WADC TECHNICAL REPORT 54-423

DESIRABLE CONTROL-DISPLAY RELATIONSHIPS FOR MOVING-SCALE INSTRUMENTS

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SEPTEMBER 1954

PROJECT No. 7182-71514

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
500 - 23 March 1955

ABSTRACT

This report summarizes a series of experiments designed (1) to investigate the effects of certain control-display relationships on making settings with moving-scale instruments, (2) to attempt to find the optimum control to moving-scale display relationship.

Two recommendations resulted: (1) Moving-scale assemblies, for use where the operator will never make control adjustments without simultaneously looking at the associated display, should have a dial which rotates in the same direction as its control knob and whose scale numbers increase from left to right. At least two scale numbers should be visible in the display aperture at all times. (2) When the operator may make crucial control adjustments by "blind reaching" (i.e., without looking at the display), moving-scale assemblies should not be used.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

JACK BOLLERUD
Colonel, USAF (MC)
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Directorate of Research

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INTRODUCTION

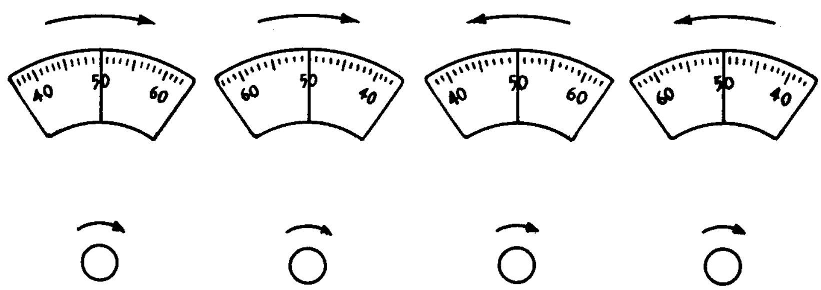
Although moving-scale instruments are in frequent use on electronic control panels and elsewhere in aircraft, their control-display movement relationship has never been standardized, presumably because no one relationship is obviously superior. It would appear desirable that:

1. The scale rotate in the same direction as its control knob (i.e., that a direct drive exist between control and display).

2. The scale numbers increase from left to right.

3. The control turn clockwise to increase settings.

Unfortunately it is not possible to incorporate all three of these desirable features in a conventional assembly. Actually, with the usual control-display orientation, only the following four combinations are possible. See Fig. 1.



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

Figure 1. Four basic control-display assembly types and their associated features. (Cross-hatch indicates "undesirable" features.)

It is apparent that each of the four assemblies has some disadvantage, but it is not possible to deduce with certainty which disadvantage is the least serious.

This report will summarize a series of experiments whose purpose was: (1) to measure the effect on performance of the "undesirable" features listed in Fig. 1, and (2) to attempt to find the optimum moving-scale assembly.

These experiments were performed in a temporal series, with each experiment except the first being motivated by the results and insights gained from the previous experiment. Because the technique used was essentially the same in all of the experiments, apparatus and procedure will be described under a general apparatus and procedure section. Where modifications of procedure are introduced, they will be described along with the specific experiment in which they occurred.

All significance levels quoted in this report will be based upon the Chi-Square test of statistical significance.

APPARATUS

In Experiment I the apparatus was a four sided black box, each side of which presented a panel 9 inches high by 11 inches wide. A one and three-eighths inch diameter black knob was centered four inches above the base of the panel and mid-way between its sides. In all subsequent experiments the apparatus was a six sided black box whose panels were 10 inches high by 8¼ inches wide. The one and three-eighths inch diameter knob was centered three inches above the base of the panel, except for assembly E in Experiments II and IV where the knob was above the dial. Here the knob was centered three inches below the top of the panel. The gear ratio between the control knob and the moving element of the display was always one to one.

In all experiments a circular dial was viewed through an aperture in the panel. The dial was three inches in diameter and contained one hundred graduation marks covering the entire three hundred and sixty degrees of its periphery. Every fifth graduation mark was longer and thicker than the other "units" marks, and every tenth mark was still longer and thicker and was numbered. Further specific details as to dial design will be discussed along with the individual experiments.

The dial aperture afforded a view of the moving scale such that eighty-two degrees of the dial periphery was visible, and three-fourths of an inch of the dial was visible along the vertical dimension. With one exception (assembly C 3, in Experiment II) a stationary vertical indicator bisected this aperture. When the indicator was a lubber line, its thickness was approximately that of the "units" graduation marks. Approximately twelve graduation marks were visible on either side of the indicator, so that two numbered "tens" marks were always visible. In Experiment IV, one assembly had a stationary scale with moving pointer. Here, of course, the "aperture" was a circle of about three and

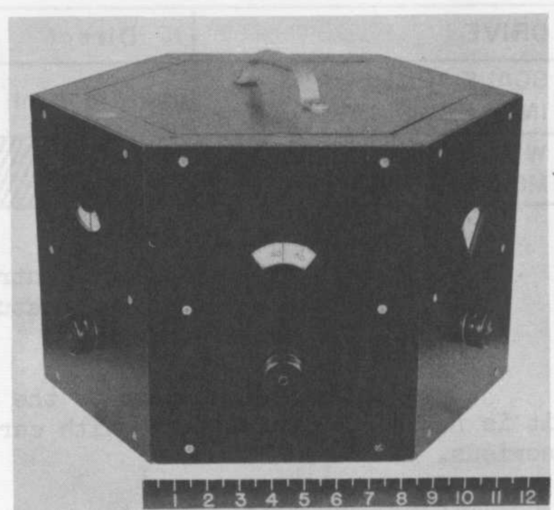


Figure 2: Typical apparatus. Three of the control panels used in Experiment II.

one-fourth inches diameter so that the entire dial was visible at one time. The distance between knob center and aperture center was about three and one-fourth inches.

PROCEDURE

The subject was seated before the control panel with the aperture at eye level. He was informed that the experimenter wanted to learn which of several control-display assemblies he preferred. He was not told that errors would be recorded, although he could see that the experimenter was taking notes. Except for Experiment III, he was required to manipulate and examine each assembly, in order to familiarize himself with the control motion to display motion relationship, before being asked to make settings with it. When the subject had familiarized himself with an assembly, the experimenter would shield the display from the subject's view, set the scale to a predetermined setting, remove the shield, and ask the subject to set the scale to another predetermined value. The setting required was always to a non-labeled value. In the first three experiments, several such settings would be made on one assembly; then a series of settings would be required on another assembly. The order of presentation of assemblies was always balanced, and every assembly received the same number of settings to a higher number, to a lower number, involving large angular distances, involving small angular distances, etc. In short, the tasks required were equated, as nearly as possible, for all assemblies.

