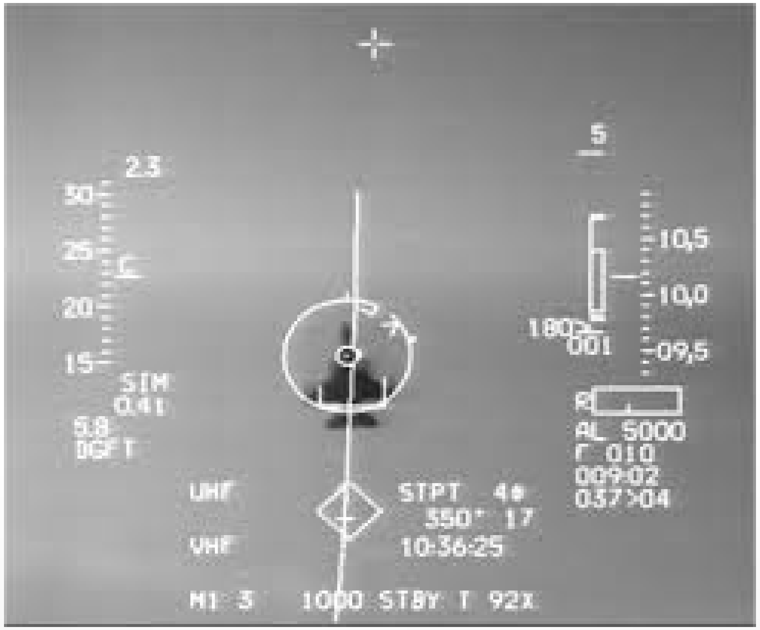
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Factors that Influence Tracking Performance

1. Preview of track ahead
2. Type of display
3. Time lag in tracking
4. Specificity of displayed error in tracking
5. Paced vs. self-paced tracking

Factors that Influence Tracking Performance

1. Preview of track ahead

- Background
  - o Preview assists operator in tracking task
  - o e.g.: driving on winding road that is visible ahead
- Functions of preview
  - o Nature of preview
    - Nature of task affects possible benefit of preview
    - Kvälseth (1979):
      - o Preview is best when shows track immediately preceding current position
      - o Better than lagged preview (gap between preview and present)
  - o Duration of preview
    - It is more important to have some preview than its duration
    - Kvälseth (1978a):
      - o Performance improves steadily when preview: approx. 0.5 s
      - o For preview > 0.5s: performance doesn't improve much
  - o Advantages of preview
    - Enables operator to compensate for time lags
    - 0.5 s preview: offers good response time for higher order control

Factors that Influence Tracking Performance

2. Type of display

- Pursuit vs. compensatory display:
  - o Table 10-2 (Poulton, 1974):
    - Summarized numerous (79) studies on tracking display
    - Conclusion: conventional pursuit display (true motion) is preferable to compensatory (relative motion) display
  - o Figure 10-13 (Brigg, 1966): error rate is higher for compensatory
- Why pursuit display generally preferred:
  1. Separate effects of target and controlled-element
     - Operator can see effects of cursor movements on error generated
     - This makes it easier to predict target's course
     - Also makes easier to learn effects of various control actions on movement of controlled element
  2. Greater movement compatibility
     - When target moves left*:
       - o Pursuit display: shows correct response movement, which is to left to chase target
       - o Compensatory display: displays cursor and error: moving right ⇒ less movement compatibility than in pursuit display

TABLE 10-2
SUMMARY OF COMPARISON OF NUMEROUS STUDIES OF PURSUIT AND COMPENSATORY TRACKING

Control order	Number of studies	Difference in results reliably in favor of:		Results inconclusive
		Pursuit	Compensatory	
Zero-order	45	29	0	16
Higher-order	34	14	7*	13

*These studies used inappropriate experimental methods, and the results should probably be disregarded.
Source: Poulton, 1974.

