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AMRL-TDR-63-68 (I)

# VOLUMETRIC WORKSPACE STUDY

## Part I. Optimum Workspace Configuration for Using Various Screwdrivers

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## ABSTRACT

The effect of various workspace configurations upon subject performance in removing and installing a component (transformer) using various screwdrivers was investigated. Subjects performed the task under 15 different workspace configurations and with the transformer placed in 3 different orientations with respect to the aperture. The different workspace configurations were achieved by combining 5 different aperture sizes (8, 10, 12, 14, and 16 inches) and 3 different depths (6, 12, and 18 inches).

Major results of this study (within the range of conditions explored) are: (a) Work time decreased as aperture size increased. However, increasing aperture size above 10 to 12 inches did not appreciably shorten work time. (b) Increasing the depth of the component within the workspace resulted in longer work time. However, work time increased appreciably only at depths in excess of 12 inches. (c) Component orientation with respect to the aperture was an important determinant of performance. Work time increased as orientation changed from a straight-line access (back) to a right-angle access (bottom and side).

## PUBLICATION REVIEW

This technical documentary report is approved.

Walter F. Grether
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Technical Director
Behavorial Sciences Laboratory

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# VOLUMETRIC WORKSPACE STUDY:

# (I) OPTIMUM WORKSPACE CONFIGURATION FOR USING VARIOUS SCREWDRIVERS

by

William N. Kama

## INTRODUCTION

The ease with which systems or components can be serviced or repaired is determined, to a large extent, by the amount of workspace available to the maintenance man. Poor access (physical and visual), inability to make certain movements, inability to exert adequate torques, etc., can have a detrimental effect on the efficiency and the effectiveness of a well-trained, highly skilled maintenance man in the performance of his tasks.

A survey of some of the available literature (refs. 1-5) reveals an abundance of information regarding minimum and maximum access openings and various space envelopes for different maintenance operations using various handtools. There is, however, relatively little information dealing with quantitative measures of the effect of available workspace upon maintenance performance. In this study, we determined the effects of various workspace configurations upon worker performance (in terms of time) for a representative maintenance task requiring the use of a screwdriver to accomplish the task.

## METHOD

### Apparatus

The apparatus used in this study consisted of: (a) the "volumetric workspace box," (b) three different screwdrivers, (c) a standard timer, and (d) a subject start/stop switch.

The volumetric workspace box (figure 1) was designed so that its length, width, and depth could be readily increased or decreased. The box was made of plywood board, $39\frac{1}{2}$ inches square, with eight slots, 7 inches long, cut into it. These slots were arranged, by pairs, in a design similar to a swastika. Each pair of slots was located approximately $10\frac{1}{2}$ inches from the edge of the board with a distance of $10\frac{3}{4}$ inches between each slot within a pair.

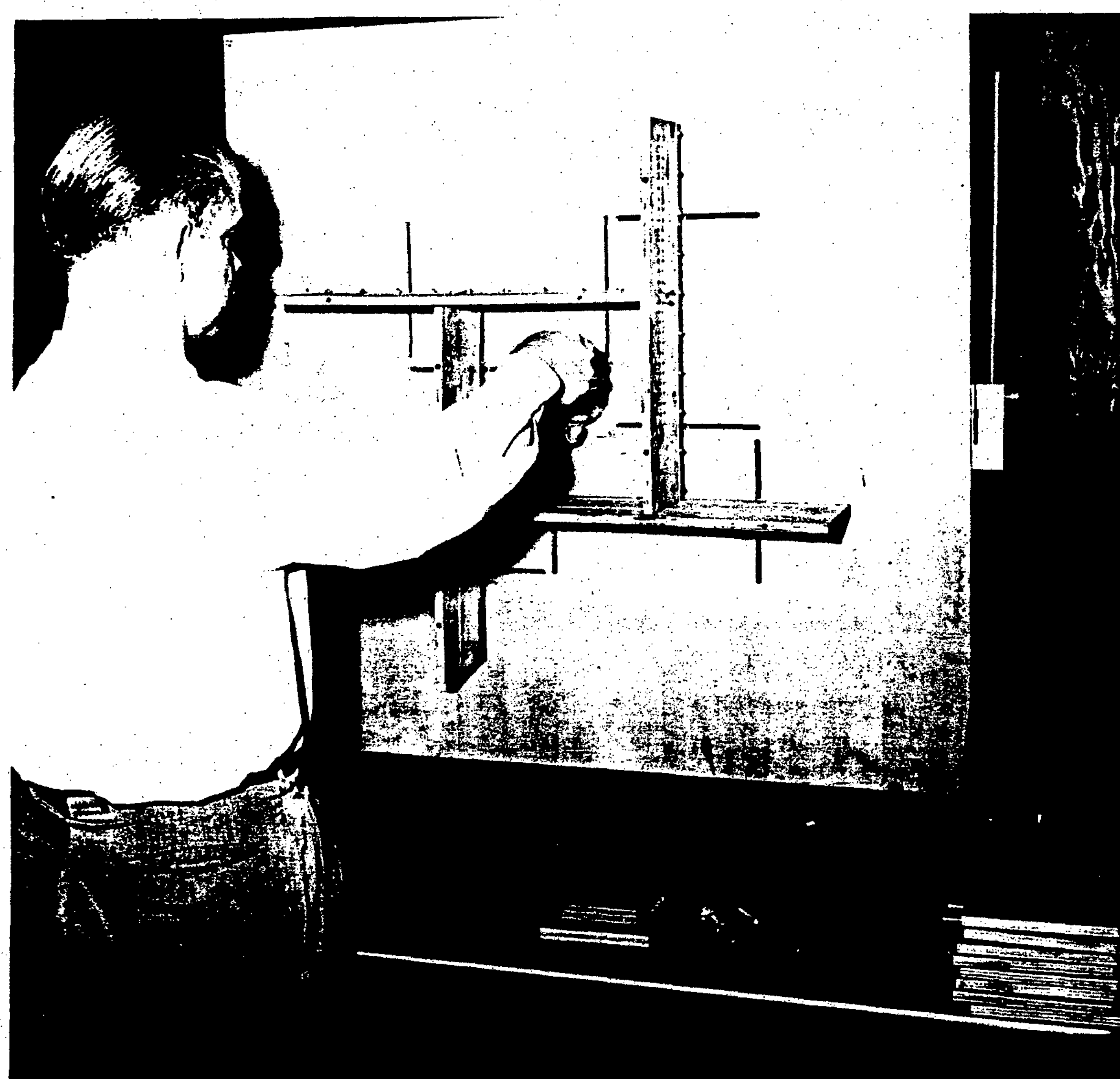

*Figure 1. The Volumetric Workspace ''Box,'' Screwdrivers, Start/Stop Switch, and Side Panels*

Four horizontal guides, used as mounts for the panels that made up the sides of the box, were placed in the slots (figure 2). These guides, $11\frac{3}{4}$ by $\frac{11}{16}$ by $\frac{1}{2}$ inches, moved within the slots and thus enabled the box to be adjusted both in length and width.