Three types of error were recorded:

a. Starting Error - an initial movement of the control in the wrong direction.

b. Terminal Overshoot - overshooting and then returning to the specified setting.

c. Setting Error - incorrect setting.

(1) Non-Reversal Error - ordinary incorrect setting.

(2) Reversal Error - incorrect setting when direction of scale increase is apparently misinterpreted.

As shown above, setting errors were further subdivided into reversal errors and non-reversal errors. A reversal error is one in which the operator apparently interprets the scale as though the scale numbers increased in the direction opposite to their true direction of increase. For example, if the experimenter sets the scale to 56 and asks the subject to set to 63, if the subject instead sets to 57, a reversal error has been committed.

At the end of the session, the subject was asked to rank the assemblies, in order of preference, from best to worst.

EXPERIMENT I

In this experiment the four control-display assemblies shown in Fig. 1 were compared, with four settings required on each assembly. There were 72 male adult subjects, consisting of four subject groups: 24 human engineering psychologists, 16 bomber-transport pilots, 16 fighter-interceptor pilots, and 16 college students.

RESULTS

The error pattern was essentially the same for all four subject groups. Therefore, only the error data for the total of all subject groups will be presented here.

A significantly greater number of starting errors were committed with the reversed drive assemblies, C and D, than with the direct drive assemblies, A and B, ($p < .001$). See Fig. 3.

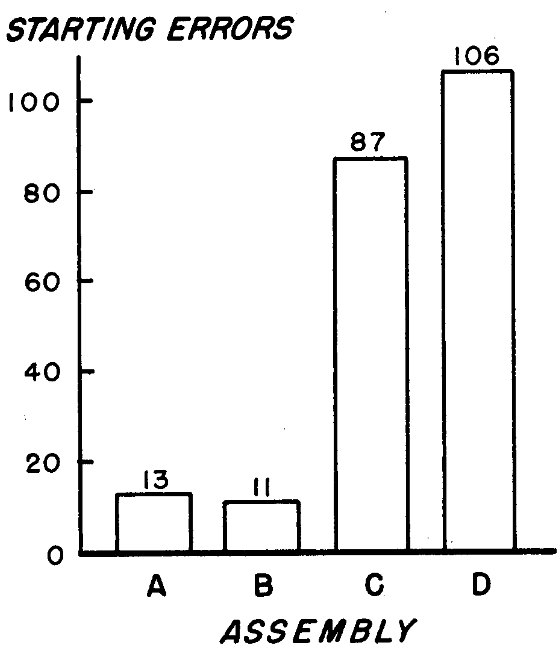


Figure 3: Number of starting errors committed on each assembly. Total for all subject groups.

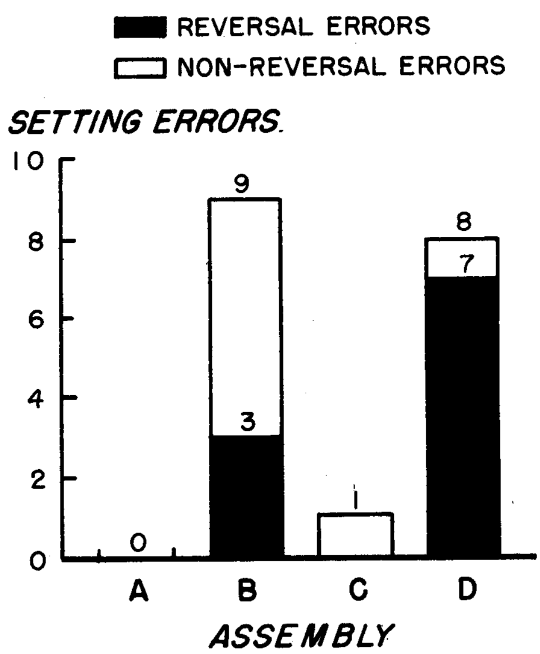


Figure 4: Number of setting errors committed on each assembly. Total for all subject groups.

Terminal overshoots occurred with about the same frequency on all four assemblies. No statistically significant differences occurred. Of all settings made, 16.75% involved terminal overshoot errors.

Combined setting errors for the two assemblies in which scale numbers increase from right to left, B and D, were significantly more frequent than combined setting errors for the two assemblies in which scale numbers increase from left to right, A and C, ($p < .001$). See Fig. 4. The same statement can be made for reversal errors, which were the most frequent type of setting error (but with $p < .01$).

Although preferences varied considerably from group to group, the general indication was a preference for direct drive and a decided rejection of assembly D. Assembly A was most frequently ranked first, but there was a strong tendency to rank assembly B second. See Fig. 5.

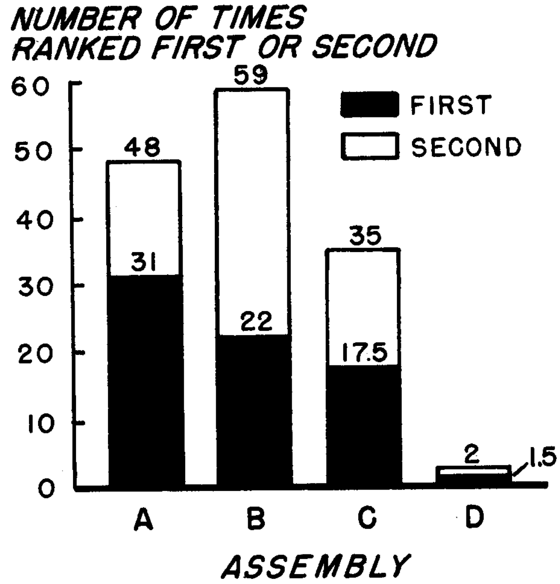


Figure 5: Number of times each assembly was ranked either first or second. Total for all subject groups.

DISCUSSION

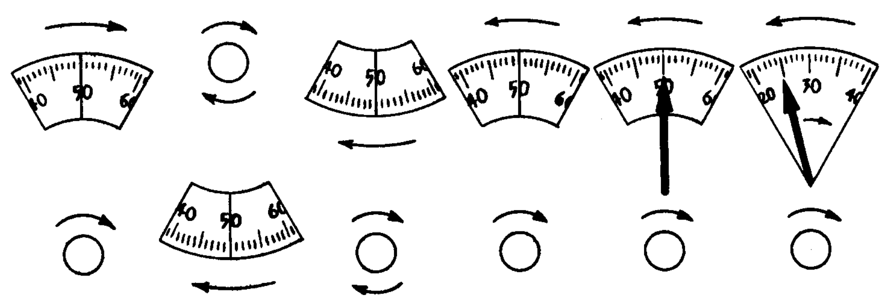
Apparently, setting errors are associated with right to left increasing scales, and starting errors and annoyance to the operator with reversed drive. Assembly A is relatively free from both types of error and is well liked. However, assembly A's control knob turns counterclockwise to increase settings. This feature is undesirable for two reasons: (1) Pilots have been strongly indoctrinated with the rule that a control should turn clockwise to increase settings; (2) The controls of practically all stationary scale, moving-pointer instruments turn clockwise to increase settings.

