King Saud University

College of Engineering

IE – 341: "Human Factors Engineering"

Spring – 2024 (2nd Sem. 1445H)

Chapter 10. Human Control of Systems Compatibility – Part II (Movement, Modality)

Prepared by: Ahmed M. El-Sherbeeny, PhD

Chapter Overview

Information Processing and Compatibility

1. Information Display – Coding (Ch. 3)
2. Fitts' Law (Ch. 3, Ch. 9)
3. Hick Hyman Law (Ch. 3)
4. Signal Detection Theory (Ch. 3)
5. Memory - Attention (Ch. 3)
6. Compatibility - Part 1 - Spatial Compatibility (Ch. 10)
7. Compatibility - Part 2 - Movement - Modality Compatibility (Ch. 10, Ch.3)

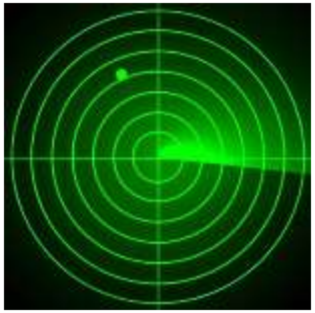
Contents

- Introduction
- Spatial Compatibility - Ch. 10 (p1)
- **Movement Compatibility** - Ch. 10 (p2)
- **Modality Compatibility** - Ch. 3 (p2)

Movement Compatibility

Movement Compatibility

- Cases when movement compatibility is important:
  - Movement of control device to *follow* movement of display (e.g. following movement of a "blip" on the radar)



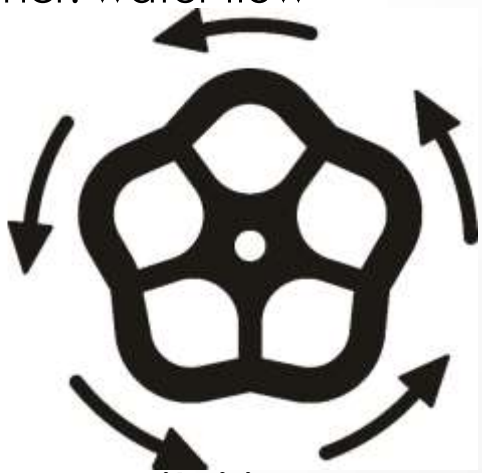
  - Movement of control device to *control* movement of display (e.g. radio)
  - Movement of control device to produce specific system response (e.g. turning steering wheel left/right)

  - Movement of display indicator with no related response (e.g. clock)

Movement Compatibility

- *Population stereotypes*:
  - Definition:
    "expectations about cognitive/physical characteristics of a group of users regarding the design of systems/products for that group"
  - Here we are concerned with expectation of people regarding movement relationships
  - Some stereotypes are stronger than others
  - e.g. expecting CW knob rotation to incr. output on electrical appliance while expecting CCW water tap rotation to incr. water flow





- Factors affecting movement compatibility:
  - Features of controls and displays
  - Physical orientation (i.e. position) of user
    (e.g. is user in same/different plane than control?)

Cont. Movement Compatibility

- Principles of movement compatibility:

1. Rotary Controls and Rotary Displays in Same Plane
2. Rotary Controls and Linear Displays in Same Plane
3. Movement of Displays and Controls in Different Planes
4. Movement Relationships of Rotary Vehicular Controls
5. Movement Relationships of Power Switches
6. Orientation of Operator and Movement Relationships (*we will skip this topic*)

- Discussion

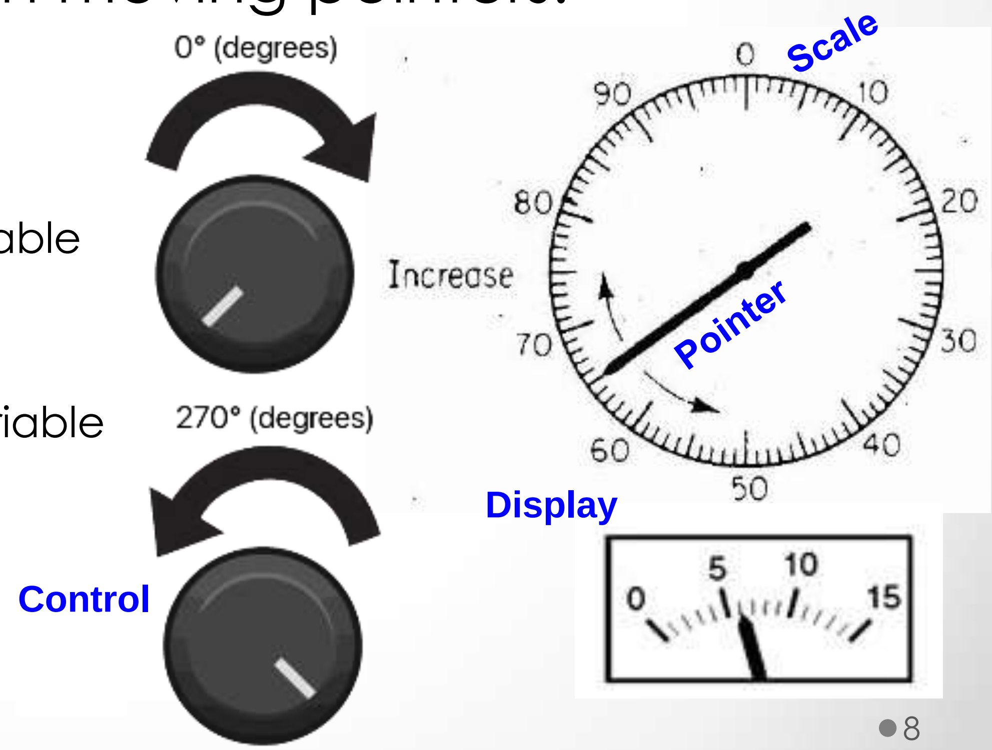
Cont. Movement Compatibility

Cont. Principles of movement compatibility:

1. Rotary Controls and Rotary Displays in Same Plane:
   A. Fixed rotary scales with moving pointers
   B. Moving scales with fixed pointers

A. Fixed rotary scales with moving pointers:

- Well-established principles
- CW rotation of control ⇒
  - CW rotation of pointer
  - Increase in value of variable
- CCW rotation of control ⇒
  - CCW rotation of pointer
  - Decrease in value of variable



Cont. Movement Compatibility

Cont. Principles of movement compatibility:

1. Rotary Controls and Rotary Displays in Same Plane:

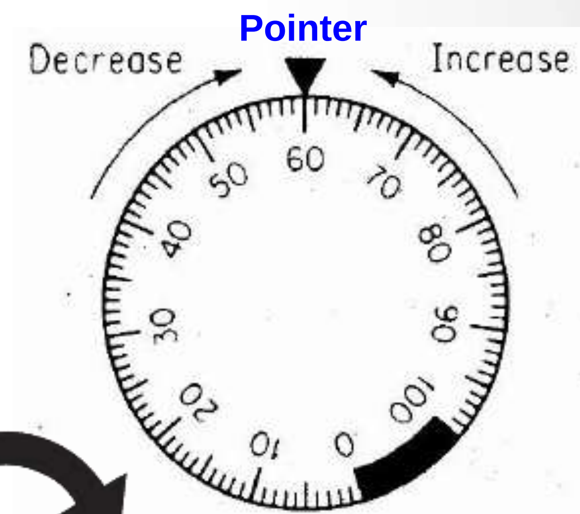
A. Fixed rotary scales with moving pointers
B. Moving scales with fixed pointers

B. Moving scales with fixed pointers:

3 Desirable Principles (*Bradley, 1954*):

1. Scale should rotate in same direction as its control knob (aka "direct drive")
2. Scale numbers should increase: left to right
3. Control should turn CW to increase settings

- Note, not possible to implement all 3 principles at the same time (in one setup)
- Can you test this from figures on right?