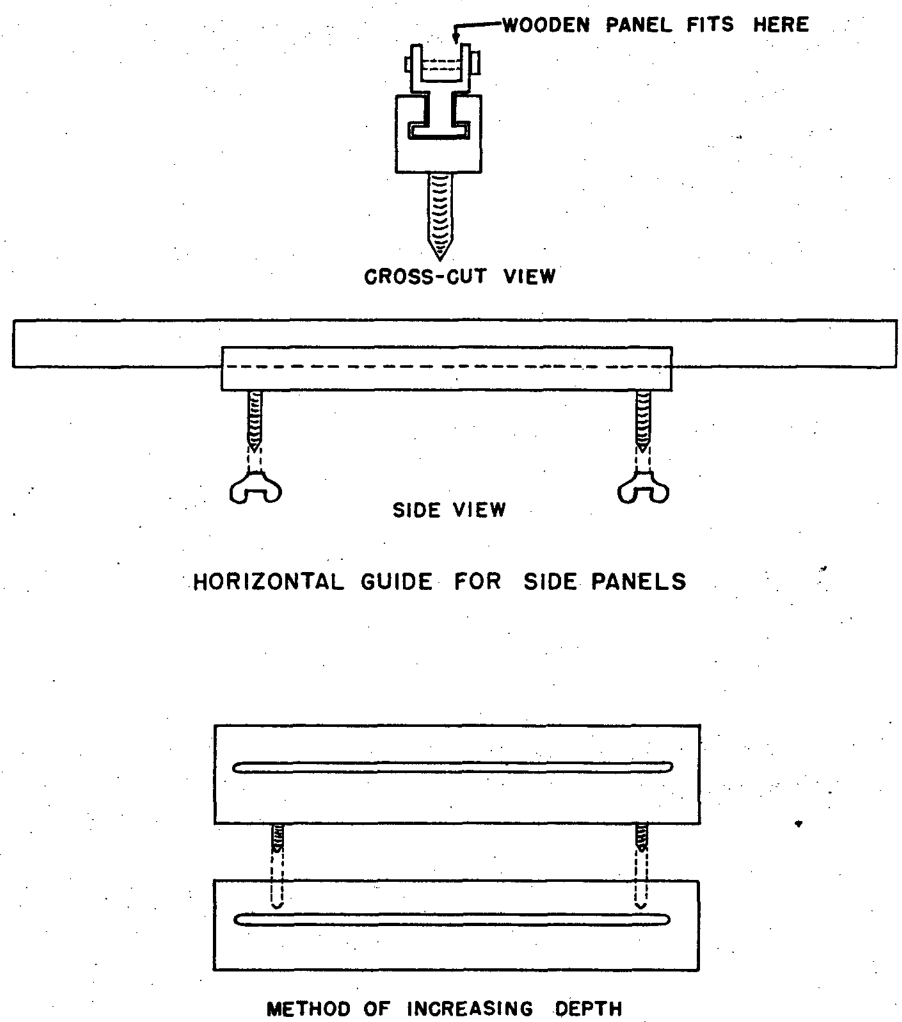


*Figure 2. Horizontal Guide and Method of Increasing Depth*

Twelve wooden panels, 19 by 6 by $\frac{1}{2}$ inches, were used to assemble the sides of the box. Four of these panels were mounted directly to the horizontal guides and could slide along the top of them. In this way, further enlargement of the box was possible. The other eight panels were used to increase the depth of the box. This was done by attaching the panels one on top of the other by means of two dowel pins (figure 2).

The entire workspace box was mounted on a metal tubing framework and could be rotated through 180 degrees.

The three screwdrivers available to the subjects in this study consisted of one common blade type and two screwholding types. The common screwdriver was $13\frac{1}{2}$ inches long with a 1-inch-diameter handle. The screwholding screwdrivers were $7\frac{5}{8}$ and $11\frac{1}{2}$ inches long and also had 1-inch-diameter handles. Which screwdriver was used on a given trial or the manner in which it was used was not controlled nor was it treated separately in the data analysis. In so doing it was realized that some experimental purity was sacrificed in the interest of achieving greater practical reality. A maintenance man typically has a large array of screwdrivers available to him and can hopefully be depended upon to select the tool most appropriate to a given application.

## Subjects

Six male, undergraduate university students and one male subject from the 6570th Aerospace Medical Research Laboratories served as subjects. Their ages ranged from 20 to 26 years with a mean of 21.6 years. All subjects were right-handed.

## Task and Procedure

The subject's task in this study was the removal and installation of a small transformer measuring $2\frac{1}{2}$ by $2\frac{1}{2}$ by 3 inches and weighing approximately 1.5 pounds. The transformer was held in place by four, flat-head, slotted screws $\frac{3}{8}$ inch long.

Testing of each subject was accomplished during three different sessions. During each of the test sessions, each subject was given 30 trials, 15 for removal and 15 for installation. The orientation of the transformer with respect to the aperture differentiated one session from the other. In one session, the transformer was mounted on the back panel of the workspace (straight-line access); in another session, on the right-side panel (right-angle access); and in a third session, on the bottom panel (right-angle-downward access). Only these three component locations were used in this study. This was done in an attempt to keep the experimental time to a minimum (this being the initial study) and because it was believed that these three component locations bracketed the extreme conditions — the straight-line access of the back location being hypothesized as the easiest and the right-angle access of the right-side location suggested as being the most difficult. For each of the three sessions, 15 workspace configurations were used. These 15 configurations consisted of all possible combinations of 5 different aperture sizes (8, 10, 12, 14, and 16 inches square) and 3 different depths (6, 12, and 18 inches). The resulting 15 configurations ranged in size from a minimum of 8 by 8 by 6 inches to a maximum of 16 by 16 by 18 inches.

Immediately before his first session, each subject was brought into the testing room and instructed as to the purpose of the study and the task to be accomplished. After receiving his instructions, the subject was given a 10-minute practice period. This practice period served to familiarize the subject with the equipment and procedure and permitted him to develop any technique which he considered to be most efficient for accomplishing the assigned task.

Two trials, one for removal and one for installation, were given at each of the 15 workspace configurations to each subject during each of the three sessions. To begin a trial, the subject placed his hand on the microswitch. At a signal from the experimenter, the subject took his hand off the switch (this started the timer) and began removing the transformer. As soon as he had removed the transformer, he placed it on the microswitch. This action stopped the timer. The subject's work time was then recorded.

After the subject's work time had been recorded, the above procedure was reversed. That is, the subject took the transformer off the microswitch (starting the timer), installed it in the workspace, and then placed his hand on the microswitch (after completing the installation). His work time was again recorded.

All of the subjects performed the task while in a standing position and with the task set at a height of 56 inches from the floor. The aperture was always in the vertical plane (90°) directly in front of the subject. The order in which the various experimental conditions were presented was counterbalanced to control for possible learning or fatigue effects.

with 7 subjects and 90 conditions?

## RESULTS

The data* obtained in this study were analyzed by means of two analyses of variance. The first shows the effects of the variables of aperture size, workspace depth, and component location (line of access) upon subject performance in removing the transformer. As indicated in the analysis (table 1), F-ratios are significant for all three variables at the .05 level. Interaction effects are also significant at the .05 level. To further evaluate the effects of these three variables on subject performance, tests of comparison for all combinations of experimental conditions were computed. These data are presented in tables 2, 3, and 4. As shown in table 2, when the component was mounted in the back location, altering aperture size and depth had little effect on subject performance——only the comparison at the 18-inch depth yielded significant t-values. For the bottom and side locations, however, changing aperture size was, as a general rule, a significant contributor to performance, particularly in those cases where performance under the 8-inch aperture condition was compared with performance under either the 10-, 12-, 14-, or 16-inch aperture conditions. Table 2 also shows that very few significant t-values were obtained for comparisons of performance between the 12-, 14-, and 16-inch aperture conditions regardless of workspace depth or task location.