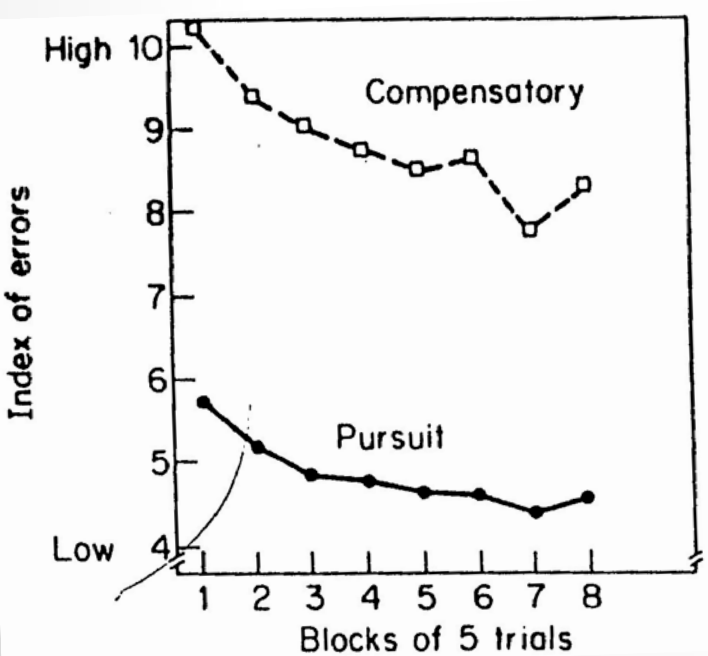


FIGURE 10-13.
Comparison of errors of subjects when using a compensatory versus a pursuit display in a tracking task. (*Source: Adapted from Briggs and Rockway, 1966, Fig. 2. Copyright © 1966 by the American Psychological Association. Reprinted by permission.*)

Factors that Influence Tracking Performance

2. Cot. Type of display

- Using digital displays:
    - o Note all previous studies were using analog (continuous) displays
    - o Kvälseth (1978b): using digital displays:
        - Harder to visualize target course (since only changing numbers)
        - Here: no difference in performance between two display types
- When compensatory display preferred:
    - o May occupy less space on control panels (i.e. practical reason)*

Factors that Influence Tracking Performance

3. Time lag in tracking

- Correcting tracking errors:
  - Step 1: operator chooses and performs corrective response
  - Step 2: controlled system must respond to control input
  - Step 3: result must be displayed to operator

- Time lag
  - Above steps all require time, aka **time lag** in the task
  - This degrades operator performance
  - Reason: time lag:
    - Requires greater demand on working memory
    - Makes a greater need to anticipate future events (in presence of lags)

Factors that Influence Tracking Performance

3. Cont. Time lag in tracking

- Types of time lags:

1. **Response lag**: time taken by operator to make a response to an input

2. **Control-system lag**: time between control action of an operator and response of the system under control
   - e.g. for sluggish higher order systems (such as large ship or plane*)
   - This's the major focus of time lag research (Figure 10-14: Poulton, 1974)
   - Three types of control-system lag:
     a. **Transmission time lag**: displays the effect of a person's response; output follows the control response by a constant time interval
     b. **Exponential time lag**: a situation in which the output is represented by an exponential function following a step input
     c. **Sigmoid time lag**: is represented by a *S*-shaped curve (resembles most the human response)

3. **Display-system lag**: time between response of the controlled system (e.g. change in target) and display of that change