Cont. Movement Compatibility

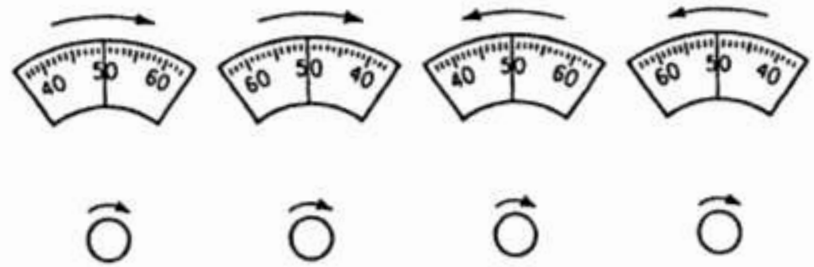
Cont. Principles of movement compatibility:

1. Rotary Controls and Rotary Displays in Same Plane:
   A. Fixed rotary scales with moving pointers
   B. Moving scales with fixed pointers

B. Moving scales with fixed pointers

- Experiment by Bradley (1954):
  - Only two principles can be achieved at the same time (i.e. must sacrifice 1)
  - Tested various control-display assemblies (4 assemblies shown: *A*, *B*, *C*, *D*)
  - Evaluation criteria:
    - starting errors (initial movement in *wrong* direction)
    - setting errors (incorrect settings)
    - rank-order preferences of subjects (i.e. subjective preference)
  - Results: most important principles (in desc. order of preference)
    1. Direct linkage ("drive") between control and display (A & B) (most imp)
    2. Scale numbers increase left to right
    3. CW control movement ⇒ increased setting (least imp)

Cont. Movement Compatibility



Assembly	A	B	C	D
Drive	Direct	Direct	Reversed	Reversed
Scale numbers increase	Left to right	Right to left	Left to right	Right to left
With clockwise knob movement setting will:	Decrease	Increase	Increase	Decrease

Results:

	A	B	C	D
Starting errors	13	11	87	106
Setting errors	0	9	1	8
Preference (number of times ranked "first")	31	22	17.5	1.5

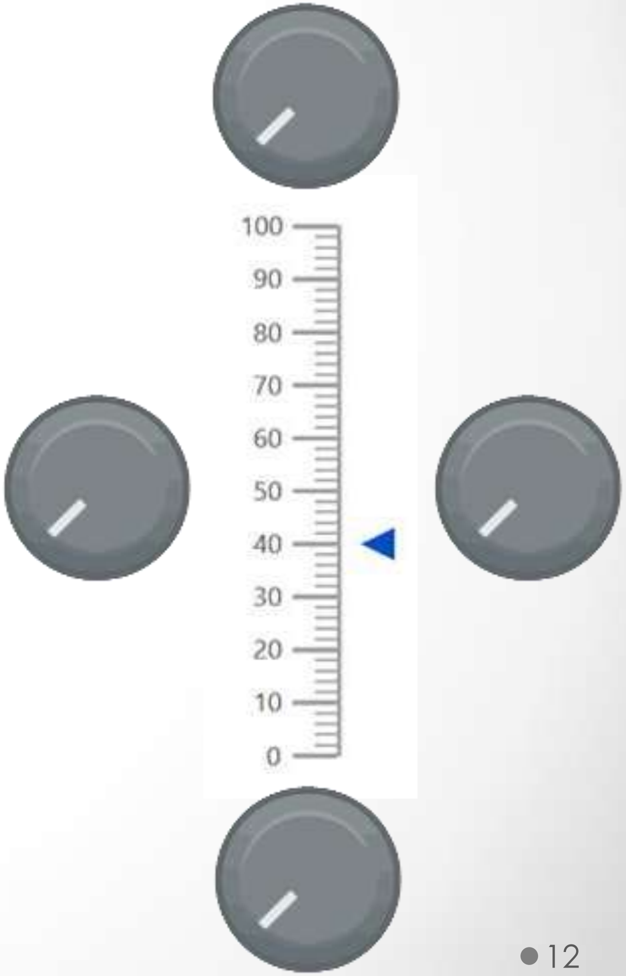
FIGURE 10-5.
Some of the moving-display and control-assembly types used in a study by Bradley. The various features relate to three desirable characteristics given below the diagrams; crosshatching indicates an undesirable feature. With the usual display orientation all three desirable features are not possible. Some data on three criteria are given at the bottom of the figure, indicating the general preferability of A. (*Source: Adapted from Bradley, 1954.*)

Cont. Movement Compatibility

Cont. Principles of movement compatibility:

2. Rotary Controls and Linear Displays in Same Plane
    - Control can be placed: above, below, to left, or to right of display

- Three Compatibility principles:
    1. ***Warrick's* principle**
    2. **Scale side principle**
    3. **Clockwise-for-increase principle**

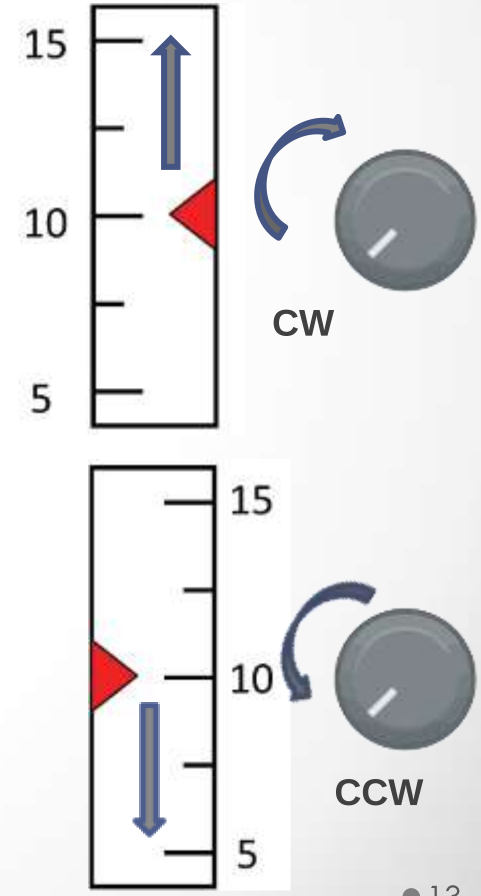


Cont. Movement Compatibility

Cont. Principles of movement compatibility:

2. Rotary Controls and Linear Displays in Same Plane
   - Control can be placed: above, below, to left, or to right of display

- Three Compatibility principles:
  1. ***Warrick's* principle** (*Warrick, 1947*):
     - expectation: pointer on display should move in same direction as the side of control nearest to it (i.e. point on circumference of control nearest to display)
     - note, this applies *only* when control is located to side of display (i.e. left or right)
     - e.g. when control is on right $\Rightarrow$ CW rotation will make pointer go up



Cont. Movement Compatibility

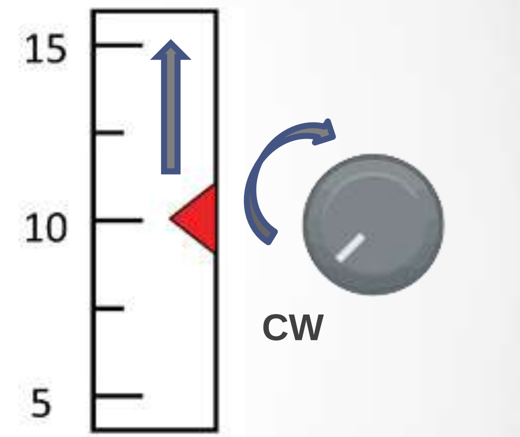
Cont. Principles of movement compatibility:

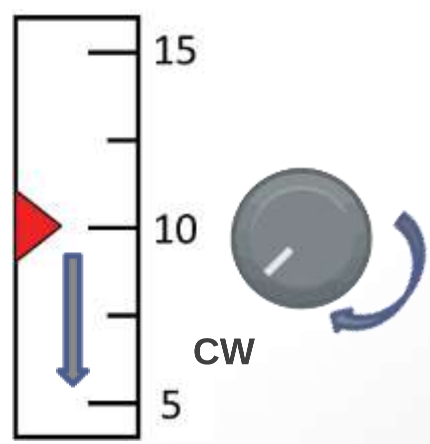
2. Rotary Controls and Linear Displays in Same Plane
   - Control can be placed: above, below, to left, or to right of display

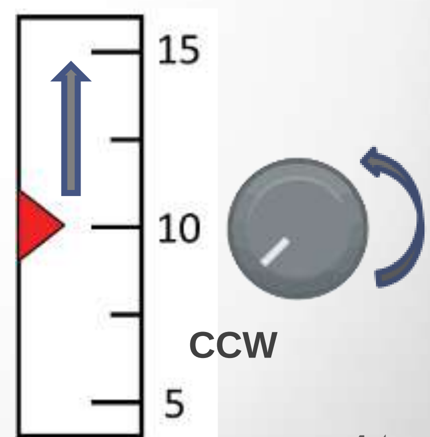
- Three Compatibility principles:
  - Two more principles: 2,3 by *Brebner* (1976), specifically for vertical displays:

2. Scale side principle:

- expectation:
  pointer should move in
  same direction
  as side of control knob
  which is on *same side*
  as scale markings on display
- this works when control is:
  top /
  bottom /
  side
  of vertical display