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*The scores used in this study for obtaining the analyses of variance (ANOV) and t-tests (tables 1-4, 6-9) have been transformed using $\sqrt{X + .5}$ in order to normalize the distribution of the scores. All other tables show the original scores.

TABLE 1

ANALYSES OF VARIANCE OF THE EFFECTS OF APERTURE, DEPTH, AND COMPONENT LOCATION UPON SUBJECT PERFORMANCE FOR REMOVAL TASK

| Source of Variation | df | SS | MS | F | p |
|---|---|---|---|---|---|
| A (aperture) | 4 | 547.47 | 136.87 | 37.29 | < .05 |
| B (depth) | 2 | 237.77 | 118.89 | 32.40 | < .05 |
| C (component location) | 2 | 557.11 | 278.55 | 75.90 | < .05 |
| A × B | 8 | 70.28 | 8.79 | 2.40 | < .05 |
| A × C | 8 | 189.77 | 23.72 | 6.46 | < .05 |
| B × C | 4 | 47.65 | 11.91 | 3.25 | < .05 |
| A × B × C | 16 | 45.60 | 2.85 | 0.78 | NS |
| Within (error) | 270 | 990.99 | 3.67 | | |
| Total | 314 | 2686.64 | | | |

TABLE 2

TABLE OF t-VALUES SHOWING COMPARISON BETWEEN APERTURES AT VARIOUS DEPTHS AND COMPONENT LOCATION FOR REMOVAL TASK (N = 7)

| Location | Depth (inches) | Comparison between Apertures (inches) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 8 vs 10 | 8 vs 12 | 8 vs 14 | 8 vs 16 | 10 vs 12 | 10 vs 14 | 10 vs 16 | 12 vs 14 | 12 vs 16 | 14 vs 16 |
| Back | 6 | 1.76 | 0.45 | 0.55 | 1.93 | 1.46 | 0.41 | 1.35 | 0.93 | 1.63 | 1.24 |
| | 12 | 1.00 | 1.66 | 1.35 | 1.43 | 0.66 | 0.34 | 1.21 | 0.04 | 0.62 | 0.74 |
| | 18 | 1.11 | 2.91* | 1.09 | 1.96* | 4.44* | 0.70 | 2.90* | 1.01 | 0.08 | 1.06 |
| Bottom | 6 | 3.00* | 8.27* | 6.59* | 7.06* | 3.20* | 1.87 | 3.10* | 1.71 | 0.00 | 1.84 |
| | 12 | 0.16 | 3.70* | 4.43* | 4.48* | 2.04* | 3.01* | 5.39* | 1.31 | 1.47 | 1.06 |
| | 18 | 2.10* | 2.22* | 2.38* | 2.43* | 0.12 | 0.01 | 1.98* | 0.41 | 1.97* | 1.52 |
| Side | 6 | 2.54* | 2.23* | 2.68* | 3.43* | 0.28 | 1.52 | 1.70 | 1.72 | 2.06* | 0.10 |
| | 12 | 3.84* | 4.84* | 6.40* | 5.19* | 0.68 | 3.12* | 2.62* | 1.76 | 1.58 | 0.16 |
| | 18 | 3.42* | 3.40* | 3.06* | 5.77* | 0.03 | 3.07* | 4.81* | 1.91 | 4.15* | 4.16* |

*p < .05

TABLE 3

TABLE OF t-VALUES SHOWING COMPARISON BETWEEN DEPTHS AT VARIOUS APERTURES AND COMPONENT LOCATION FOR REMOVAL TASK (N = 7)

| Location | Comparison between Depths (inches) | Aperture (inches) | | | | |
|---|---|---|---|---|---|---|
| | | 8 | 10 | 12 | 14 | 16 |
| Back | 6 vs 12 | 1.04 | 1.00 | 0.79 | 0.00 | 1.14 |
| | 6 vs 18 | 3.20* | 3.43* | 0.28 | 1.09 | 2.22* |
| | 12 vs 18 | 3.88* | 4.85* | 0.43 | 0.89 | 1.08 |
| Bottom | 6 vs 12 | 0.56 | 2.74* | 5.43* | 2.23* | 1.16 |
| | 6 vs 18 | 2.08* | 4.12* | 6.22* | 2.83* | 2.28* |
| | 12 vs 18 | 1.81 | 0.91 | 1.68 | 1.80 | 0.88 |
| Side | 6 vs 12 | 2.22* | 1.40 | 1.11 | 0.79 | 2.07* |
| | 6 vs 18 | 4.11* | 2.95* | 4.02* | 5.23* | 2.08* |
| | 12 vs 18 | 1.95* | 1.40 | 6.46* | 2.98* | 0.88 |

* $p < .05$

TABLE 4

TABLE OF t-VALUES SHOWING COMPARISON BETWEEN COMPONENT LOCATIONS FOR REMOVAL TASK (N = 7)

| Depth (inches) | Comparison between Locations | Aperture (inches) | | | | |
|---|---|---|---|---|---|---|
| | | 8 | 10 | 12 | 14 | 16 |
| 6 | Back vs Side | 4.75* | 2.84* | 7.77* | 1.30 | 3.21* |
| | Back vs Bottom | 5.85* | 2.23* | 1.23 | 0.20 | 0.57 |
| | Bottom vs Side | 1.31 | 1.61 | 6.94* | 1.27 | 3.16* |
| 12 | Back vs Side | 5.61* | 4.15* | 4.28* | 2.50* | 3.86* |
| | Back vs Bottom | 4.02* | 4.72* | 3.39* | 2.29* | 1.09 |
| | Bottom vs Side | 2.88* | 0.26 | 1.49 | 1.37 | 1.74 |
| 18 | Back vs Side | 5.28* | 6.15* | 6.29* | 5.29* | 5.04* |
| | Back vs Bottom | 2.29* | 3.98* | 4.19* | 1.86 | 0.99 |
| | Bottom vs Side | 1.05 | 2.56* | 2.47* | 0.25 | 1.17 |

* $p < .05$

Table 3, showing tests of comparison between different workspace depth conditions for various aperture and component location conditions, indicates that depth was a more critical variable for the bottom and side component locations than for the back location (straight-line access). Out of 12 individual comparisons, only 5 significant t-values were obtained for comparisons of various depths for the back location condition, while 8 significant t-values were obtained for the bottom location, and 10 for the side location.

A similar review of table 4 provides an indication of the effect of component location on subject performance. In comparing the back location with the side location, 14 out of 15 computed t-values were significant. In comparing the back versus the bottom location and the bottom versus the side location, 9 and 5 significant t-values, respectively, were obtained. The effects of shifting the component location were greatly reduced under the larger aperture conditions. Only 3 out of 9 t-values were significant for the 14- and 16-inch aperture sizes.

Graphic presentation of subject performance in removing the transformer is shown in figures 3, 4, and 5. These data, taken from table 5, show the effect of the three variables upon performance. Examining these graphs shows that work times decreased as aperture size increased. The variables of depth and component location (line of access) affected performance, work times increasing as depth increased and as the location of the component was moved from a straight-line access (back location) to a right-angle access (bottom and side location).