If, then, one is reluctant to accept assembly A on the supposition that there will be habit interference between the direction of turn of its control and the direction of turn of the controls of most other aircraft instruments for increase, only assemblies B and C remain to be chosen from, since assembly D is obviously unacceptable. Setting errors are associated with assembly B, starting errors with assembly C. Of the two types of error, setting errors would appear to be by far the most serious, even though they occur much less frequently than starting errors.

It was decided, therefore, to attempt (1) to "modify" assembly A so that its left to right increasing scale and its direct drive would be preserved, but so that its control would turn clockwise to increase settings, and (2) to modify assembly C so as to reduce its starting errors. This decision initiated Experiment II.

EXPERIMENT II

Six assemblies were tested in this experiment. Two assemblies, E and F, were "modifications" of assembly A in that, by changing the control-display orientation, assembly A's direct drive and left to right increasing scale were preserved, while A's undesirable direction of control turn for increase was reversed. Since their controls turn clockwise to increase settings, E and F are different from A in a major feature and are, therefore, not true modifications. Consequently, entirely new letters are used to designate these two assemblies. Two assemblies were modifications of assembly C. Assembly C2 simply replaced the lubber line of assembly C with a stationary pointer. This was done because, if the operator adopts the attitude that it is the lubber line that moves rather than the dial, then there is a "direct drive" between the knob and the lubber line; i.e., if knob turns clockwise, dial moves counterclockwise, but the relative motion of the lubber line with respect to the dial is clockwise . It was hoped that a stationary pointer would foster this attitude. Assembly C3 went farther in this direction by using a moving pointer. A 360 degree clockwise rotation of the knob produced a 60 degree clockwise rotation of the pointer and a 300 degree counterclockwise rotation of the dial. Assemblies A and C were included for comparison with their modifications. The six assemblies are shown diagramatically in Fig. 6.



ASSEMBLY	A	E	F	C	C2	C3
DRIVE	Direct	Direct	Direct	Reversed	Reversed	Reversed
SCALE NUMBERS INCREASE	Left to Right	Left to Right	Left to Right	Left to Right	Left to Right	Left to Right
WITH CLOCKWISE KNOB MOVEMENT SETTING WILL:	Decrease	Increase	Increase	Increase	Increase	Increase

Figure 6: The six control-display assemblies used in Experiment II and their associated features. (Cross-hatch indicates "undesirable" features.)

Eighty-seven male, adult subjects were run. There were four subject groups: 24 human engineering psychologists, 15 pilots (10 bomber, 5 fighter), 24 college students, and 24 college students who had been specially "instructed" as to what attitude to adopt toward the indicator while making settings. Four settings were required on each assembly.

RESULTS

The error and preference patterns for the four subgroups were quite similar; therefore, only data for the group as a whole will be reported.

The general starting error pattern showed three distinct groups: (1) assemblies A and E on which very few starting errors were committed, (2) assemblies C, C2, and C3 on which many starting errors were committed, and (3) assembly F whose error frequency was always between groups (1) and (2). In no case were there significant differences in starting errors within group (1) or group (2). There were always significant differences in starting errors between any member of group (1) and any member of group (2) ($p < .01$). For the total of all subject groups, starting errors on assembly F were significantly greater than those on any member of group (1) ($p < .001$), significantly smaller than those on any member of group (2) ($p < .01$).

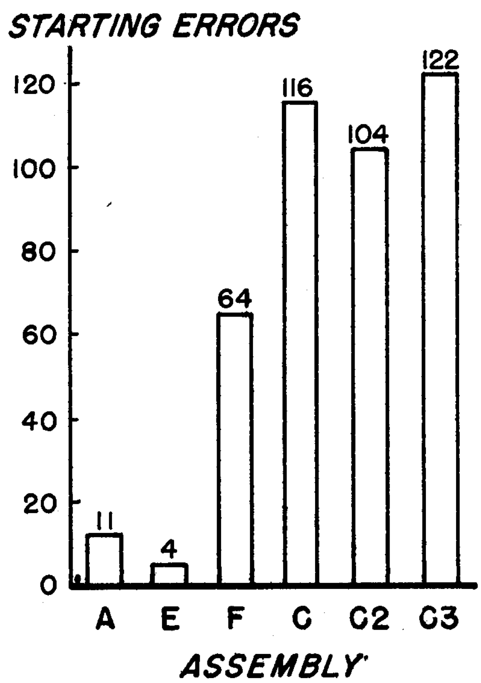


Figure 7: Number of starting errors committed on each assembly by the total of all subject groups.

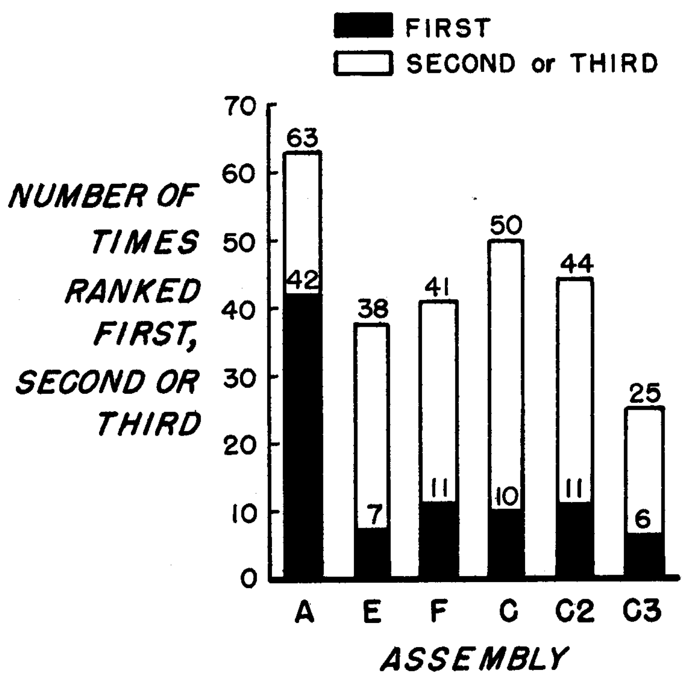


Figure 8: Number of times each assembly was ranked either first, second or third. Total for all subject groups.