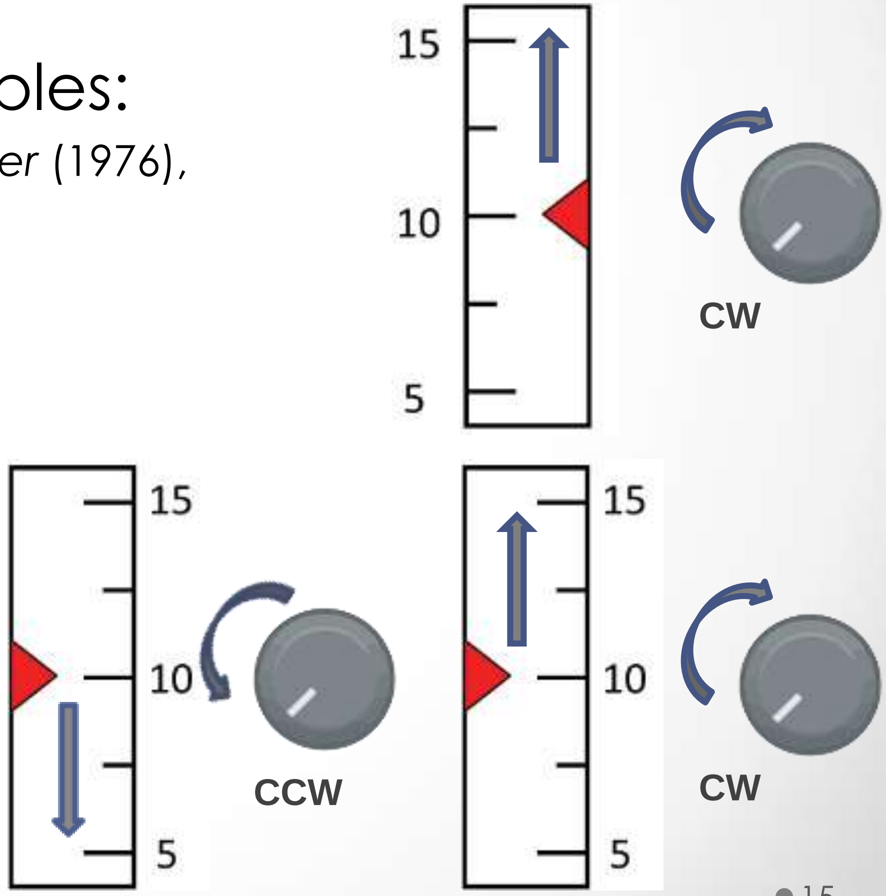
Cont. Movement Compatibility

Cont. Principles of movement compatibility:

2. Rotary Controls and Linear Displays in Same Plane
   - Control can be placed: above, below, to left, or to right of display

- Three Compatibility principles:
  - Two more principles: 2,3 by *Brebner* (1976), specifically for vertical displays:

3. **Clockwise-for-increase principle**:
   - expectation:
     when people
     turn rotary control CW ⇒
     value of display increases
     no matter where control is
     (relative to display)

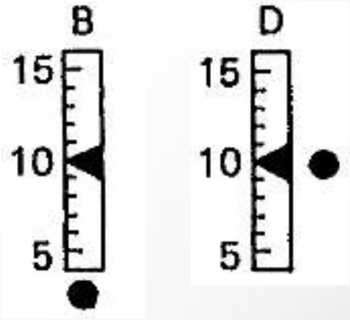


Cont. Movement Compatibility

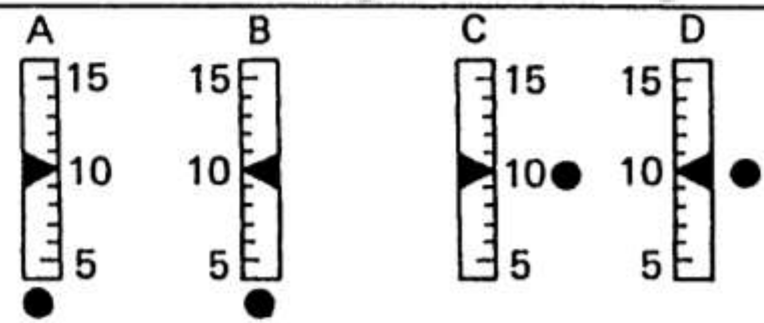
Cont. Principles of movement compatibility:

2. Rotary Controls and Linear Displays in Same Plane
   - Control can be placed: above, below, to left, or to right of display

- Three Compatibility principles:
  - The three principles are compared on the next slide:
    - two studies (conducted in 1976, 1981)
    - various arrangements of displays and controls (4 shown: *A*, *B*, *C*, *D*)
    - subjects were asked to turn knob to "move indicator to 15": (CW or CCW?)
  - Results (regarding both studies):
    - When principles match ("congruent") ⇒ stereotype is stronger (i.e. *B*, *D*)
    - When principles don't match ⇒ stereotype is weaker (i.e. *A*, *C*)
    - Best arrangements:
      B (when rotary knob is below the scale)
      D (when rotary knob is to the right of the scale)



Cont. Movement Compatibility



	A	B	C	D
Predictions:				
Warrick's principle	NA	NA	C	C
Scale-side principle	CC	C	CC	C
Clockwise-for-increase	C	C	C	C
Results: Percent choosing:				
Clockwise	43 (45)	80 (72)	73 (57)	86 (85)
Counterclockwise	57 (55)	20 (28)	27 (43)	14 (15)

NA = not applicable C = clockwise CC= counterclockwise

FIGURE 10-6.
Four configurations of rotary controls and vertical linear scales. Shown are the predicted stereotypes based on three principles. The percentages choosing each direction of rotation to move the pointer to 15 are shown for two studies: Brebner and Sandow (1976) and, in parentheses, Petropoulos and Brebner (1981).

Cont. Movement Compatibility

Cont. Principles of movement compatibility:

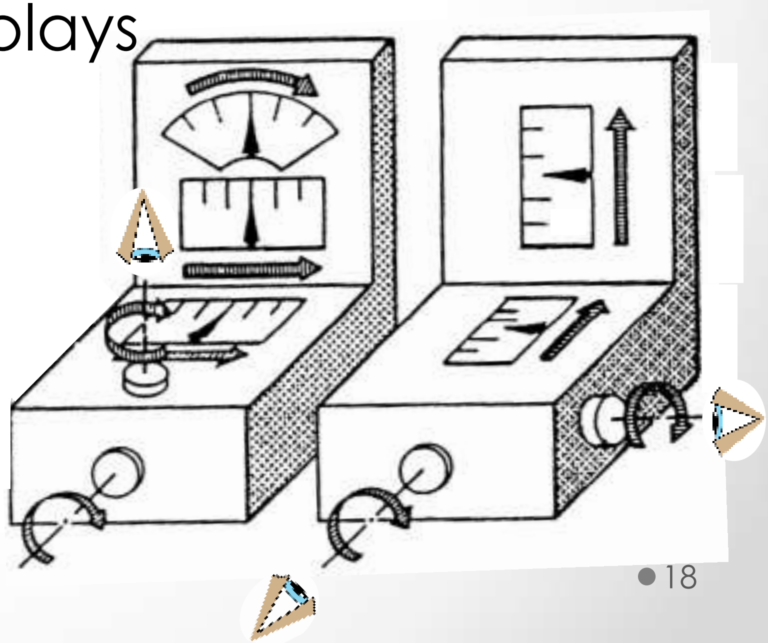
3. Movement of Displays and Controls in Different Planes (i.e. 3-D device)

- Investigated types:
  A. Rotary controls with linear displays (in different planes)
  B. Stick-type controls with linear displays (in different planes)

A. Rotary controls with linear displays

Two general principles (*Holding, 1957*):

1. General CW for increase



Cont. Movement Compatibility

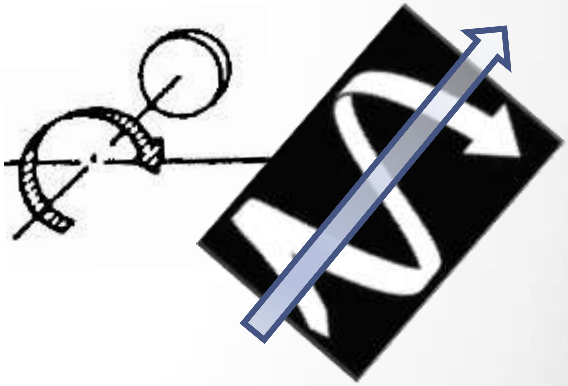
Cont. Principles of movement compatibility:

3. Cont. Movement of Displays and Controls in Different Planes (i.e. 3-D device)

A. Cont. Rotary controls with linear displays

Cont: Two general principles (*Holding,1957*):

1. General CW for increase
2. Helical/screwlike hand tendency for movement:*
    - CW rotation is associated with moving away from individual
    - CCW rotation is associated with moving towards individual



Cont. Movement Compatibility

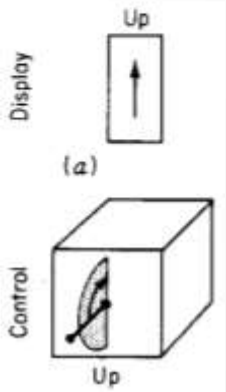
Cont. Principles of movement compatibility:

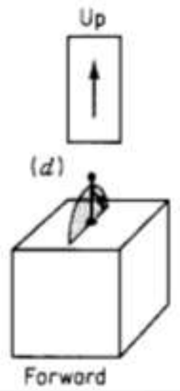
3. Cont. Movement of Displays and Controls in Different Planes (i.e. 3-D device)