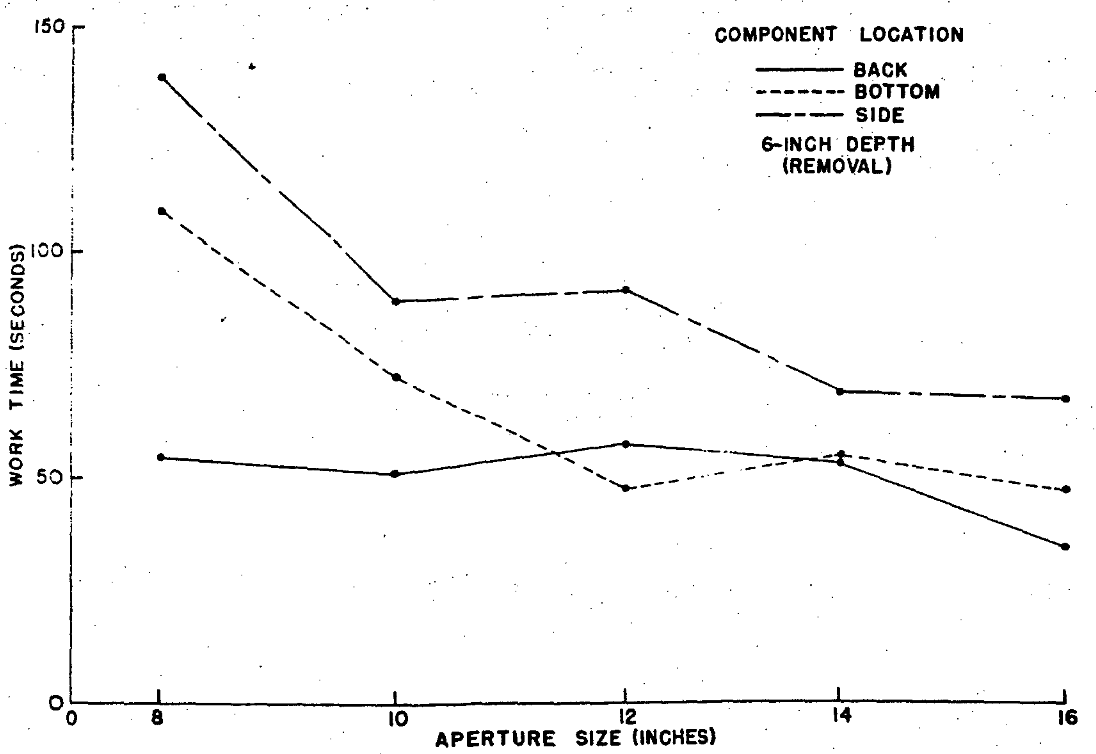


*Figure 3. Removal Time as a Function of Aperture Size (6-inch depth)*

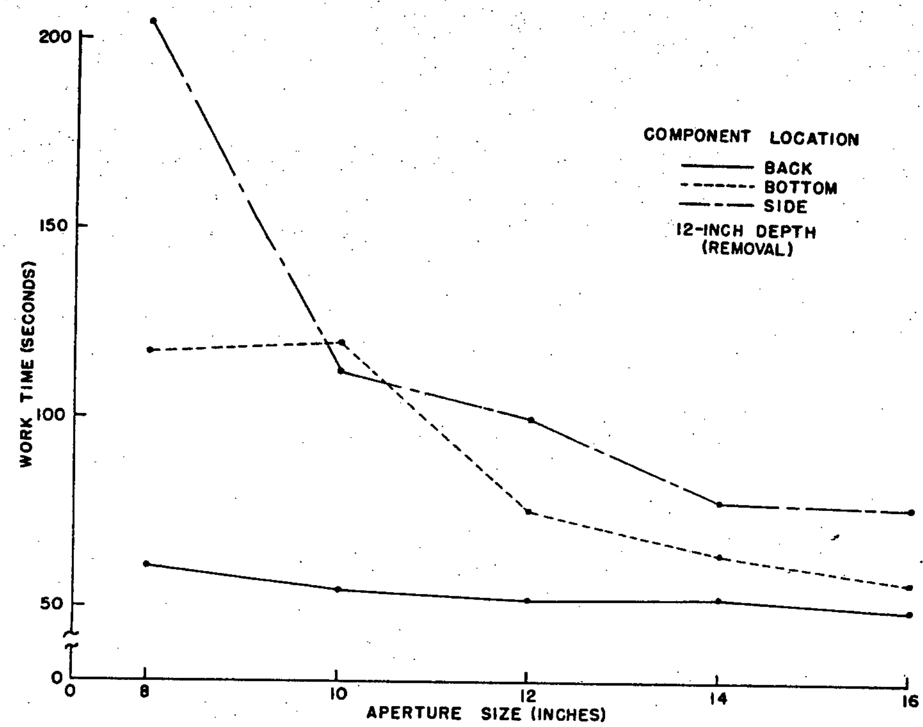


*Figure 4. Removal Time as a Function of Aperture Size (12-inch depth)*

*Figure 5*

*Removal Time as a Function of Aperture Size (18-inch depth)*

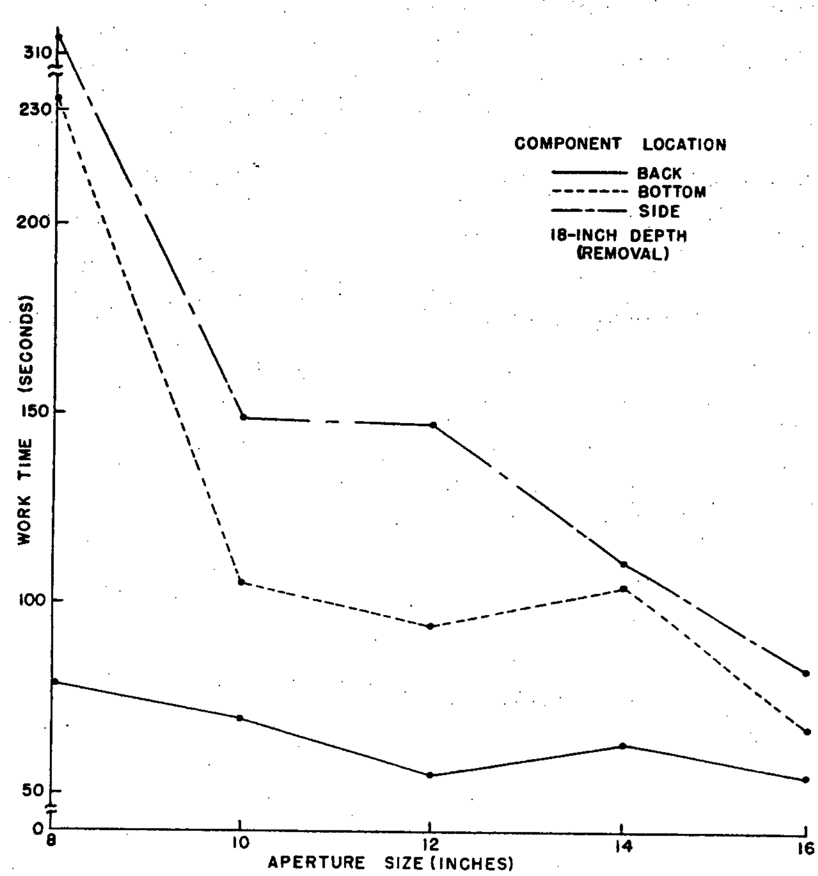

TABLE 5

MEAN REMOVAL TIMES
(SECONDS)

| Depth (inches) | Aperture (inches) | Location | | |
|---|---|---|---|---|
| | | Back | Bottom | Side |
| 6 | 8 | 54.91 | 109.62 | 139.48 |
| | 10 | 51.12 | 72.93 | 89.87 |
| | 12 | 57.30 | 47.47 | 91.39 |
| | 14 | 52.70 | 54.90 | 68.89 |
| | 16 | 44.89 | 47.47 | 67.90 |
| 12 | 8 | 61.62 | 117.51 | 204.49 |
| | 10 | 54.76 | 120.34 | 112.78 |
| | 12 | 52.56 | 76.39 | 100.60 |
| | 14 | 52.70 | 64.96 | 78.50 |
| | 16 | 49.56 | 57.00 | 77.44 |
| 18 | 8 | 78.50 | 232.87 | 314.35 |
| | 10 | 69.56 | 105.27 | 148.60 |
| | 12 | 55.06 | 94.09 | 147.62 |
| | 14 | 63.52 | 104.86 | 110.25 |
| | 16 | 54.61 | 67.24 | 82.45 |