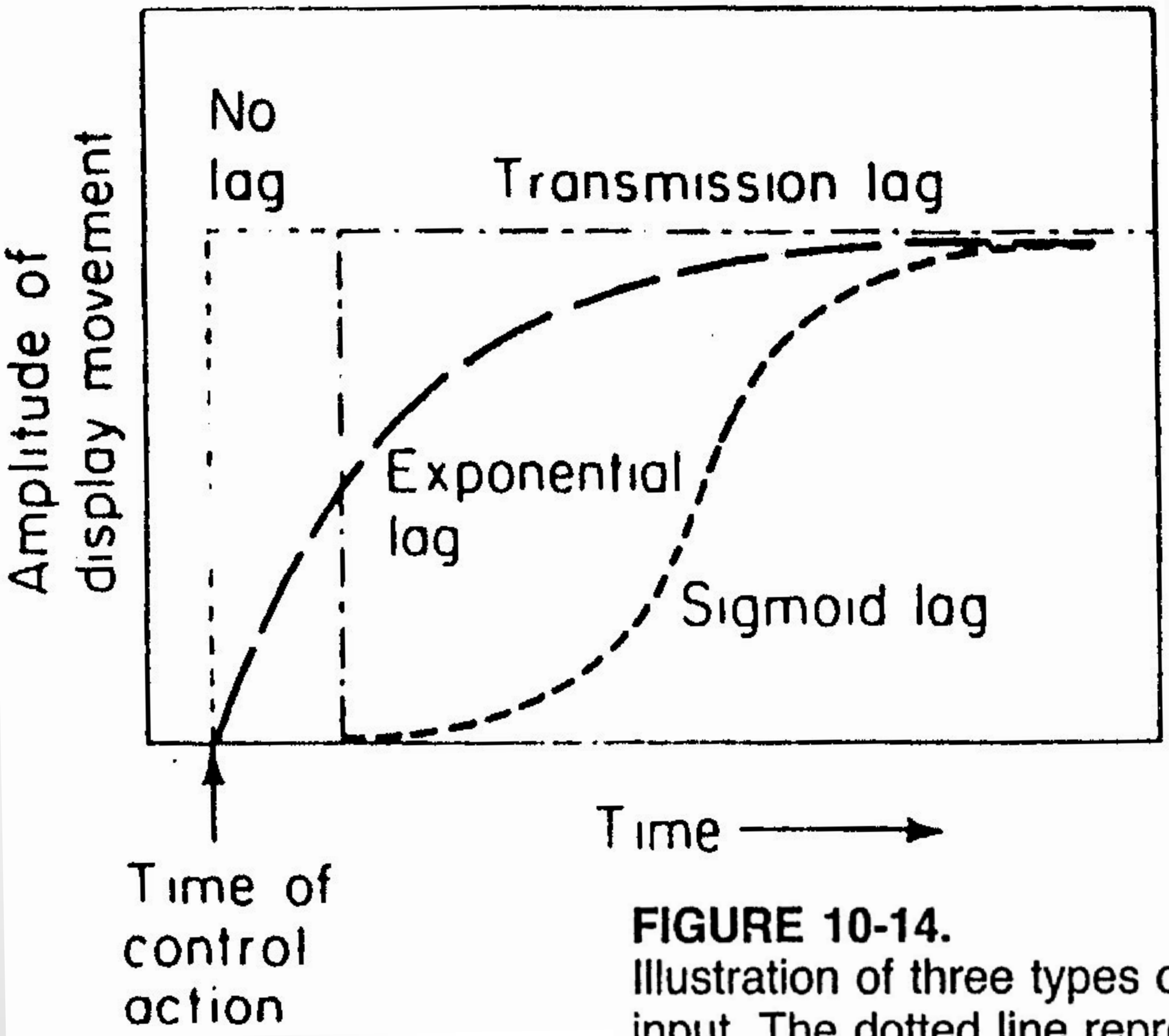


FIGURE 10-14.
Illustration of three types of time lag following a step input. The dotted line represents the output when there is no lag, as (theoretically) might be the case when turning on a switch. The human response to a step input with most tracking systems tends to be somewhat similar to a sigmoid lag curve. (*Source: Poulton, 1974, Fig. 11.9, p. 206.*)

Factors that Influence Tracking Performance

3. Cont. Time lag in tracking

- Effect of lags on performance
  - o Kao and Smith,1978 (Figure 10-15):
    - Study of compensatory tracking for control using one-hand (unimanual) vs. two-hands (bimanual)
    - Result a: as time lags ↑ (≤ 0.8 s) ⇒ performance ↓ for both control types
    - Result b: for longer display lag (1.5 s) ⇒ bimanual control affected more
- Ways to minimize error in tracking
  - o All three types of control lag increase undesirable error in tracking
  - o Suggestions to minimize error:
    - Poulton (1974): reducing order of a system from acceleration (2^{nd} order) to rate (1^{st} order) control using an exponential lag
    - Rockway (1954): with long delays: control-response ratio (C/R ratio) can have effect on tracking performance:
      - o C/R ratio: ratio of movement of control vs. movement of display*
      - o Higher ratios (1:3 and 1:6) ⇒ performance ↓ with long lags
      - o Low ratios (1:15 and 1:30) ⇒ performance stays the same or even improves