B. Stick-type controls with linear displays

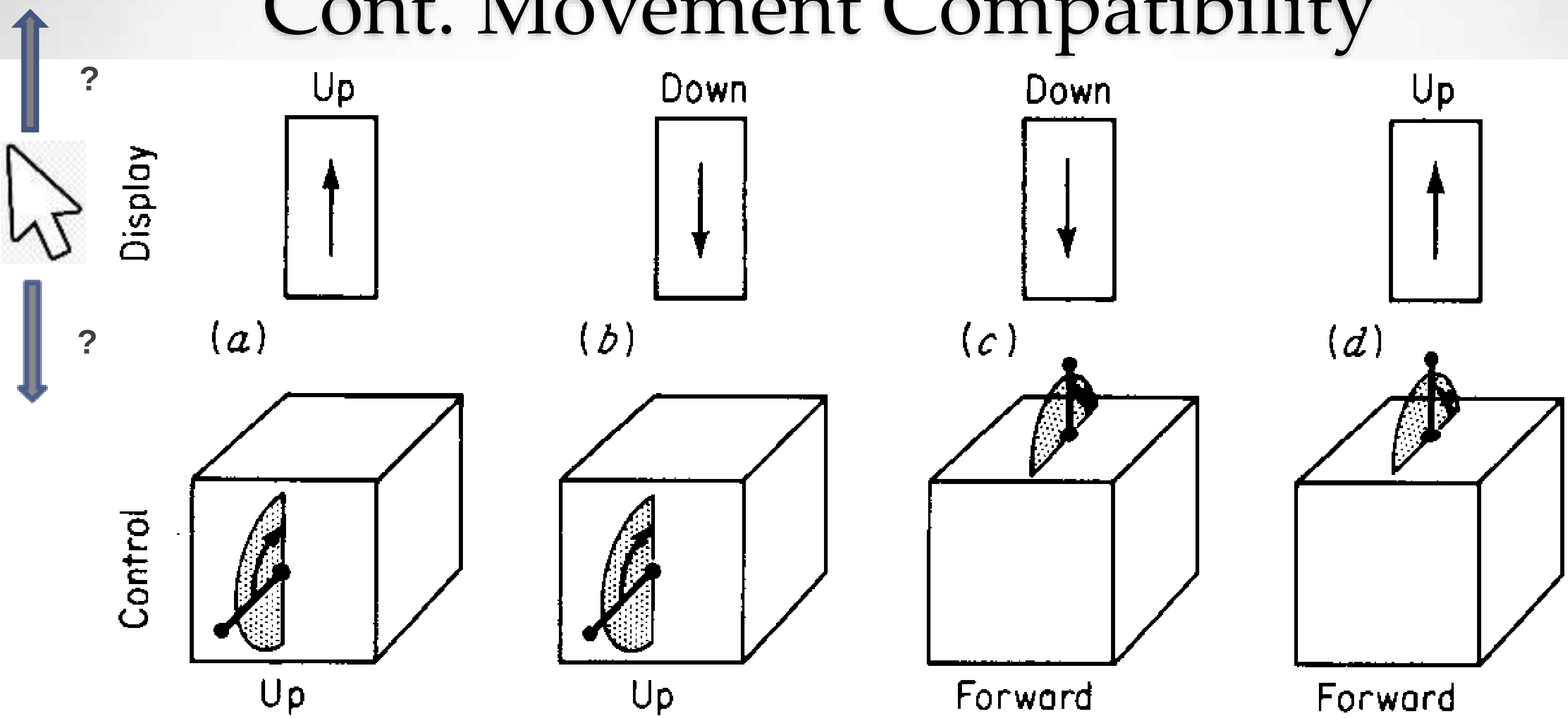
Study by *Spragg, Finck, and Smith* (1959)

- Investigated 4 combinations of control-display movements (next slide)
- Involved with tracking task
- For horizontally mounted stick (vertical plane):
  - Up-up relationship
    i.e. move control up ⇒
    display (e.g. cursor) moves up: preferred (*a*)
  - Up-down relationship (*b*): less preference
- For vertically mounted stick (horizontal plane):
  - Less difference between
    forward-up (*d*) and
    forward-down (c) relationship





Cont. Movement Compatibility



Average Tracking Score	239	149	221	227

FIGURE 10-7.
Tracking performance with horizontally mounted and vertically mounted stick controls and varying control-display relationships. (*Source: Adapted from Spragg, Finck, and Smith, 1959, data based on trials 9 to 16.*)

Cont. Movement Compatibility

Cont. Principles of movement compatibility:

3. Cont. Movement of Displays and Controls in Different Planes (i.e. 3-D device)

- Stick-type & Rotary controls with linear displays

  Study by *Grandjean* (1988):

  - Used results from all earlier experiments
  - Made recommendations regarding:
    - movement compatibility relationships for both:
    - stick-type controls with linear displays, and
    - rotary controls with linear displays
  - Note, his recommendations and those from a more recent study (*Strasser, 2022*) are shown on the following three slides (examine all carefully)

Cont. Movement Compatibility

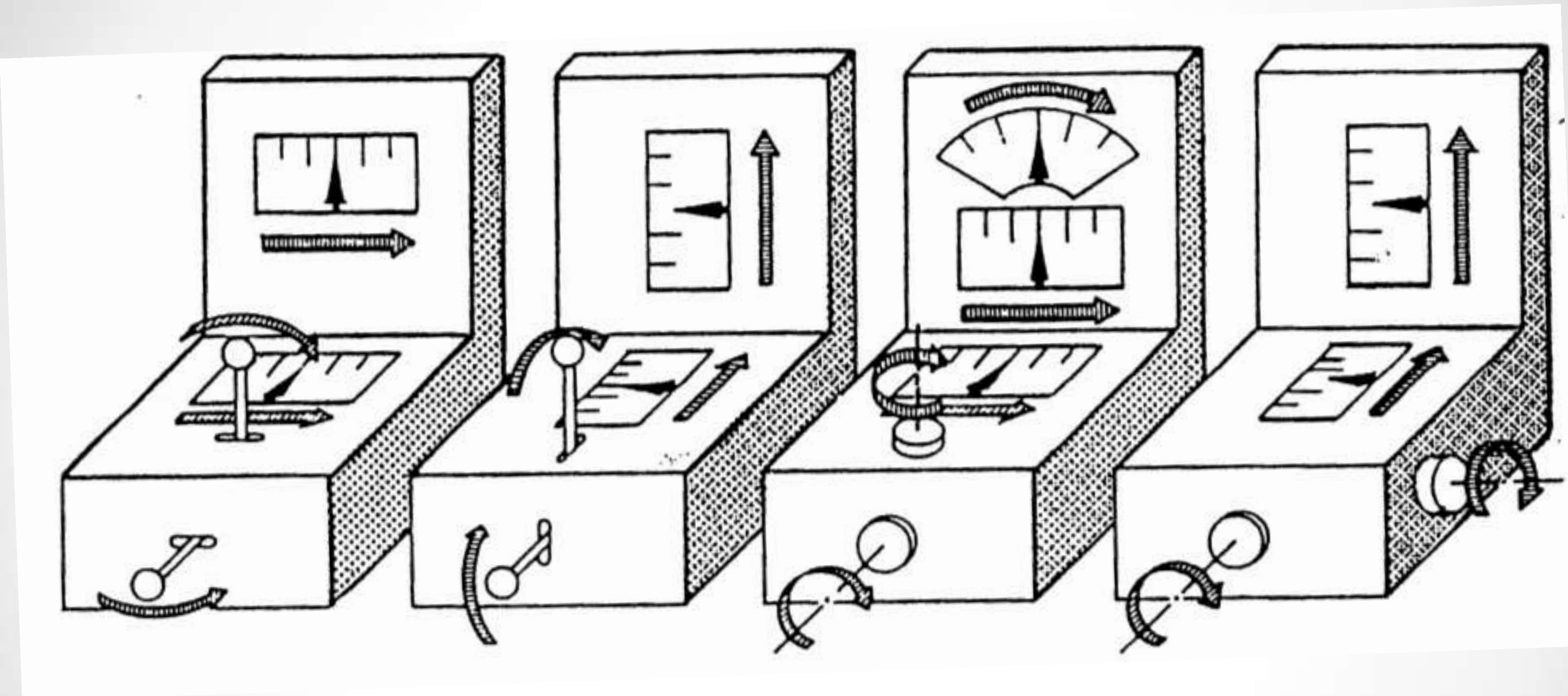
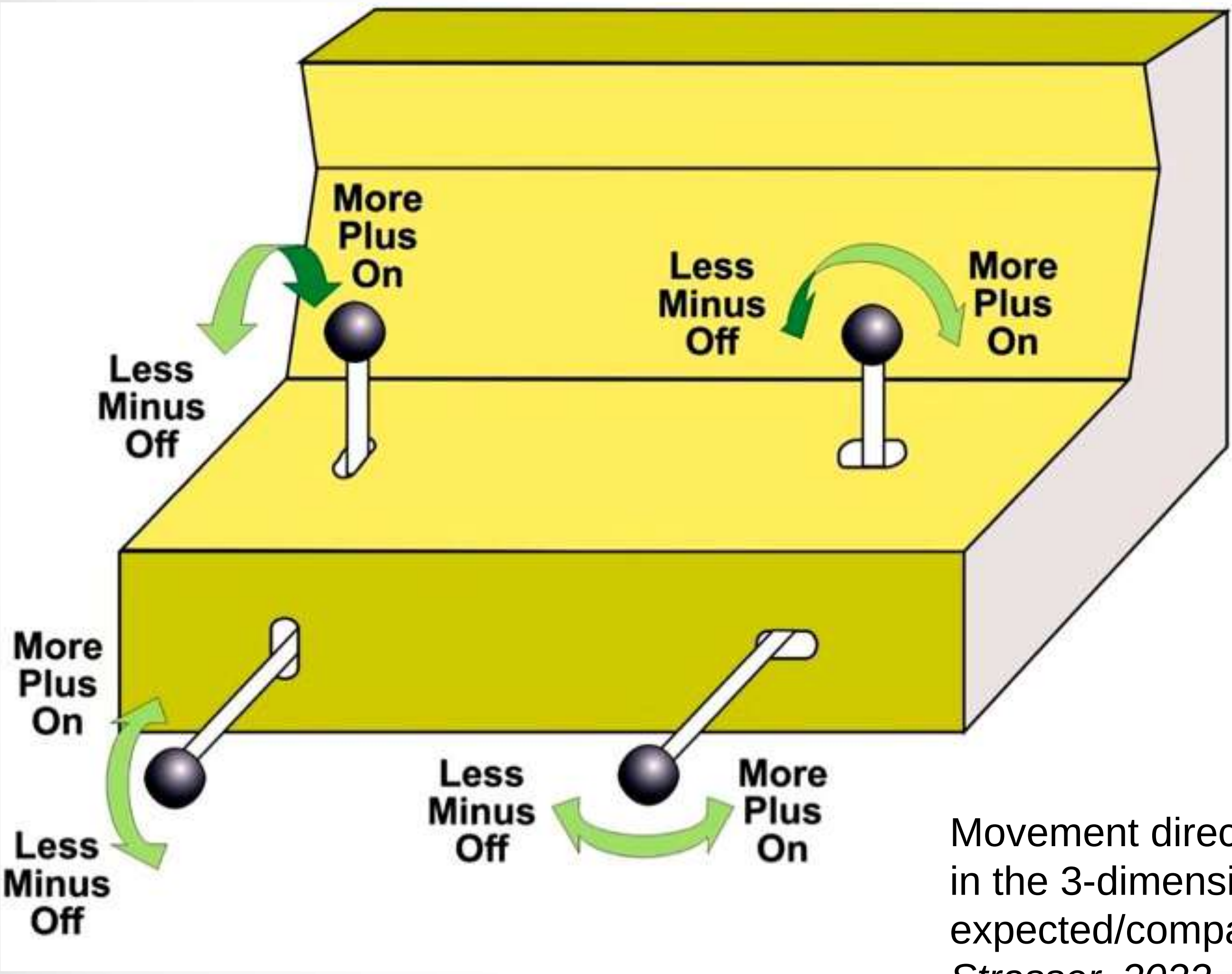