Figures 3, 4, and 5 indicate that the overall effect of the variables of depth and component location upon performance is reduced, to some extent, by increasing the aperture size. To depict the magnitude of these effects tables 11 through 21 (Appendix I) were prepared. These tables show the differences between mean performance times, both as an absolute value and as a percentage for each combination of experimental conditions. Table 15, for example, shows that, with the component in the back location in a workspace having an 8-inch aperture, increasing the depth of the workspace from 6 to 12 inches resulted in a 12% increase in work time, while increasing the depth from 6 to 18 inches caused an increase in work times of 43%. In contrast, comparable figures for the 16-inch aperture condition yielded percentage increases of 10 and 22%, respectively.

The magnitude of the effect of the component location variable was also greatly reduced as aperture size was increased. As can be seen in table 17, with workspace conditions of a 6-inch depth and 8-inch aperture, changing component location from the back to the bottom of the workspace resulted in a 100% increase in work time. Under the same conditions, changing component location from the back to the side of the work place resulted in a 154% increase in work time. When the aperture size was increased to 16 inches, however, the magnitude of the above effects decreased to 6% and 51%, respectively.

Figures 3, 4, and 5 also show that increasing the aperture size beyond that of 10 to 12 inches does not, as a general rule, appreciably shorten work time. The results of t-tests carried out between performances under aperture conditions 10 inches or larger seem to support this position. Only 16 of 54 tests of comparison were statistically significant.

Figures 3, 4, and 5 also illustrate the fact that, for all aperture sizes and depths, the side location produced work times that were longer than those found for the other two locations. Comparisons (table 17) between the back and side locations showed work times for the side location to average 74%, 107%, and 141% longer at each of the three depth conditions. Comparisons of performance under the bottom and side location conditions showed that work times for the side location condition were greater than for the bottom location condition by 42% at the 6-inch depth, 31% for the 12-inch depth, and 32% for the 18-inch depth.

The second analysis of variance shows the effect of aperture size, workspace depth, and task location upon subject performance during installation of the transformer. As in the first analysis, all three variables produced F-ratios that were significant at the .05 level (table 6). Interaction effects also were significant at the .05 level. Further analyses of these variables are presented in tables 7, 8, and 9.

TABLE 6.

ANALYSES OF VARIANCE OF THE EFFECTS OF APERTURE, DEPTH, AND COMPONENT LOCATION UPON SUBJECT PERFORMANCE FOR INSTALLATION TASK

| Source of Variation | df | SS | MS | F | p |
|---|---|---|---|---|---|
| A (aperture) | 4 | 1820.98 | 455.25 | 85.09 | <.05 |
| B (depth) | 2 | 192.46 | 96.23 | 17.99 | <.05 |
| C (component location) | 2 | 1065.49 | 532.75 | 99.58 | <.05 |
| A × B | 8 | 154.46 | 19.31 | 3.61 | <.05 |
| A × C | 8 | 808.75 | 101.09 | 18.90 | <.05 |
| B × C | 4 | 32.00 | 8.00 | 1.52 | NS |
| A × B × C | 16 | 66.35 | 4.15 | 0.78 | NS |
| Within (error) | 270 | 1445.24 | 5.35 | | |
| Total | 314 | 5586.33 | | | |

TABLE 7

TABLE OF t-VALUES SHOWING COMPARISON BETWEEN APERTURES
AT VARIOUS DEPTHS AND COMPONENT LOCATION FOR INSTALLATION TASK
(N = 7)

| Location | Depth (inches) | Comparison between Apertures (inches) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 8 vs 10 | 8 vs 12 | 8 vs 14 | 8 vs 16 | 10 vs 12 | 10 vs 14 | 10 vs 16 | 12 vs 14 | 12 vs 16 | 14 vs 16 |
| Back | 6 | 2.28* | 0.00 | 2.21* | 0.30 | 1.52 | 0.15 | 2.07* | 0.93 | 0.18 | 1.91 |
| | 12 | 4.85* | 3.73* | 1.56 | 2.55* | 0.03 | 2.41* | 0.12 | 1.82 | 0.09 | 0.71 |
| | 18 | 2.72* | 3.52* | 0.13 | 4.79* | 1.68 | 0.63 | 2.01* | 0.98 | 0.03 | 1.18 |
| Bottom | 6 | 3.15* | 4.87* | 5.15* | 3.27* | 1.89 | 1.96* | 0.53 | 0.03 | 0.69 | 0.87 |
| | 12 | 4.33* | 7.32* | 6.74* | 6.70* | 1.71 | 2.50* | 1.41 | 1.73 | 0.39 | 1.53 |
| | 18 | 6.74* | 6.95* | 7.27* | 7.75* | 2.48* | 0.25 | 5.80* | 1.32 | 2.08* | 2.05* |
| Side | 6 | 1.76 | 3.32* | 3.20* | 3.16* | 1.93 | 1.79 | 2.42* | 0.31 | 1.04 | 0.75 |
| | 12 | 3.92* | 6.75* | 11.43* | 14.79* | 1.11 | 2.06* | 2.09* | 2.04* | 2.03* | 0.71 |
| | 18 | 4.39* | 5.43* | 5.72* | 4.62* | 2.06* | 2.09* | 1.82 | 1.17 | 0.83 | 0.17 |

* $p < .05$

TABLE 8

TABLE OF t-VALUES SHOWING COMPARISON BETWEEN DEPTHS FOR INSTALLATION TASK (N = 7)

| Location | Comparison between Depths (inches) | Aperture (inches) | | | | |
|---|---|---|---|---|---|---|
| | | 8 | 10 | 12 | 14 | 16 |
| Back | 6 vs 12 | 5.66* | 1.29 | 2.21* | 0.23 | 1.20 |
| | 6 vs 18 | 6.99* | 1.71 | 1.29 | 1.01 | 1.96* |
| | 12 vs 18 | 1.44 | 2.97* | 0.54 | 1.07 | 0.72 |
| Bottom | 6 vs 12 | 1.62 | 0.91 | 1.03* | 0.61 | 0.12 |
| | 6 vs 18 | 4.13* | 1.06 | 3.39* | 2.49* | 0.29 |
| | 12 vs 18 | 2.10* | 0.34 | 1.21 | 3.01* | 0.61 |
| Side | 6 vs 12 | 0.98 | 0.88 | 2.28* | 0.20 | 0.84 |
| | 6 vs 18 | 2.44* | 1.74 | 4.04* | 2.04* | 1.81 |
| | 12 vs 18 | 2.07* | 0.61 | 1.44 | 1.41 | 1.62 |