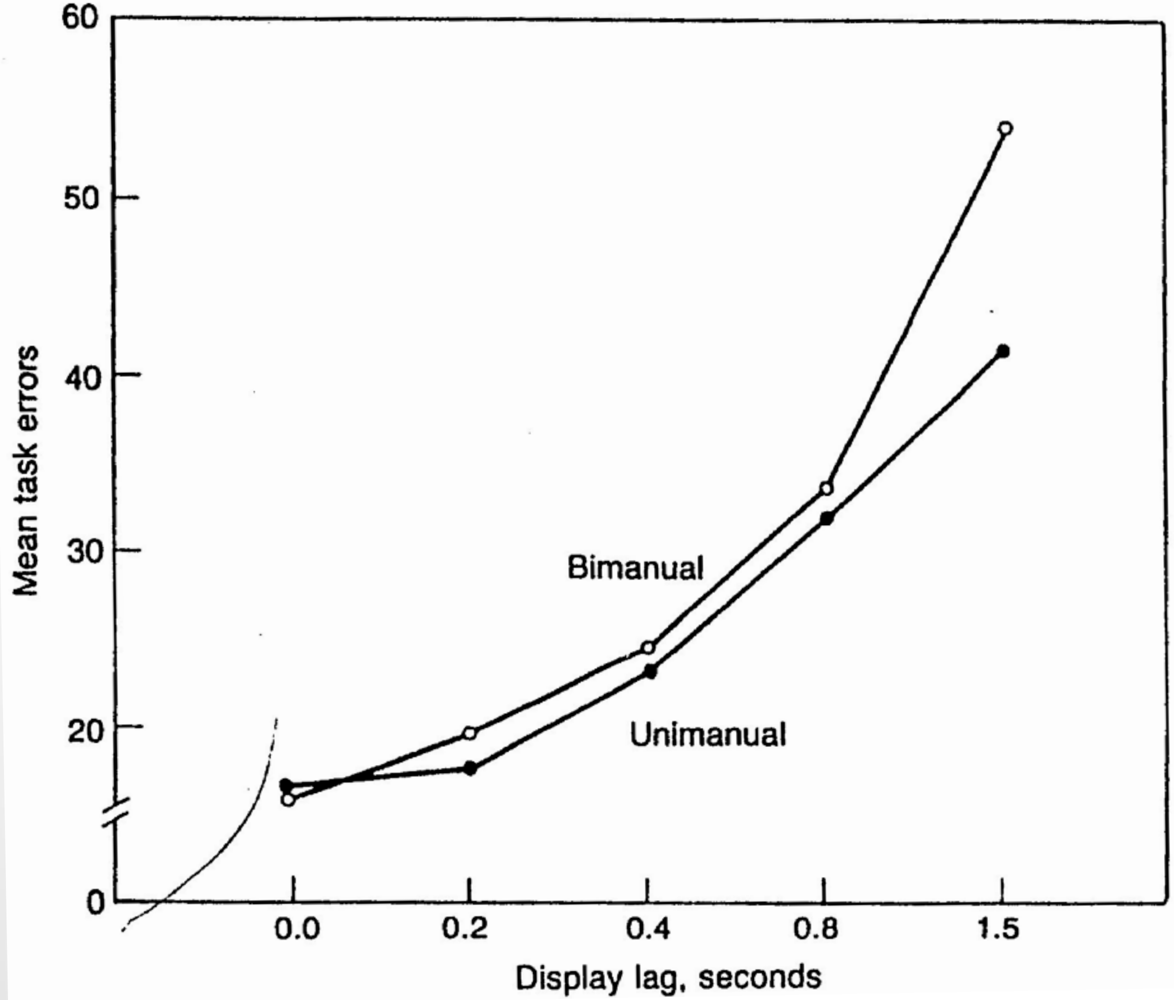


FIGURE 10-15.
Illustration of the effects of various display lags in a compensatory tracking task performed with bimanual and unimanual control. The difference for the 1.5 s display lag is statistically significant. (*Source: Kao and Smith, 1978, Fig. 2, p. 666.*)