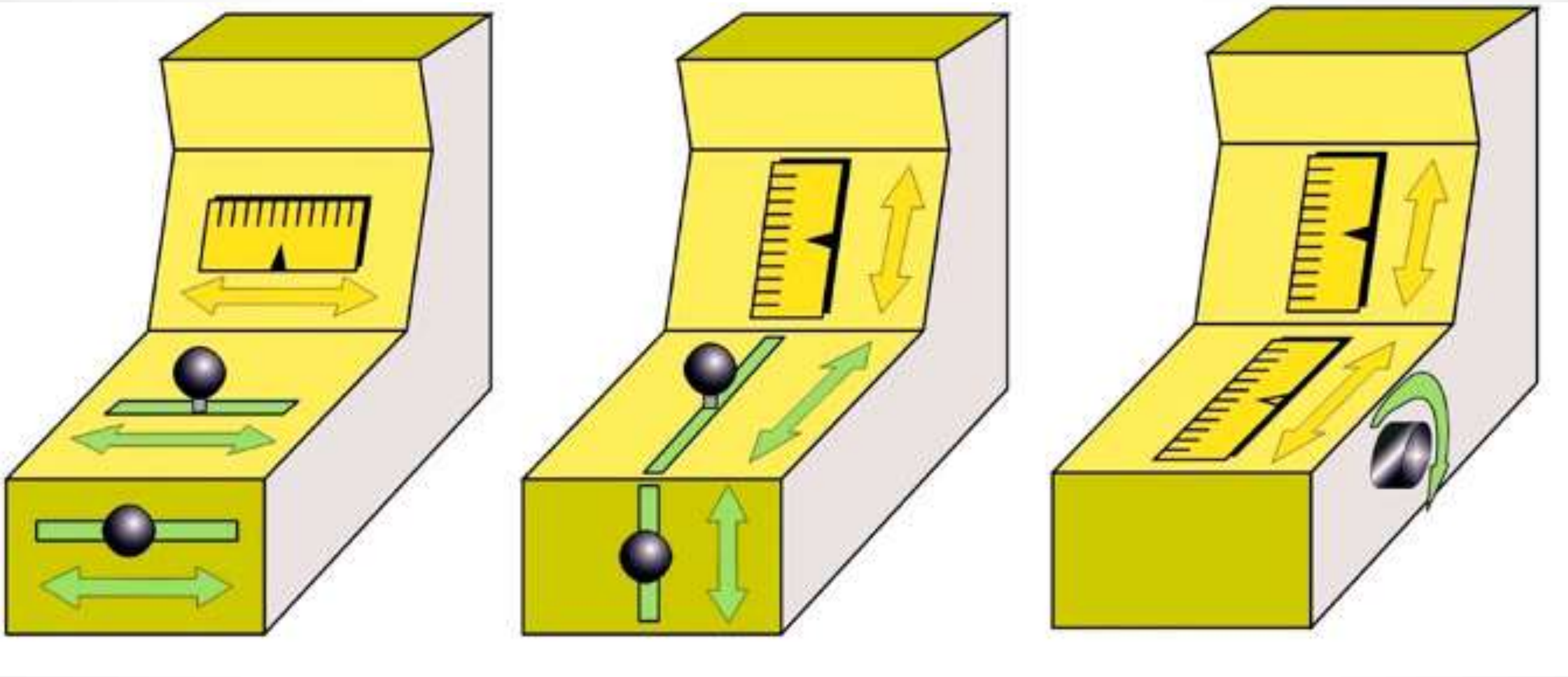
FIGURE 10-8.
Recommended movement relationships for rotary and stick-type controls and linear displays located in various planes. (*Source: Grandjean, 1988, Fig. 112.*)

Cont. Movement Compatibility



Movement directions of stick-type controls in the 3-dimensional space and expected/compatible effects. (*Source: Strasser, 2022, Fig. 50.*)

Cont. Movement Compatibility



Controls and displays in various planes arranged compatibly:
- Highest grade of unambiguity (i.e. clearest) is in the left.
- Less favorable arrangements in the middle.
- Knobs and scales in different planes in the right part (i.e. rotary control element placed in a vertical plane with a longitudinal display) is not especially compatible and may lead to uncertainty. (*Source: Strasser, 2022, Fig. 52.*)

Cont. Movement Compatibility

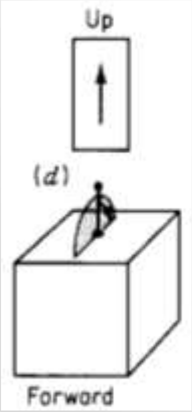
Cont. Principles of movement compatibility:

3. Cont. Movement of Displays and Controls in Different Planes (i.e. 3-D device)

- Cont. Stick-type & Rotary controls with linear displays

  Note, *Simpson* (1988) found some reservations to these results:

  - For 3D tasks in which a control lever controls up-down movement of physical machine component
  - e.g.: drill press
  - Best stereotype found:
    to move component up ⇒
    need to move control forward
  - Similar stereotype: to move component down ⇒ move control lever aft (i.e. back)
  - Conclusion: use fore/aft control to raise/lower components (vs. up/down movements)



Cont. Movement Compatibility

Cont. Principles of movement compatibility:

4. Movement Relationships of Rotary Vehicular Controls
   - In car, there is no “display” of system “output”
   - There is just “response” of vehicle (to control)

- Compatibility Principles
  1. If wheel is in horizontal plane ⇒ operator orients him/herself to forward point of control
  2. If wheel is in vertical plane ⇒ operator orients him/herself to top of control