* $p < .05$

TABLE 9

TABLE OF t-VALUES SHOWING COMPARISON BETWEEN COMPONENT LOCATIONS FOR INSTALLATION TASK (N = 7)

| Depth (inches) | Comparison between Locations | Aperture (inches) | | | | |
|---|---|---|---|---|---|---|
| | | 8 | 10 | 12 | 14 | 16 |
| 6 | Back vs Side | 4.07* | 2.98* | 3.64* | 2.46* | 3.58* |
| | Back vs Bottom | 5.57* | 1.91 | 0.98 | 0.75 | 1.38 |
| | Bottom vs Side | 1.76 | 2.19* | 3.44* | 2.85* | 1.03 |
| 12 | Back vs Side | 3.65* | 3.01* | 3.91* | 6.87* | 3.53* |
| | Back vs Bottom | 6.78* | 2.70* | 2.17* | 1.21 | 1.13 |
| | Bottom vs Side | 1.90 | 1.60 | 2.68* | 6.22* | 2.70* |
| 18 | Back vs Side | 6.04* | 4.57* | 3.62* | 2.65* | 5.80* |
| | Back vs Bottom | 8.64* | 3.01* | 1.64 | 0.90 | 0.89 |
| | Bottom vs Side | 1.41 | 2.95* | 3.28* | 1.30 | 4.12* |

* $p < .05$

Using the data in table 10, figures 6, 7, and 8 graphically present subject performance in installing the transformer. The graphs show the effect of the variable of aperture size, workspace depth, and component location upon performance. The graphs also show that the results obtained for installation are very similar to those obtained for removal (figures 3, 4, and 5). As expected, work times decreased as aperture size increased, while depth and component location had a significant effect on performance, work times increasing as depth increased and as component location was moved from the back to the bottom to the side of the workspace.