As in the preceding experiment, terminal overshoot errors occurred with about equal frequency on all assemblies. No statistically significant differences occurred. Of all settings made, 23.47% involved terminal overshoot errors.

There were no reversal errors on any assembly in this experiment. Five non-reversal setting errors were committed. These errors did not group themselves about any particular assembly or subject group, so there was no suggestion that they were not randomly distributed.

Assembly A was ranked best with significantly high frequency by the total of all subject groups ($p < .001$).

DISCUSSION

The modifications designed to reduce starting errors on assembly C were a complete failure. They neither reduced starting errors appreciably nor resulted in any significant increase in subjects' preference.

Assembly E was a limited success in that it proved to be relatively free from both starting and setting errors. It had the disadvantage, however, that, in making a setting, the subject's hand tended to obscure the dial. In order to see the dial, the subject either had to assume an awkward head position or had to use an awkward grasp on the knob. Furthermore, this assembly was not well liked.

Starting errors were more frequent on assembly F than on assemblies A and E, even though all three are direct drive assemblies. A possible reason for this is the fact that, although there is direct drive between control and display, adjacent portions of control and display move in opposite tangetial directions (Warrick, 6).

Assembly A again was most frequently ranked first, and it gave rise to fewer starting errors than any assemblies except E. Here the difference was not significant.

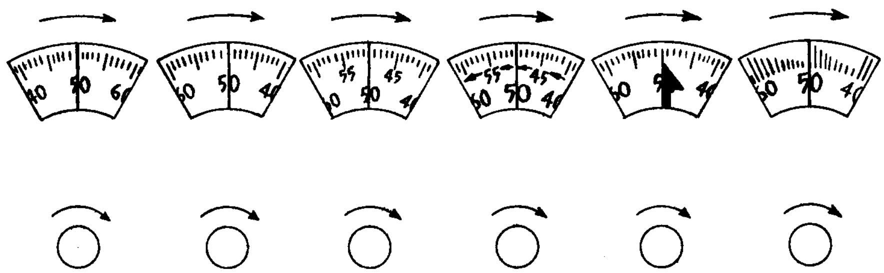
Only assemblies A and E could be considered satisfactorily free from starting errors. However, assembly A has the original disadvantage that its control turns counterclockwise to increase settings. Assembly E has the drawback that the hand tends to obscure the dial when making settings. It was decided, therefore, to explore the possibility of modifying assembly B so as to reduce its tendency to give rise to setting errors. Experiment III resulted from this decision.

EXPERIMENT III

Six assemblies were tested in this experiment: four were modifications of assembly B; assembly B itself was included for comparison with its modifications; and assembly A, being probably the best assembly up to this point, was included as a sort of criterion for excellence.

Assembly B2 differed from assembly B only in that every fifth graduation mark was numbered. The numbers for the "fives" graduation marks were smaller and nearer to the periphery of the dial than were the numbers for the "tens" marks. It was hypothesized that reversal errors are attributable to the subject's field of attention being confined to a narrow region surrounding the indicator, and that, when every tenth mark is numbered, this region may include only one scale number. Since direction of scale increase is indeterminate when the position of only one scale number is known, scale interpretation errors (i.e., reversal errors) may be expected. It was hoped that, by numbering every fifth mark, two numbers would be crowded into the hypothesized "field of attention", thereby making direction of scale increase obvious.

Assembly B3 was the same as assembly B2 except that in each interval between two scale numbers an arrow pointed toward the higher number (i.e., pointed in the direction of scale increase). It was hoped that the arrows would further reduce scale interpretation errors by (1) showing direction of scale increase, and (2) widening the hypothesized "field of attention" by encouraging eye movements in the direction of the arrow.



ASSEMBLY	A	B	B2	B3	B4	B5
DRIVE	Direct	Direct	Direct	Direct	Direct	Direct
SCALE NUMBERS INCREASE	Left to Right	Right to Left	Right to Left	Right to Left	Right to Left	Right to Left
WITH CLOCKWISE KNOB MOVEMENT SETTING WILL:	Decrease	Increase	Increase	Increase	Increase	Increase

Figure 9: The six control-display assemblies used in Experiment III and their associated features. (Cross-hatch indicates "undesirable" features.)

Assembly B4 differed from assembly B only in that the lubber line indicator of assembly B was replaced by a stationary barb which pointed toward the lower scale number. With the type of scale used in this experiment, reversal errors always involve an error in the "tens" digit (e.g., setting 38 when 42 is called for is a reversal error). Since the "tens" digit of the lower numbered mark and the "tens" digit of the setting under the indicator are identical, it was hoped that, by drawing the operator's attention to the lower numbered mark, reversal errors might be reduced. Obviously this assembly and the preceding one were based upon conflicting hypotheses.

Assembly B5 employed a "staircase" scale. Reversal errors in reading stationary staircase scales had already been investigated by Christensen (2); however, the scale used here differed from Christensen's scale in that the lower end of each graduation mark was the same distance from the center of the dial and the marks increased in length upward for increasing scale settings. It was felt that reversal errors might be less likely under these circumstances.

Ten settings were required on each assembly. The particular settings required were picked for their presumed susceptibility to reversal errors. Sixty male college students served as subjects. No pilots or human engineering psychologists were tested because Experiments I and II had indicated that the pattern of errors for pilots and psychologists was the same as that for students.

The subjects were not allowed to manipulate and examine the assemblies previous to making settings on them. On his first setting with each assembly, therefore, the subject had no way of knowing which way the dial would rotate for a given direction of rotation of the knob. In this section, therefore, "errors" committed on the first trial with each assembly will be excluded from the starting error data.

RESULTS

Starting errors were quite infrequent, averaging 5.33 per assembly for the entire subject group, out of 540 settings required per assembly . There were no significant differences among the six assemblies.

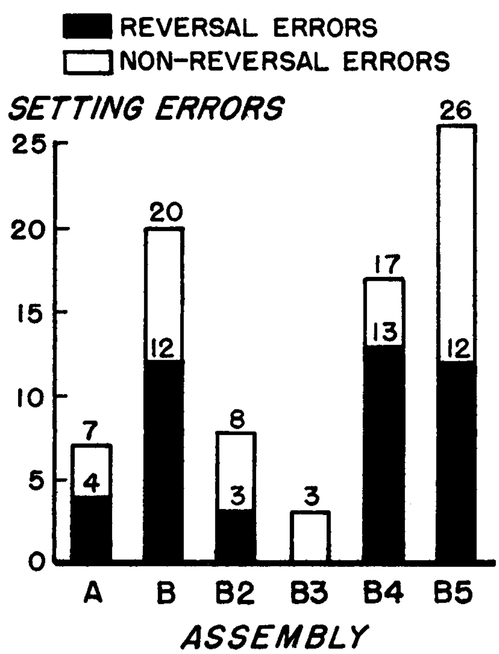


Figure 10: Number of setting errors committed on each assembly.