Factors that Influence Tracking Performance

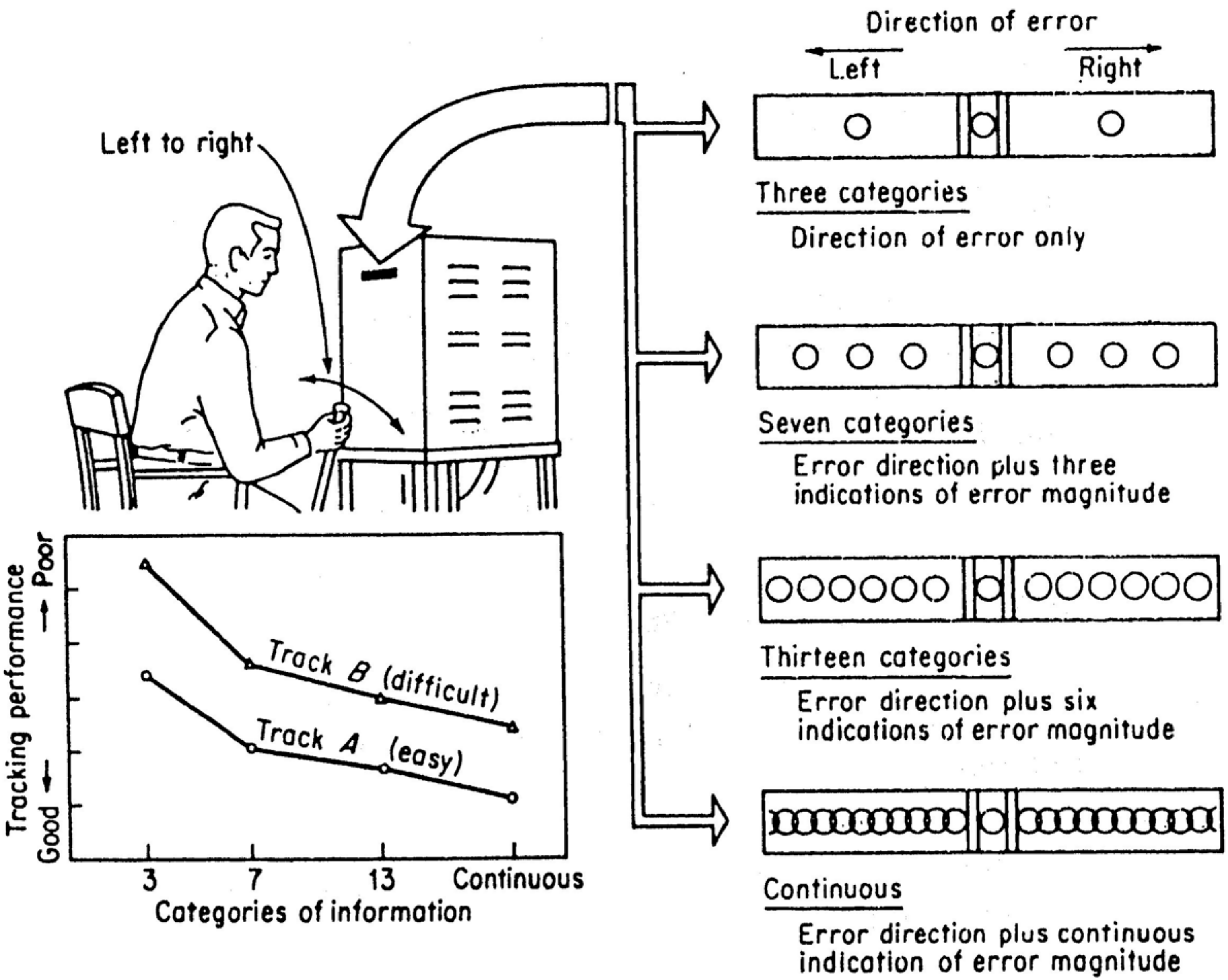
4. Specificity of displayed error in tracking

- Occurs in certain compensatory displays
- Error (difference between input and output) presented with various degrees of specificity
- Tracking experiment (Hunt, 1961: Figure 10-16) shows such variations:
  a. 3 categories of specificity (left, on target, right)
  b. 7 categories
  c. 13 categories
  d. Continuous (i.e. analog)
  - Accuracy for tracking performance measure for 2 levels of difficulty
  - Result: performance ↑ with increased # of categories of info. (i.e. more specificity), especially with continuous feedback (for easy and hard)
- Other experiments also show: more specific display info. ⇒ performance ↑

5. Paced vs. self-paced tracking

- Most tracking tasks: self-paced:
  - Person has control over rate of output (e.g. driving car: selecting speed)
- Some tracking tasks: paced tracking (i.e. person has no control)
  - e.g. Poulton (1974): plane pilot when landing: must keep plane within speed range & keep plane in defined path
- Tracking is easiest with self-paced & more difficult as external pacing ↑