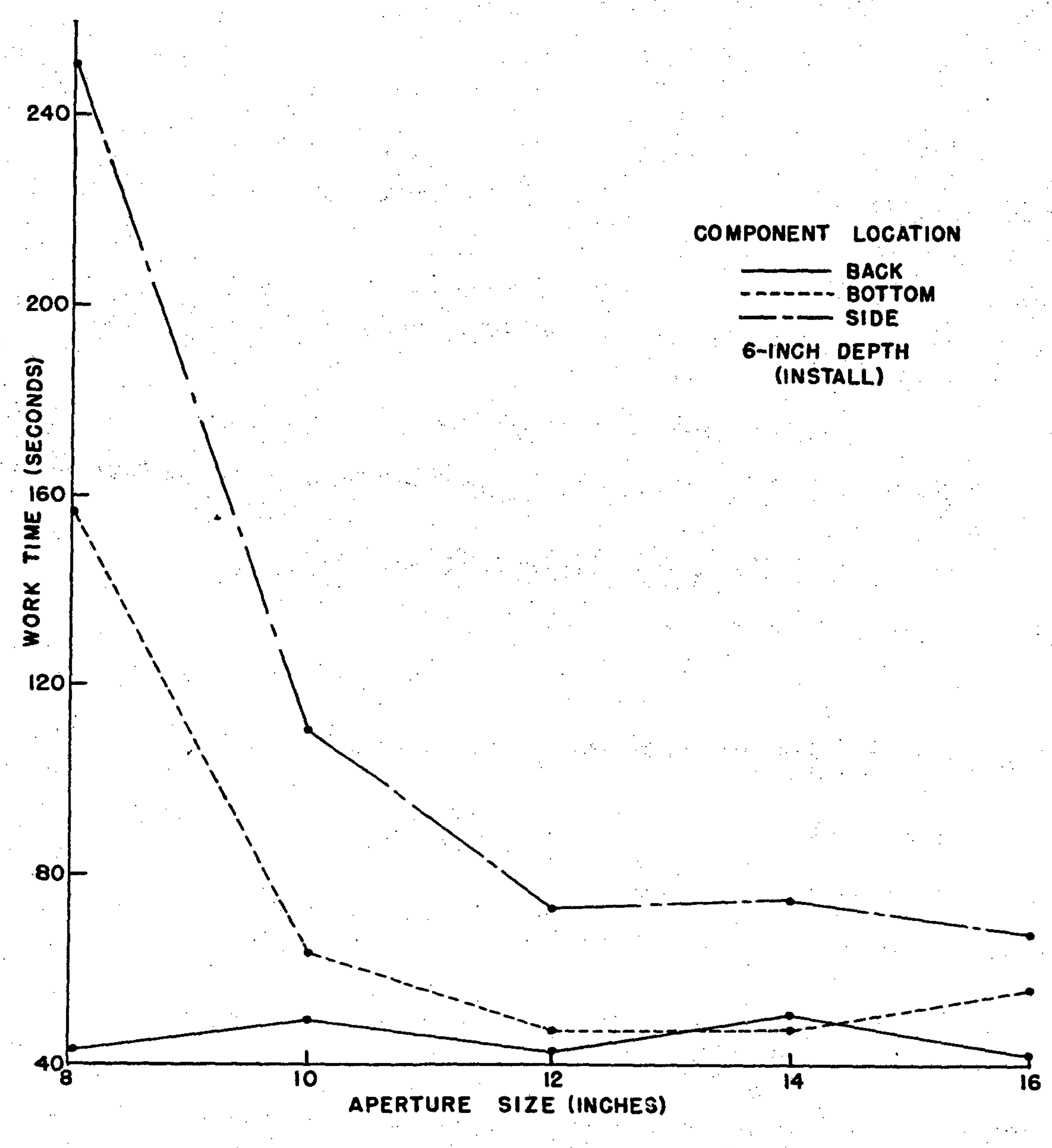


*Figure 6. Installation Time as a Function of Aperture Size (6-inch depth)*

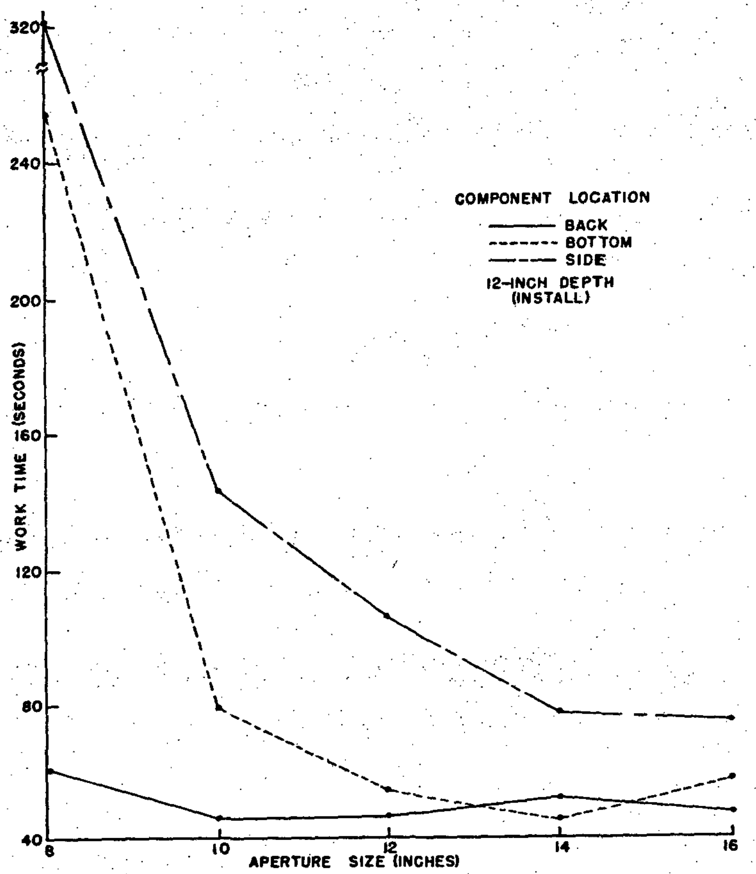


*Figure 7*

*Installation Time as a Function of Aperture Size (12-inch depth)*

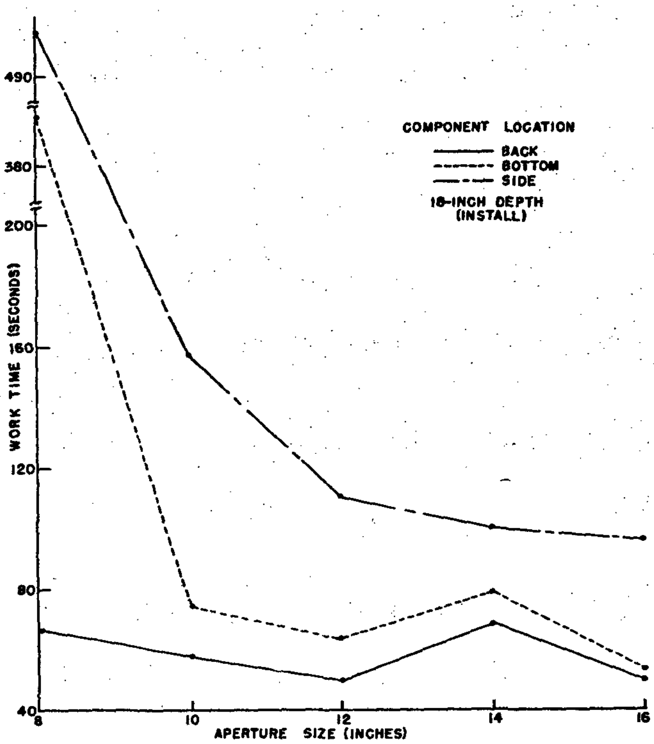


*Figure 8*

*Installation Time as a Function of Aperture Size (18-inch depth)*

TABLE 10

MEAN INSTALLATION TIME
(SECONDS)

| Depth (inches) | Aperture (inches) | Location | | |
|---|---|---|---|---|
| | | Back | Bottom | Side |
| 6 | 8 | 42.90 | 156.50 | 251.54 |
| | 10 | 49.70 | 64.16 | 110.88 |
| | 12 | 42.90 | 47.75 | 73.27 |
| | 14 | 50.84 | 47.61 | 75.52 |
| | 16 | 42.12 | 55.95 | 68.56 |
| 12 | 8 | 60.84 | 254.08 | 321.13 |
| | 10 | 46.38 | 79.03 | 143.04 |
| | 12 | 46.51 | 54.32 | 105.88 |
| | 14 | 51.98 | 45.83 | 77.62 |
| | 16 | 46.92 | 57.30 | 74.48 |
| 18 | 8 | 66.42 | 396.01 | 504.45 |
| | 10 | 57.60 | 74.65 | 157.00 |
| | 12 | 49.56 | 63.04 | 115.13 |
| | 14 | 68.72 | 78.32 | 99.60 |
| | 16 | 49.42 | 52.71 | 95.26 |

A comparison of figures 3, 4, 5, 6, 7, and 8 points out the similarity of the results for removal and installation. However, it is readily apparent, from figures 6, 7, and 8, that installation of the component in the right-side and bottom locations requires significantly more time than does component removal at the same locations under the 8-inch aperture conditions. This is probably caused by a combination of right-angle access and the rather awkward positioning requirements that are associated with these two locations during installation.

As in the case for removal, the graphs show that increasing aperture size beyond that of 10 to 12 inches does not significantly shorten work time during the installation of the transformer. Comparison of aperture sizes 10 inches or larger produced only 16 significant t-values out of 54 comparisons (table 7).

Analysis of the effect of the variables of workspace depth and component location upon work time in installing the transformer demonstrates a significant difference between the 6- and 18-inch depths and between the back location and the bottom and right-side locations. In comparing various depths (table 8), 8 of the 15 significant t-values obtained can be attributed to differences between the 6- and 18-inch depths, while in comparing component locations, 21 of the 30 significant t-values obtained are attributable to differences between the back location and either the bottom or side location (table 9). All t-values were significant to the .05 level.

Absolute and percentage differences between mean installation times for the various conditions used in this study are shown in tables 18 through 21 of the appendix.

## DISCUSSION

In this study the effect of available workspace upon performance of a simple maintenance task requiring the use of a screwdriver to remove and install a component located in three different positions within the workspace was investigated. Workspace, as used in this study, was determined by a combination of depth and aperture size. Thus, an example of a workspace configuration would be a "box" having an aperture of 8 by 8 inches and a depth of 6 inches.

Analysis of the data obtained in this study indicates that all three variables—aperture size, workspace depth, and task location—played an important role in determining how well each subject performed on the required task. Increasing the aperture size of the workspace increased the efficiency of the subject's performance—i.e., shorter work times were evidenced. On the other hand, increasing the depth at which the component was placed in the workspace produced a detrimental effect on performance. Work time increased with the increase in depth. The effect of depth, however, was somewhat minimized as aperture size increased. Component location (line of access to task) also had a significant effect on subject performance, work time increasing as the location of the component was moved from the back to the bottom to the right side of the workspace.

Several suppositions can be made regarding this increase in work time, especially at the 8-inch-square aperture for installation. For the side and bottom locations, both of which incidentally are right-angle line of access, visual access was interfered with causing the subjects to accomplish essentially two blind positioning operations in attaching the two innermost screws. This, plus the fact that the subjects were required to hold and position the transformer in a rather awkward manner, probably resulted in the right-side location being the most detrimental to performance during installation.

The results of this study further indicate that, when the component was located on the right side of the workspace, work time was always longer than for the other two component locations (figures 3, 4, 5, 6, 7, and 8). Thus, for any task requiring a screwdriver, the right-side location is a poor choice—at least for right-handed subjects.

Although increasing the aperture size of the workspace tended to yield better work time, it is noted that increasing it beyond the 10- to 12-inch size does not produce appreciably shorter work time (tables 2 and 7). Thus, for this particular task, the effective optimal performance time (for both removal and installation) is achieved with an aperture of about 10 to 12 inches.

Within the range of conditions explored in this study, work times were essentially the same for both the 6- and 12-inch depths. Significant differences in work times were found, however, between the 6- and 18-inch depths (tables 3 and 8).

Under the experimental conditions of this study, the component location yielding the best performance was that in which the component was located on the back panel of the workspace. This location permitted straight-line access to the component mounting screws and yielded work times significantly faster than those obtained for either the bottom or right-side locations (tables 4 and 9). Locating the component on the right side of the workspace resulted in the poorest performance——presumably because of the awkward access angle this position required for right-handed subjects.