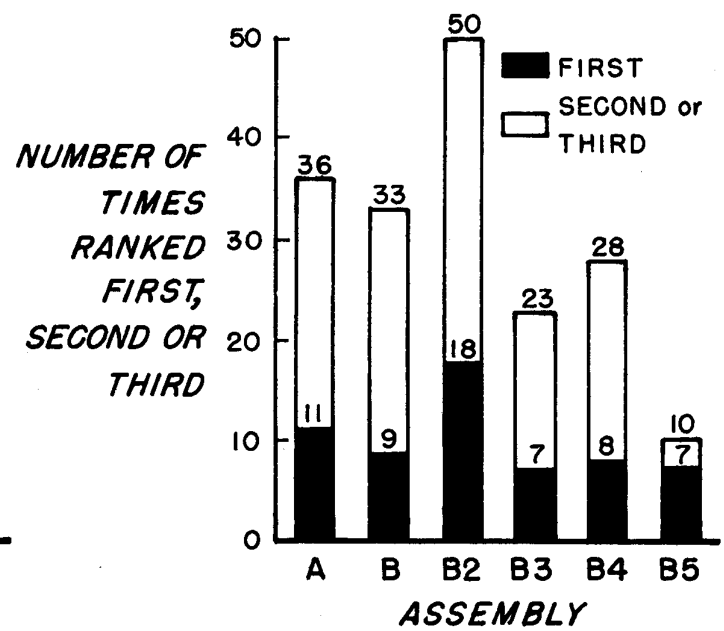


Figure 11: Number of times each assembly was ranked either first, second or third.

Terminal overshoots occurred with about equal frequency on all assemblies tested. There were no significant differences. Of all settings made, 10.72% involved terminal overshoot errors.

On the basis of setting errors, the six assemblies can be roughly divided into two groups: (1) assemblies A, B2, and B3 on which there were few setting errors, (2) assemblies B, B4 and B5 on which setting errors were relatively frequent. There were no significant differences in either setting errors or reversal errors within either of these groups. Significant differences usually exist between members of the two groups ($p < .20$ to $p < .001$ for setting errors; $p < .10$ to $p < .001$ for reversal errors). Of particular interest is the fact that modifications B2 and B3 were significant improvements over the original assembly, B, ($p < .05$ and $p < .001$ respectively for setting errors; $p < .05$ and $p < .01$ respectively for reversal errors only). See Fig. 10.

Assembly B2 was significantly often ranked first ($p < .01$); it was also ranked in the "top half" of the rankings (i.e., either first, second or third) with significant frequency ($p < .001$). See Fig. 11.

DISCUSSION

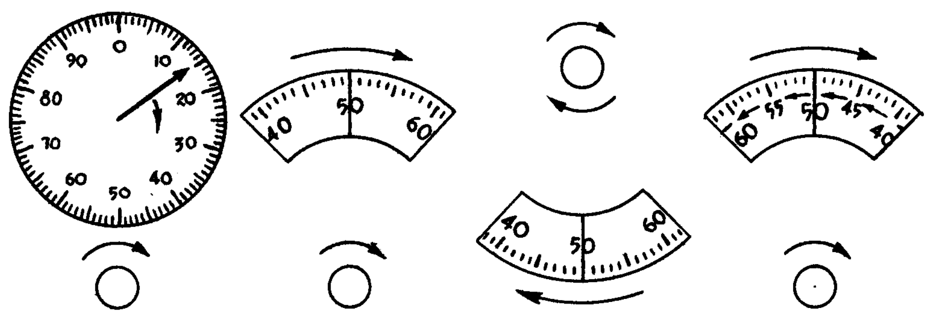
The setting error results indicate clearly that assemblies B4 and B5 are no improvement over assembly B. Assemblies B2 and B3 would appear to be as free from setting errors as assembly A; however, two points should be considered in evaluating this result. First, there were no setting errors of any type on assembly A in either Experiment I or Experiment II. Second, in the present experiment there were five assemblies whose scales increased from right to left, while only assembly A had a scale which increased from left to right. Therefore, the setting errors on assembly A may be attributable to habit interference from the preceding scales. In fact, only one of the setting errors on assembly A (a non-reversal error) occurred when A was the first assembly on which settings were made. This is despite the fact that approximately two-fifths of the setting errors and one-half of the reversal errors on the assemblies with right to left increasing scales occurred when the assembly was the first on which settings were made. Regardless, however, of whether or not assemblies B2 or B3 are as good as assembly A, it must be concluded that the numbering of every fifth mark and the addition of arrows definitely reduces setting errors on a right to left increasing scale.

At this point we have four assemblies, A, E, B2 and B3 which are relatively free from both starting and setting errors. These results, however, have been obtained when only moving-scale assemblies were being compared. The question arises, therefore: What would be the interaction effect if a moving-scale assembly were used alternately with a stationary scale, moving-pointer assembly as is frequently the case in aircraft? Perhaps, under these conditions, one of the above assemblies would prove to be definitely superior to the others. This consideration initiated Experiment IV.

EXPERIMENT IV

In this experiment three instrument "systems" were used. A system consisted of two assemblies, a moving-pointer assembly and a moving-scale assembly. The same moving-pointer assembly, assembly P, was used in all three systems. It had a stationary scale whose diameter and graduation marks were the same as those of assemblies A and E. Every tenth graduation mark was numbered, with the zero mark at the top of the dial, the 50 at the bottom. Here, of course, the entire dial was visible at one time. The moving-scale assemblies used in the three systems were assemblies A, E and B3, the "best" assemblies, as judged by frequency of errors, from experiments I, II and III respectively. The three systems, therefore, will be designated as systems P-A, P-E and P-B3.

The experiment consisted of three sessions, with 48-hour intervals between sessions. At each session the subject was tested with one of the three systems. Sixteen settings were required at each session, settings with the moving-pointer assembly being alternated with settings with the moving-scale assembly. Half of the subjects made their first setting, at each session, with the moving-pointer assembly, half with the moving-scale assembly. For each of these groups, each system was presented the same number of times at the first, second and third session, and each system was preceded (and followed) by every other system the same number of times.