FIGURE 10-16.
Compensatory displays used in study of the effects of specificity of feedback error information and tracking performance. The feedback error was presented by the use of lights (3, 7, 13, and continuous). (*Source: Adapted from Hunt, 1961.*)



Procedures for Facilitating Tracking Performance

- Humans have limitations (as shown in part-1):
  - o Built-in time lags (i.e. processing time)
  - o Limited bandwidth
  - o Poor anticipation of system's future state
- Tracking performance is influenced (i.e. -vely) by;
  - o Control order
  - o Preview
  - o Time lags
- Limitations/influences:
  - o Important especially for higher order systems (2nd, 3rd, 4th order)
  - o ⇒ often such system characteristics exceed capabilities of operator

- Procedures to compensate for these obstacles:
  1. Aiding
  2. Predictor displays
  3. Quickening

Procedures for Facilitating Tracking Performance

1. Aiding:
   - o Background:
     - Initially developed for gunnery tracking systems
     - Also: any application where operator follows target with device
     - Effect: modify output of control to help tracker
   - o Other types of aiding:
     - **Rate aiding:**
       - o Single adjustment of control affects: rate and position of tracking
       - o e.g.: using telescope to track high-flying plane:
         - If we fall behind ⇒ telescope speeds up (i.e. rate of motion ↑) ⇒ position also ↑
         - If telescope is ahead of target ⇒ rate ↓ ⇒ position also ↓
       - o This simplifies matching device rate with target rate ⇒ better tracking
     - **Acceleration aiding:**
       - o Control movement controls: acceleration, rate, and position

Procedures for Facilitating Tracking Performance

1. Cont. Aiding:
   - o Operational effects of aiding
     - It removes operator mental efforts of differentiation/integration/algebra
     - ⇒ operator can focus on amplification (i.e. figuring out ratio of movement of control vs. controlled element*)
   - o Factors affecting aiding:
     - Nature of the input signal
     - Control order
     - System type: pursuit or compensatory

Procedures for Facilitating Tracking Performance

2. Predictor displays
   - o Another procedure for simplifying control of higher-order systems
   - o e.g.: used with large bodies such as submarines
   - o Procedure:
     - Uses fast-time model of system to predict future movement of system
     - Displays this depiction on some device
   - o Function of predictor displays:
     - Model predicts real system's future based on assumptions of what the operator will do with the control, e.g.:
       - o Return control to neutral position
       - o Hold it in its place
       - o Move it to another extreme
     - Predictions: reduce difference bet. predicted and desired output
     - Display: shows both present and predicted (future) state of system
   - o Examples of predictor display
     1. Figure 10-17: present & predicted path of submarine (10 s)
     2. Figure 10-18: present & predicted path of aircraft (8 s) during landing

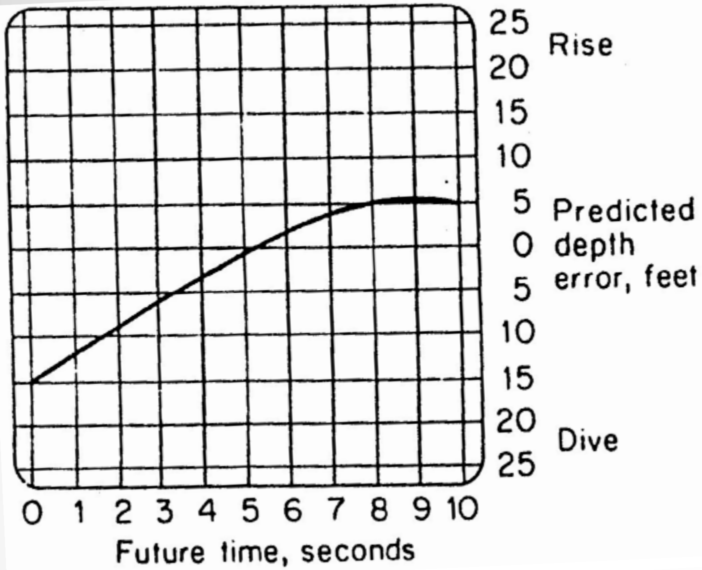


FIGURE 10-17.
Example of a predictor display for a submarine. The display shows the predicted depth error, in feet, extrapolated to 10 s, assuming that the control device would be immediately returned to a neutral position. (*Source: Kelley, 1962.*)