Cont. Movement Compatibility

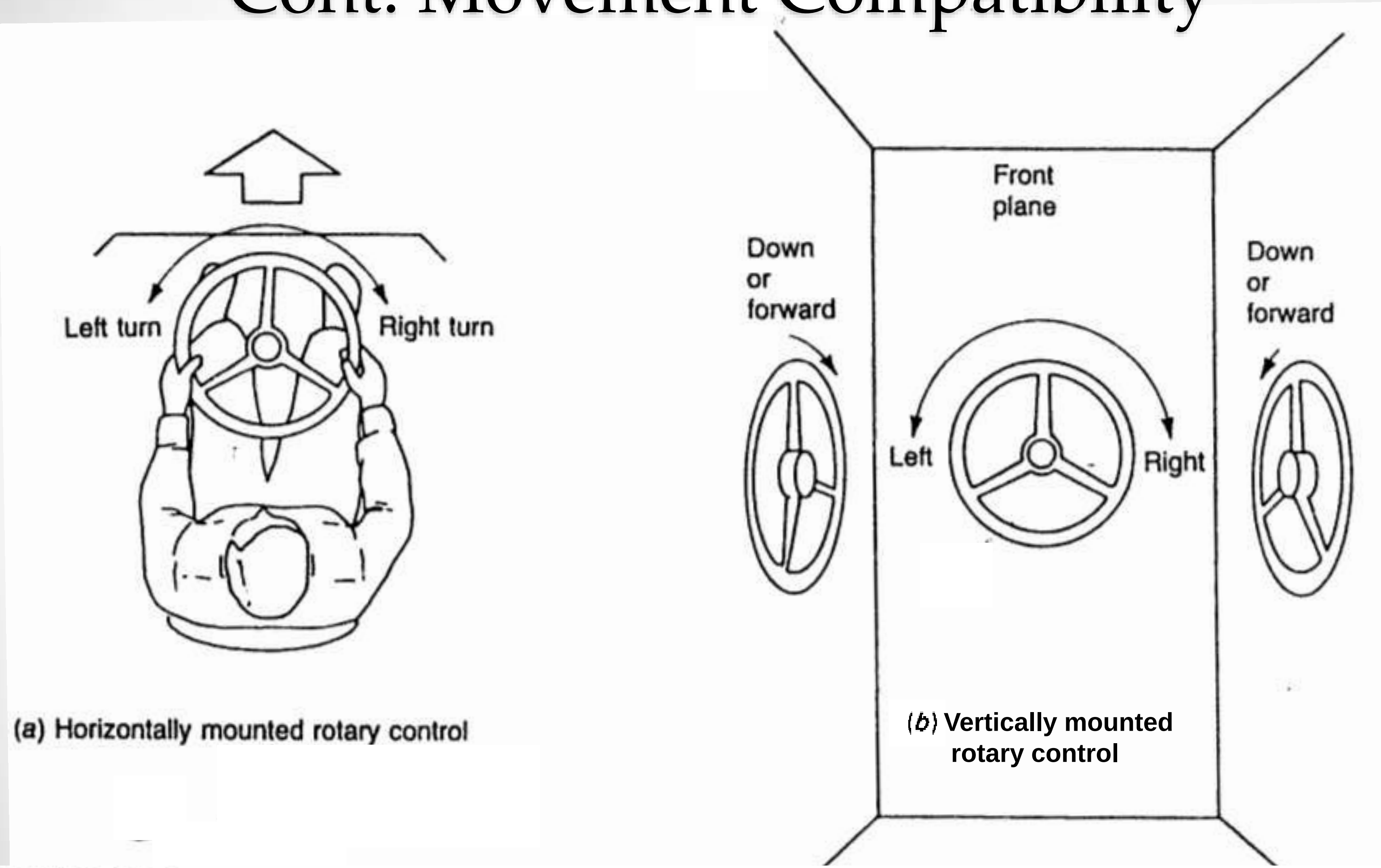


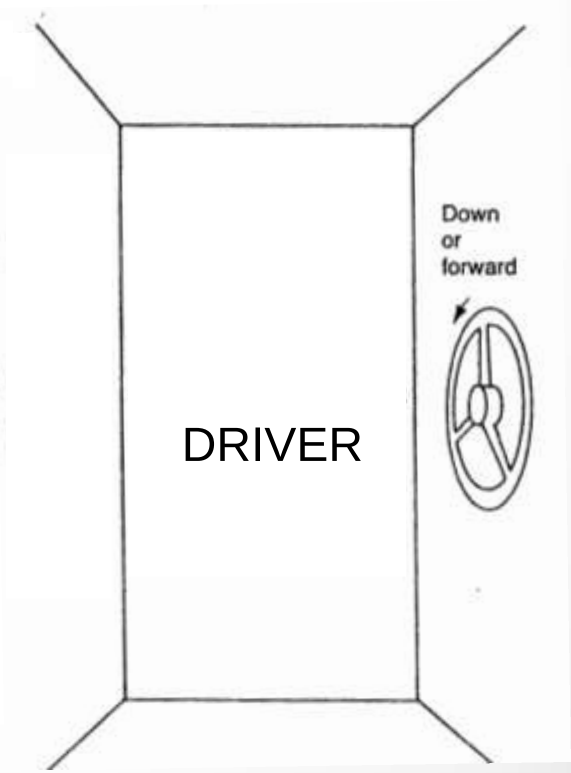
FIGURE 10-9.
The most compatible relationships between the direction of movement of horizontally and vertically mounted rotary controls and the response of vehicles. (*Source: Adapted from Chapanis and Kinkade, 1972, Figs. 8-6 and 8-7.*)

Cont. Movement Compatibility

Cont. Principles of movement compatibility:

4. Movement Relationships of Rotary Vehicular Controls

- Case study: shuttle cars for underground coal miners:
  - Control wheel exists in underground coal mines for controlling left/right turns
  - Wheel is on *right side* of car relative to driver as car goes in one direction
  - Thus, when going in opposite direction ⇒ wheel is on driver's left
  - Result: new drivers have significant problem learning to control cars
  - Can you suggest solution?



Cont. Movement Compatibility

Cont. Principles of movement compatibility:

5. Movement Relationships of Power Switches
   - US stereotype: up = on, down = off
   - UK stereotype: opposite
   - What about left-right operation?

- Experiment: *Lewis* (1986)
  - Tested choosing turning on power switch:
    - Up vs. Down
    - Left vs Right
    - Toward vs. Away
  - Measure: %ge of subjects choosing option:
    - Up = on (97%)
    - Right = on (71%)
    - Away = on (52%)
  - Conclusions:
    - Stick with vertical power switches
    - Other orientations are not encouraged

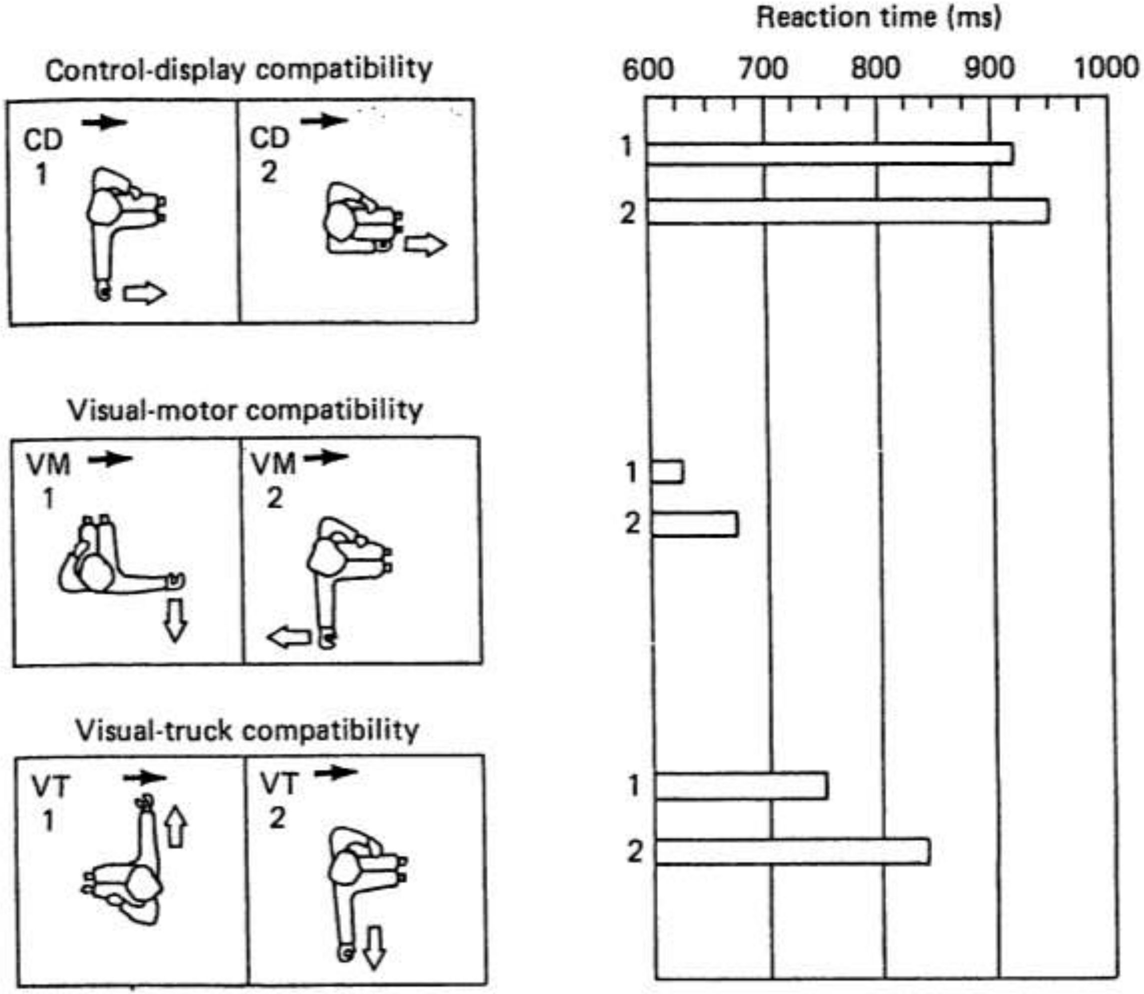
Cont. Movement Compatibility

Cont. Principles of movement compatibility:

6. Orientation of Operator and Movement Relationships
   - Previous cases: operator faces display, control in front of body
   - In some situations: operator looking at 90° or 180° angle from control
   - e.g.: adjusting car's right mirror remotely on dashboard (in front of driver) ⇒ mirror is at 90° angle to right of control

- Three principles of directional compatibility:
  - Experiments conducted by *Worringham and Beringer* (1989), next slide
  - Subjects were shown target on monitor, asked to move cursor to target using control lever
  - Measure: mean RT (to first movement)
  1. Control-display compatibility
     - Control movement in one direction ⇒ parallel movement of cursor on display, independent of operator position or orientation
     - i.e. it doesn't matter which way operator is facing

Cont. Movement Compatibility



Location of screen

Direction of arm movement for rightward cursor

FIGURE 10-10.
Relationships between direction of arm movement and cursor movement for various conditions investigated by Worringham and Beringer. See text for explanation of control-display, visual-motor, and visual-trunk compatibilities. Shown also are the mean reaction times (time to first movement) found in each situation. (*Source: Adapted from Worringham and Beringer, 1989, Fig. 2.*)

Cont. Movement Compatibility

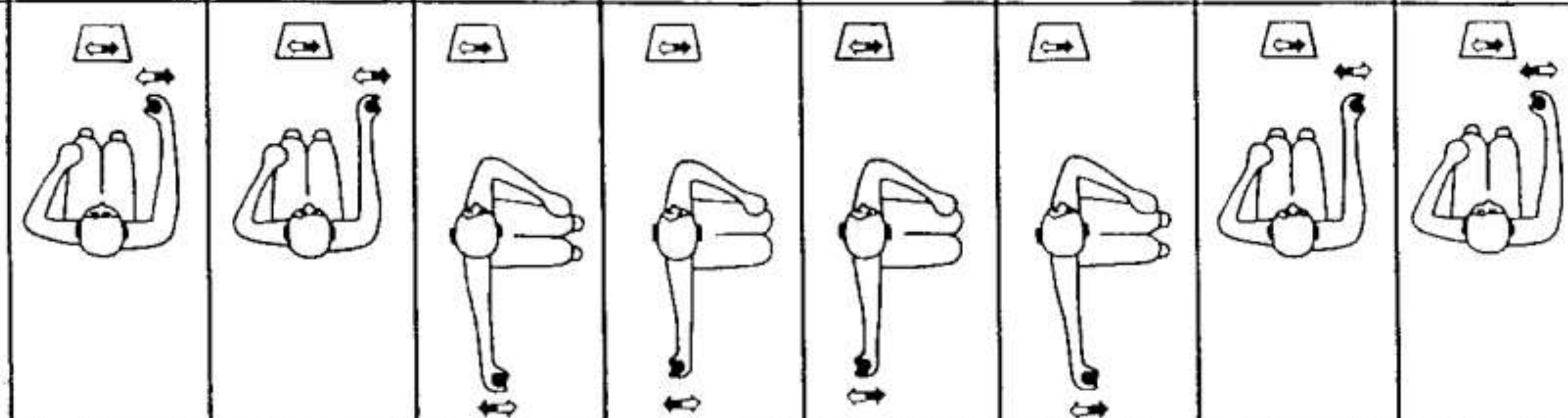
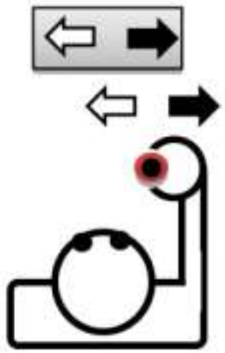
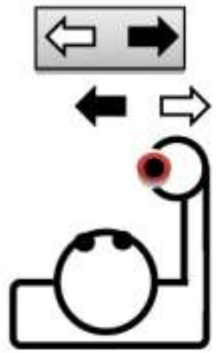
VISUAL FIELD	COMP	COMP	COMP	COMP	INCOMP	INCOMP	INCOMP	INCOMP
MUSCLE SYNERGY	COMP	INCOMP	COMP	INCOMP	COMP	INCOMP	COMP	INCOMP
CONTROL DISPLAY	COMP	COMP	INCOMP	INCOMP	COMP	COMP	INCOMP	INCOMP
BODY POSITION								

Figure 1. Plan view of head, trunk and limb orientation for each condition. The filled (or unfilled) end of the arrow adjacent to the hand shows the joystick direction required to move the cursor in the direction shown by the filled (or unfilled) end of the arrow in the representation of the screen at the top of each panel. The first two panels show, respectively, examples of supinated and pronated forearm positions.

Cont. Movement Compatibility

Control display	Compatible	Incompatible	Compatible	Incompatible
Visual field	Compatible	Incompatible	Incompatible	Compatible
Muscle synergy	Compatible	Incompatible	Incompatible	Compatible
Operator posture				
			Joystick control	Display

Cont. Movement Compatibility

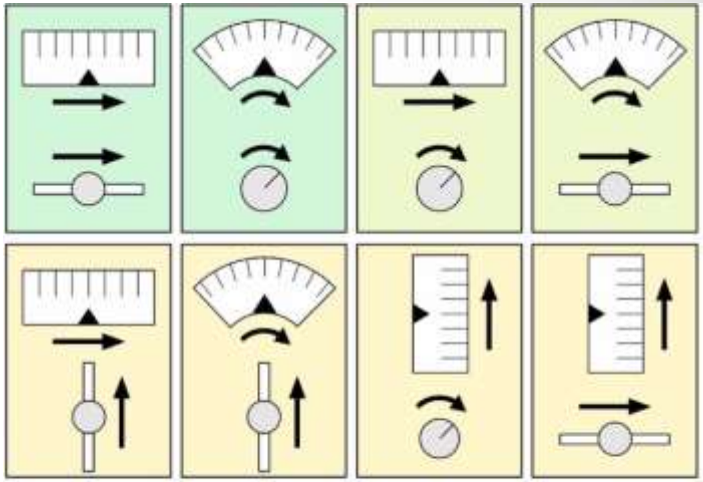
Cont. Principles of movement compatibility:

6. Orientation of Operator and Movement Relationships

- Cont. Three principles of directional compatibility:
  1. Control-display compatibility
  2. Visual-motor compatibility
     - Direction of motion of cursor in subject's visual field while looking at display = same as direction of motor response if looking at controlling limb
     - e.g. to move cursor to right as subject looks at display ⇒ move control to right (just as if you were looking at control)
     - This compatibility produced shortest RT
  3. Visual-trunk compatibility
     - Direction of movement of cursor in subject's visual field while looking at display = same as direction of movement control relative to subject's trunk
     - e.g. to move cursor to right as subject looks at display ⇒ move control right from body centerline (regardless of head/body position)

Cont. Movement Compatibility

Cont. Principles of movement compatibility:



- Discussion
  1. Clear-cut population stereotypes
     exist for control-display relationships
     (yet not universal, and not in every case)
  2. When population stereotype is not present,
     or when principles are in conflict ⇒
     designer must make decision, e.g.:
     a) Design control-display relationships
        to match those existing
        in other systems already being used
        (i.e. use standardization in this case)
     b) Choose relationship
        that is logical/explainable
        (this also makes it easier to train people to use it)
  3. In absence of stereotype, previous experience, and logical principle:
     - Base design decision on empirical tests
       of possible relationships using intended user population

Modality Compatibility

Modality Compatibility

- What modality compatibility refers to:
  - Some stimulus-response modality combinations: more compatible with certain tasks than others
- Study by *Wickens, Sandry, and Vidulich* (1983):
  A. Participants performed either one of the following tasks (next slide),
    - **Verbal** task (respond to command, "turn on radar beacon tacan**")
    - **Spatial** task (bring cursor over a specified target)

  B. Each task presented through either,
    - **Auditory** (A) modality (speech)
    - **Visual** (V) modality (display on screen)

  C. Participant responded either by,
    - **Speaking** (S) response
    - **Manually** (M) performing the command

  D. Results shown in next slide (all presentation/response modalities):
    - **RT** measured for each of the presentation/response modalities
  - Most compatible combinations (fastest performance):
    - **Verbal** task: **A** presentation with **S** response
    - **Spatial** task: **V** presentation with **M** response
  - Note, can you explain findings above?