ASSEMBLY	P	A	E	B3
DRIVE BETWEEN KNOB AND MOVING ELEMENT OF DISPLAY	Direct	Direct	Direct	Direct
DIRECTION OF SCALE INCREASE	Left to Right Right to Left	Left to Right	Left to Right	Right to Left
WITH CLOCKWISE KNOB MOVEMENT SETTING WILL:	Increase	Decrease	Increase	Increase

Figure 12: The four control-display assemblies used in the three systems of Experiment IV and their associated features. (Cross-hatch indicates "undesirable" features.)

Different, but similar lists of settings were used at each session. Half of the settings in each list were chosen for presumed susceptibility to reversal errors - all being settings to a higher number. The second half of the list alternated settings to a higher number with settings to a lower number in the hope that this would prove conducive to starting errors.

As many settings were required to start and finish in the scale region 75 - 0 - 25 as in the scale region 25 - 50 - 75. This was done because, on the moving-pointer assembly, scale numbers increase from left to right in the upper half of the dial and from right to left in the lower half of the dial.

When a setting is made on a scale whose direction of increase is opposite to that of the scale used for the immediately preceding setting, a "scale conflict" will be said to have occurred. The settings required were chosen so that there were the same number of scale conflicts for each of the three systems, for each of the three moving-scale assemblies, and for each of the two assemblies composing a system.

Seventy-two male and twenty-four female college students served as subjects.

RESULTS

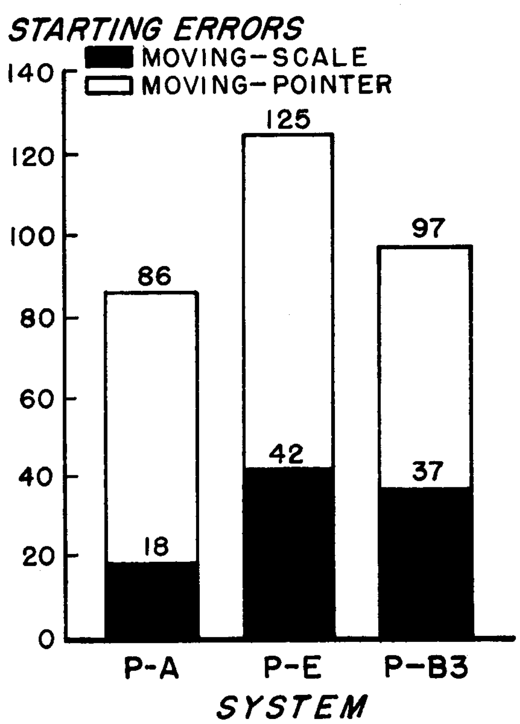


Figure 13: Number of starting errors committed on each system.

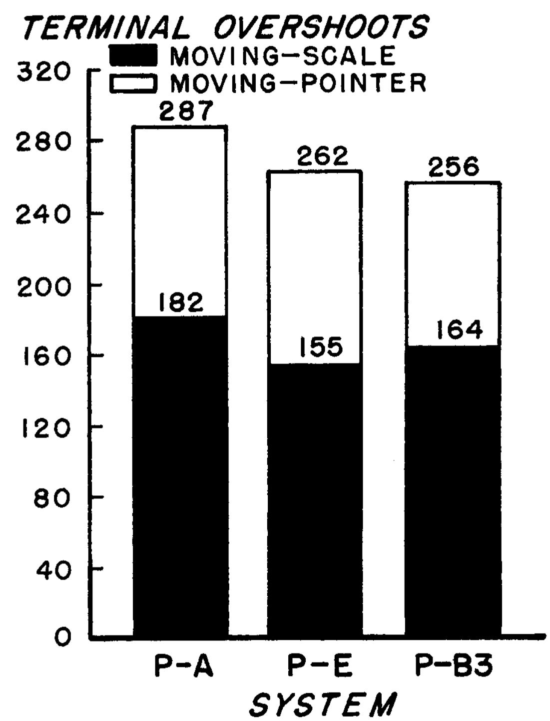


Figure 14: Number of terminal overshoot errors committed on each system.

A significantly greater number of starting errors occurred on system P-E than on system P-A ($p < .01$), and on assemblies E and B3 than on assembly A ($p < .01$ and $p < .05$). Also, within each system, starting errors were significantly more frequent on the moving-pointer assembly than on the moving-scale assembly ($p < .05$ to $p < .001$). See Fig. 13.

There were no significant differences in terminal overshoots between systems or between moving-scale assemblies. However, within each system, terminal overshoots were significantly more frequent on the moving-scale assemblies than on the moving-pointer assembly ($p < .01$ to $p < .001$). See Fig.14.

Non-reversal setting errors failed to differentiate between either systems or assemblies. They average 12.67 per system.

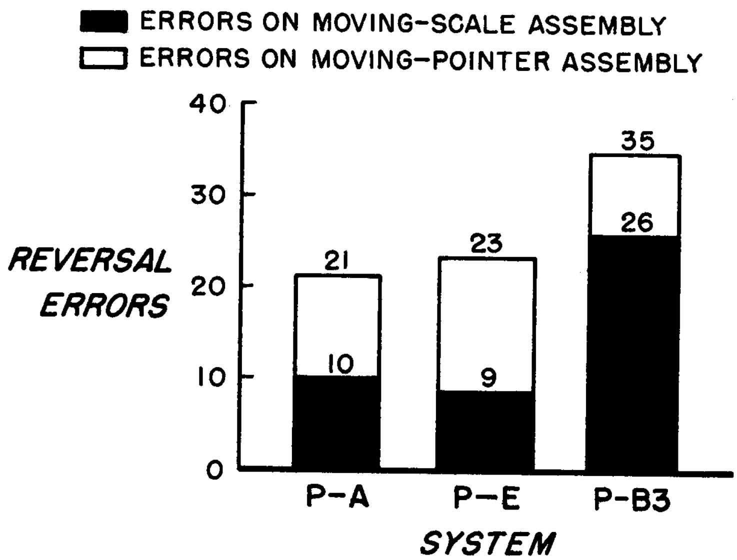
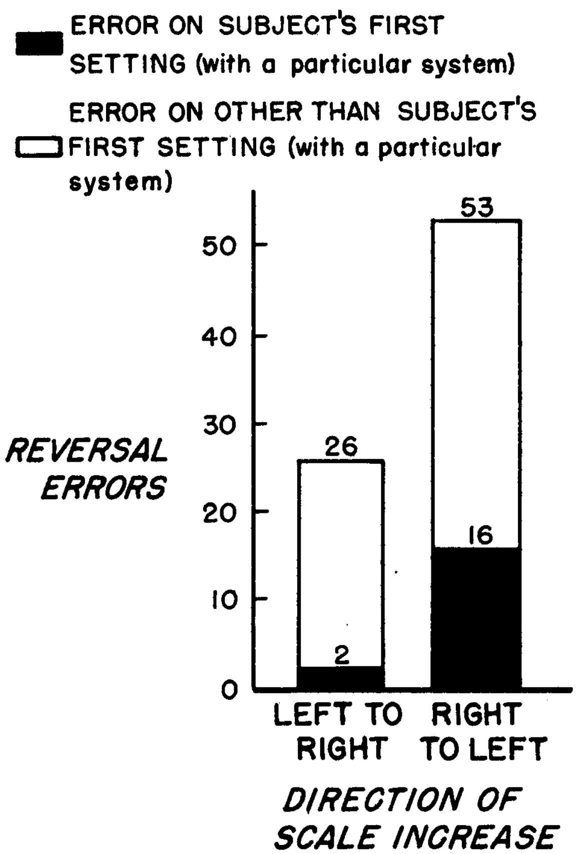