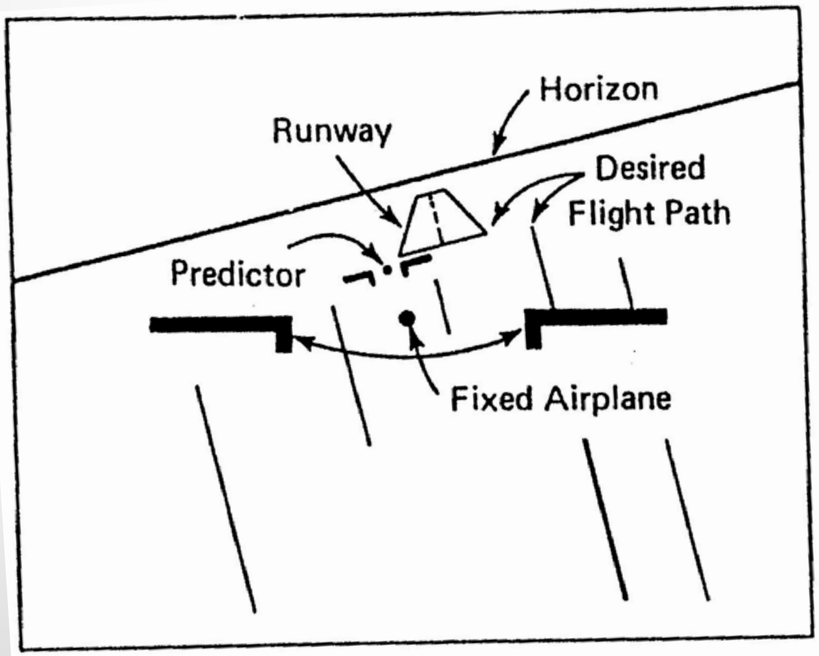


FIGURE 10-18.
Stylized representation of an aircraft predictor display showing the present and predicted position of an aircraft 8 s in the future during a landing approach. (*Source: Jensen, 1981, Fig. 1. Copyright by the Human Factors Society, Inc. and reproduced by permission.*)

Procedures for Facilitating Tracking Performance

2. Cont. Predictor displays

- Advantages of predictor displays:
  - Useful with complex control systems where operator needs to anticipate several seconds in advance
  - e.g. with submarines, aircraft, spacecraft
  - Experiment by Dey (1972):
    - Simulated control of VTOL (vertical takeoff and landing)
    - Index of deviation from desired course:
      - With predictor display: 2.48
      - Without predictor display: 7.92
    - Other experiments: also showed control performance ↑ with predictor display

Procedures for Facilitating Tracking Performance

3. Quickening:

- Closely related to predictor displays
- Displays info. about where system will be in future given action by operator
- ⇒ operator learns quickly (from where name *quickening* comes) future consequences of control action
- Predictor vs. quickening displays:
  - Predictor displays:
    - Show current state/position of system
    - Generally result in better tracking performance
  - Quickened displays:
    - Do not show current state/position of system
    - Look like regular displays
    - Show what the situation will be in the future
    - Preferred only in specific conditions
- Example of how quickening display may be misleading:
  - May show that controlled element is on target
  - This may not necessarily mean controlled element is on target *now*
  - Only means it is predicting that element will be on target in future

Procedures for Facilitating Tracking Performance

- Discussion
  - o Usefulness of many methods of facilitating tracking performance depend on:
    - Type of input (step, ramp, sine wave, etc.)
    - Control order (zero, first, second, etc.)
    - Type of display (pursuit, compensatory)
  - o Aiding:
    - Useful in some situations
    - Has limited general applicability
  - o Combining predictor and quickened displays:
    - In general pursuit displays (for higher order systems): much easier and safer to use than quickened displays
    - However, it’s possible to combine both displays in one display $\Rightarrow$ performance found to possibly improve

References

- ***Human Factors in Engineering and Design***. Mark S. Sanders, Ernest J. McCormick. 7th Ed. McGraw: New York, 1993. ISBN: 0-07-112826-3.
- **Slides by: *Dr. Woohyung Park***