Racon (transmitter-receiver used in navigation)

Cont. Modality Compatibility

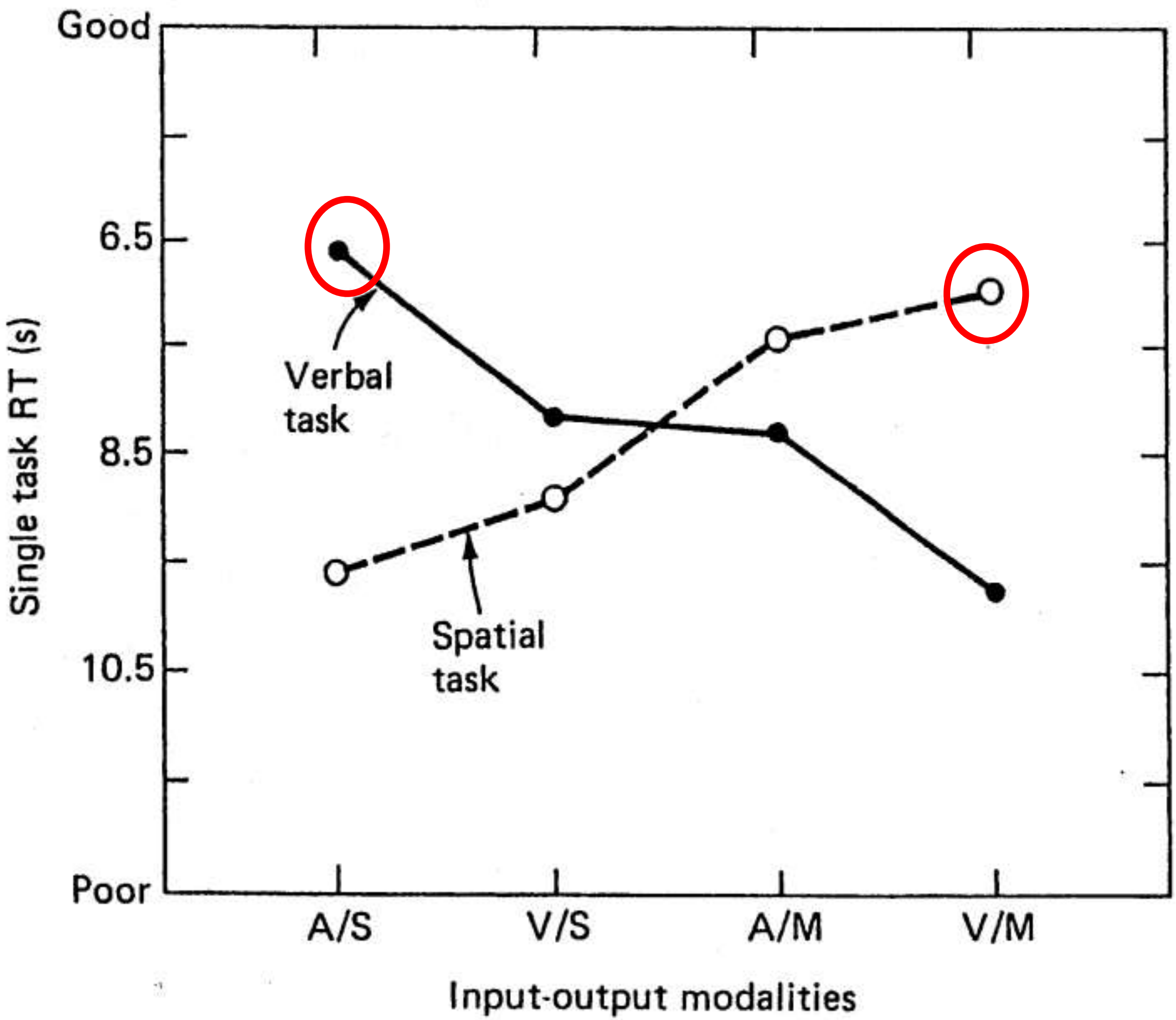


FIGURE 3-1
An example of modality compatibility. Input modality: A = auditory (speech) and V = visual (displayed on screen). Output modality: S = spoken response and M = manual response. For verbal tasks, the best input-output combination is A/S. For spatial tasks, the best combination is V/M. (*Source: Wickens, Sandry, and Vidulich, 1983, Fig. 6. Reprinted with permission of the Human Factors Society, Inc. All rights reserved.*)

Table 3.1 (sensory modality)

TABLE 3-1
WHEN TO USE THE AUDITORY OR VISUAL FORM OF PRESENTATION

Use auditory presentation if:	Use visual presentation if:
1 The message is simple.	1 The message is complex.
2 The message is short.	2 The message is long.
3 The message will not be referred to later.	3 The message will be referred to later.
4 The message deals with events in time.	4 The message deals with location in space.
S The message calls for immediate action.	S The message does not call for immediate action.
6 The visual system of the person is overburdened.	6 The auditory system of the person is overburdened.
7 The receiving location is too bright or dark-adaptation integrity is necessary.	7 The receiving location is too noisy.
8 The person's job requires moving about continually.	8 The person's job allows him or her to remain in one position.

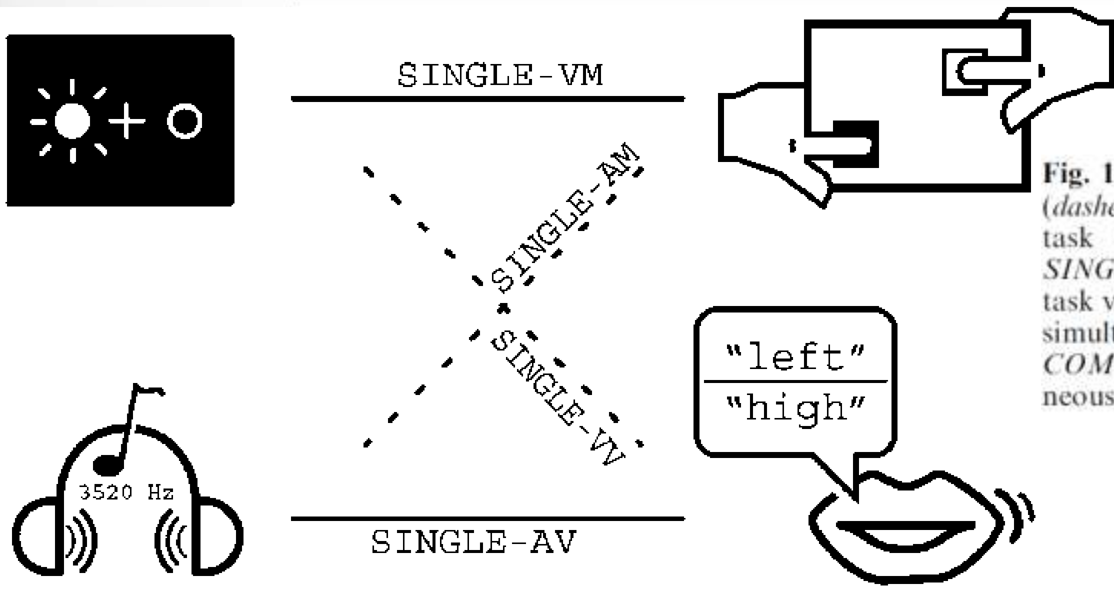


Fig. 1 Modality compatible (*solid lines*) and modality incompatible (*dashed lines*) stimulus–response pairs. *SINGLE-VM* single task visual–manual; *SINGLE-AV* single task auditory–vocal; *SINGLE-AM* single task auditory-manual; *SINGLE-VV* single task visual–vocal. SINGLE-VM and SINGLE-AV were performed simultaneously in the modality compatible dual task (*DUAL-COMP*). SINGLE-AM and SINGLE-VV were performed simultaneously in the modality incompatible dual task (*DUAL-INCOMP*)

References

- ***Human Factors in Engineering and Design***. Mark S. Sanders, Ernest J. McCormick. 7th Ed. McGraw: New York, 1993. ISBN: 0-07-112826-3.
- ***Compatibility as guiding principle for ergonomics work design and preventive occupational health and safety***. H. Strasser, Zeitschrift für Arbeitswissenschaft, 76, 2022. pp. 243–277.
- ***Interface Design and Display-Control Compatibility***. S. Tsang, et al, Measurement and Control, 48(3), 2015.