Figure 15: Frequency of reversal errors on the three systems.

Reversal errors were significantly more frequent on assembly B3 than on either assembly A or assembly E ($p < .05$ and $p < .01$ respectively). Also, within system P-B3 reversal errors occurred with significantly greater frequency on assembly B3 than on assembly P ($p < .01$). See Fig. 15.

A significantly greater number of reversal errors were committed on scales whose numbers increased from right to left than would be expected by chance ($p < .001$). This is true both of reversal errors which occurred on the first setting with a given system and of reversal errors which occurred after the first setting ($p < .001$ and $p < .01$ respectively). See Fig. 16.

A significantly greater number of reversal errors occurred when a scale conflict existed between the scale in question and the preceding scale than when no such conflict existed ($p < .02$). However, if reversal errors are divided into those occurring on right to left scales and those occurring on left to right scales, only the former occurred significantly more frequently under conditions of scale conflict than when no conflict existed ($p < .01$); the same trend exists for the latter, but it is not significant. See Fig. 17. Cases in which a reversal error was committed on the first setting with a particular system and cases in which the preceding setting was also a reversal error are not included in calculating the significance level for the above statements; since, in the former, there was no preceding scale, and, in the latter, it would be difficult to say whether or not the direction of scale increase was accurately perceived during the preceding setting.



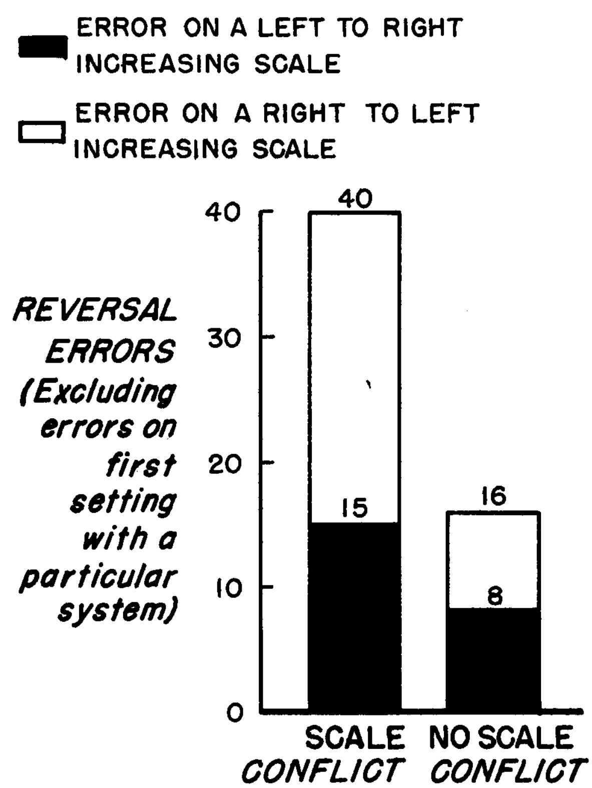


Figure 16: Frequency of reversal errors on left to right vs right to left increasing scales. (58.33% of settings were on left to right increasing scales.)

Figure 17: Frequency of reversal errors when scale conflict existed and when there was no scale conflict. (50% of settings after the first involved scale conflict.)

At the conclusion of the experiment, the subject was asked to rank the four assemblies in order of preference. The moving-pointer assembly was ranked first (and was ranked first or second) with significantly high frequency ($p < .001$ for both statements). See Fig. 19. It should be remembered, in evaluating these results, that by the end of the experiment the subject had had three times as much experience with the moving-pointer assembly as he had had with any one of the moving-scale assemblies.

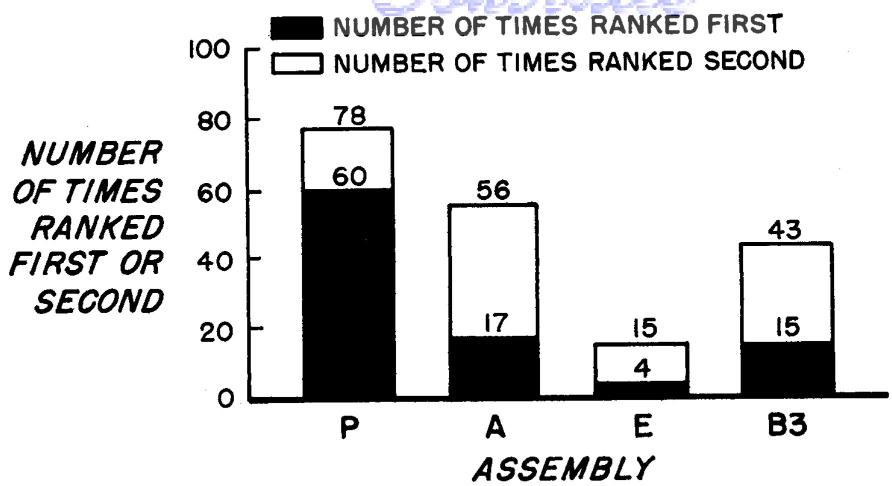


Figure 18: Number of times each assembly was ranked either first or second.

GENERAL DISCUSSION

Throughout this series of experiments, there were repeated indications that assembly A, considering starting errors, setting errors and preferences, was the best assembly. In none of the experiments were there significantly more starting errors or setting errors on assembly A than on another assembly, nor was another moving-scale assembly ever significantly preferred over assembly A.

The reason for continuing the experiments in the face of A's obviously superior position, from the point of view of errors and preferences, was that A's control knob turns counterclockwise to increase settings. It was feared there would be habit interference between controls which turn clockwise to increase (as most do) and those which turn counterclockwise to increase (Assembly A.)

There were increasing indications, however, as the experiments progressed, that this was not the case. If conflicting direction of control rotation for increase gave rise to confusion, one would expect it to be reflected in frequent occurrence of starting errors. A was the only assembly (of six assemblies) in Experiment II whose control turned counterclockwise to increase settings; however, assembly A gave rise to relatively few starting errors and the error pattern indicated only that starting errors were associated with reversed drive. In Experiment III, where all assemblies had direct drive but only assembly A's control turned counterclockwise to increase, starting errors were quite infrequent and there were no significant differences among them. Experiment IV, however, provided the best test. At any given session, the subjects made settings with only one system. System P-E and P-B3 contained assemblies both of whose controls turned clockwise to increase settings. System P-A, on the other hand, required alternate settings on assemblies whose directions of control rotation for increase were opposed (i.e., A's control turn counterclockwise to increase, P's turned clockwise to increase). If there were habit interference due to controls turning in opposite directions for increase, it would be expected that system P-A would give rise to more starting errors than would either system P-E or system P-B3. Just the opposite was the case. Significantly fewer starting errors occurred on system P-A than on system P-E. Fewer, but not significantly fewer, starting errors occurred on system P-A than on system P-B3.

It might be argued that, while no habit interference would be expected with naive subjects, much habit interference would be expected with subjects strongly indoctrinated with the principle that a control should turn clockwise to increase settings (as Air Force pilots are). To test this hypothesis, a number of human engineering psychologists (all of whom can be expected to have been so indoctrinated) were presented with an assembly similar to assembly A (differing in panel dimensions, color, etc. but having the same display-control relationships) whose scale was set either to 39 or to 64. Without being allowed to manipulate or examine the assembly, they were asked to set to 64 if the indicator was already at 39, to set to 39 if the indicator was already at 64. Of 17 subjects asked to make the decreasing setting, all 17 turned the control clockwise. This exceeds chance at the .001 level of significance. Of 16 subjects asked to make the increasing setting, 13 turned the control counterclockwise ($p < .02$). In both cases the clockwise to increase principle was violated. Apparently the subjects were hypothesizing a direct drive relationship between control and display rather than following any human engineering principle that a control should turn clockwise to increase settings.

Results from a somewhat similar experiment using naive subjects agree with the above experiment for left to right increasing scales, and indicate further that, when scale numbers increase from right to left, neither direction of control rotation predominates.

It can be concluded, then, that interference between turning clockwise to increase and turning counterclockwise to increase does not appreciably contribute to starting errors if the operator simultaneously observes a direct drive display while making his setting. No such statement can be made, however, for the situation where an operator makes "increases" or "decreases" with a control without looking at its display.

Another reason for the adoption of assembly A when a moving-scale is needed is to be found in the data on reversal errors. In Experiments I, III and IV, settings were required on both left to right and right to left increasing scales and reversal errors were fairly frequent. In Experiment II, all scales increased from left to right and there were no reversal errors. Two possible conclusions are suggested by these data: (1) that right to left increasing scales are conducive to reversal errors in and of themselves, (2) that requiring an operator to make settings on both left to right and right to left increasing scales is conducive to reversal errors on both scales. A more elaborate analysis of the data confirms conclusion (1) and tends to confirm conclusion (2). The truth of statement (1) was demonstrated in Experiment IV by the fact that, of reversal errors which occurred on the first setting at a particular session, a significantly greater proportion of reversal errors occurred when the assembly had a right to left increasing scale than would be expected by chance. Statement (2) is partially confirmed by the fact that in Experiment IV far more reversal errors occurred on right to left increasing scales when a scale conflict occurred than when no such conflict existed. The trend for left to right increasing scales also indicates, although without statistical significance, that scale conflicts are conducive to reversal errors. It seems likely that statistical significance was not obtained because the total number of errors on left to right increasing scales was small. A reanalysis of reversal error data for Experiments I and III yielded similar results: a greater proportion of reversal errors than would be expected by chance occurred when the preceding assembly's scale increased in the opposite direction.

We are faced, then, with the fact that moving-scale assemblies should have scales which increase in the same direction as the scales of other assemblies which must be manipulated by the operator. Since practically all horizontal linear scales and semicircular stationary scales increase from left to right, and since stationary circular scales which leave a gap at the bottom are predominantly left to right scales, the greatest degree of uniformity in direction of scale increase will be achieved if moving scale assemblies are standardized with left to right increasing scales.

SUMMARY

1. Moving-scale assemblies with reversed drive between control and display gave rise to far more starting errors than did direct drive, moving-scale assemblies.

2. Starting errors were much more frequent on direct drive moving-pointer assemblies than on direct drive moving-scale assemblies.

3. Terminal overshoot errors failed to differentiate between moving-scale assemblies, but occurred much more frequently on direct drive moving-scale assemblies than on direct drive moving-pointer assemblies.

4. Non-reversal setting errors were a poor indicator of comparative performance.

5. Whether settings were made on a single assembly in isolation or on a group of assemblies, "reversal" type setting errors were far more frequent on assemblies with right to left increasing scales than on assemblies with left to right increasing scales. Reversal errors were more frequent when the scale on which the error occurred and the scale used in the preceding setting were in conflict than when they increased in the same direction.

6. The reversal errors associated with right to left increasing scales were appreciably reduced by more frequent numbering of scale graduation marks. It appeared that the addition of arrows between scale numbers, pointing toward the higher number probably further reduced such errors.

7. Making alternating settings with controls which turned in opposite directions to increase resulted in no more starting errors than making alternating settings with controls whose direction of turn to increase was the same.

8. Subjects long indoctrinated with the principle that a control should turn clockwise to increase, nevertheless immediately turned counterclockwise to increase when asked to make a setting on an unfamiliar moving-scale assembly with a left to right increasing scale.

9. Moving-scale assemblies were not as well liked, by naive subjects, as moving-pointer assemblies. Among moving scale assemblies, preferences were apparently influenced by (a) a desire for control and display to rotate in the same direction, (b) an aversion to unconventional display features and control-display orientations.

RECOMMENDATIONS

1. Moving-scale assemblies, for use where the operator will never make control adjustments without simultaneously looking at the associated display, should have a dial which rotates in the same direction as its control knob and whose scale numbers increase from left to right. At least two scale numbers should be visible in the display aperture at all times.

2. When the operator may make crucial control adjustments by "blind reaching" (i.e., without looking at the display), moving-scale assemblies should not be used.

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