## SUMMARY AND CONCLUSIONS

This study was an attempt to determine the relative speed of subjects in removing and installing a component within different workspace restrictions and with the component located in different orientations with respect to the aperture. The experimental variables in this study were aperture size, depth, and component location. The combination of the variables of depth and aperture size determined the different workspace configurations used in this study. Since there were five aperture sizes (8, 10, 12, 14, and 16 inches) and three depths (6, 12, and 18 inches), 15 different configurations were possible.

The task was the removal and installation of a transformer, $2\frac{1}{2}$ by $2\frac{1}{2}$ by 3 inches, which was held in place by four flat-head, slotted, $\frac{3}{8}$-inch screws. This transformer was mounted at one of three different locations——back, bottom, and side (right)——within the workspace.

Each subject, having access to three different screwdrivers, removed and installed the transformer under each of the different workspace configurations and with the component located at each of the three different positions.

Major findings resulting from this study are:

1. Work time decreased as aperture size increased. However, within the range of conditions explored in this study, increasing aperture size beyond that of 10 to 12 inches did not appreciably shorten work time.

2. Increasing the depth of the component within the workspace resulted in increased work time. However, work time became appreciably longer only when depth was increased from the 12-inch to the 18-inch depth.

3. Component location (or line of access to the component) is an important determinant of work time, work time becoming much longer as the component is moved from a straight-line access (back) to a right-angle line of access (bottom and side).

The following recommendations resulted from this study:

1. For tasks requiring the use of screwdrivers, the data suggest that, within the range of conditions studied, optimal performance times will be achieved in a workspace having an aperture size not less than 10 or 12 inches square, regardless of the orientation of the component within the workspace. Smaller size apertures may be used, however, with little or no increase in work time, if the task to be performed is oriented in a manner to provide direct-line access to the task.

2. Assuming workspaces having aperture sizes similar to those used in this study, components which require the use of screwdrivers should be located at a depth not exceeding 12 inches within the workspace. At depths beyond 12 inches, an increasing work penalty is paid in removing or installing the components.

3. In the placement of components within a workspace configuration, a straight-line access to components will produce better work times than right-angle accesses for tasks requiring a screwdriver. Thus, if it is at all feasible, straight-line access to components should be used wherever possible.

These recommendations are based on a "shirt sleeve" environment and a clean workspace—i.e., only the transformer was located in the workspace with no other components blocking the path to the transformer. In drawing generalizations from these data, these two restrictions should be borne in mind.

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TABLE 11

DIFFERENCE BETWEEN MEANS AS A FUNCTION OF APERTURE (REMOVAL)

| Location | Depth (inches) | Aperture Size (inches) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 8 to 10 | 8 to 12 | 8 to 14 | 8 to 16 | 10 to 12 | 10 to 14 | 10 to 16 | 12 to 14 | 12 to 16 | 14 to 16 |
| Back | 6 | 3.79 | 2.39* | 2.21 | 10.02 | 6.18* | 1.58* | 6.23 | 4.60 | 12.41 | 7.81 |
| | 12 | 6.86 | 9.06 | 8.92 | 12.06 | 2.20 | 2.06 | 5.20 | 0.14* | 3.00 | 3.14 |
| | 18 | 8.94 | 23.44 | 14.98 | 23.89 | 14.50 | 6.04 | 14.95 | 8.46* | 0.45 | 8.91 |
| Bottom | 6 | 45.60 | 62.15 | 54.72 | 62.15 | 25.46 | 18.03 | 25.46 | 7.43* | 0.00 | 7.43 |
| | 12 | 2.83* | 41.12 | 52.55 | 60.51 | 43.95 | 55.38 | 63.34 | 11.43 | 19.39 | 7.96 |
| | 18 | 127.60 | 138.78 | 128.01 | 165.63 | 11.18 | 0.41 | 38.03 | 10.77* | 26.85 | 37.62 |
| Side | 6 | 49.61 | 48.09 | 70.54 | 71.58 | 1.52* | 20.98 | 21.97 | 22.50 | 23.49 | 0.99 |
| | 12 | 91.71 | 103.89 | 125.99 | 127.05 | 12.18 | 34.28 | 35.34 | 22.10 | 23.16 | 1.06 |
| | 18 | 165.75 | 166.73 | 204.10 | 231.90 | 0.98 | 38.35 | 66.15 | 37.37 | 65.17 | 27.80 |

* Represents an inversion—i.e., performance times increasing instead of decreasing

TABLE 12

DIFFERENCE BETWEEN MEANS AS A FUNCTION OF APERTURE
(INSTALLATION)

| Location | Depth (inches) | Aperture Size (inches) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 8 to 10 | 8 to 12 | 8 to 14 | 8 to 16 | 10 to 12 | 10 to 14 | 10 to 16 | 12 to 14 | 12 to 16 | 14 to 16 |
| Back | 6 | 6.80* | 0.00 | 7.94* | 0.78 | 6.80 | 1.14* | 7.58 | 7.94* | 0.78 | 8.72 |
| | 12 | 14.46 | 14.33 | 8.86 | 13.92 | 0.13* | 5.60* | 0.54* | 5.47* | 0.41* | 5.06 |
| | 18 | 8.82 | 16.86 | 2.30* | 17.00 | 8.04 | 11.12* | 8.18 | 19.16* | 0.14 | 19.30 |
| Side | 6 | 92.34 | 108.75 | 108.89 | 100.55 | 16.41 | 16.55 | 8.21 | 0.14 | 8.20* | 8.34* |
| | 12 | 175.05 | 199.76 | 208.25 | 196.78 | 24.71 | 33.20 | 21.73 | 8.49 | 2.98* | 11.47* |
| | 18 | 321.36 | 332.97 | 317.69 | 343.30 | 11.61 | 3.67* | 21.94 | 15.28* | 10.33 | 25.61 |
| Bottom | 6 | 140.66 | 178.27 | 176.02 | 182.98 | 37.61 | 35.36 | 42.32 | 2.25* | 4.71 | 6.96 |
| | 12 | 178.09 | 215.25 | 243.51 | 246.65 | 37.16 | 65.42 | 68.56 | 28.26 | 31.40 | 3.14 |
| | 18 | 347.45 | 389.32 | 404.85 | 409.19 | 41.87 | 57.40 | 61.74 | 15.53 | 19.87 | 4.34 |

* Represents an inversion—i.e., performance times increasing instead of decreasing

TABLE 13

PERCENT DECREASE IN TIMES DUE TO INCREASE IN APERTURE SIZE

| Location | Depth (inches) | Aperture Size (inches) 8 to 10 | 8 to 12 | 8 to 14 | 8 to 16 | 10 to 12 | 10 to 14 | 10 to 16 | 12 to 14 | 12 to 16 | 14 to 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Removal** | | | | | | | | | | | |
| Back | 6 | 7 | 4 | 4 | 18 | 12* | 3* | 12 | 8 | 22 | 15 |
| | 12 | 11 | 15 | 14 | 20 | 4 | 4 | 9 | 2/10 | 6 | 6 |
| | 18 | 11 | 30 | 19 | 30 | 21 | 9 | 21 | 15* | 1 | 14 |
| Bottom | 6 | 42 | 57 | 50 | 57 | 35 | 25 | 35 | 16* | 0 | 14 |
| | 12 | 2* | 35 | 45 | 51 | 37 | 46 | 53 | 15 | 25 | 12 |
| | 18 | 55 | 60 | 55 | 71 | 11 | 2/10 | 36 | 11* | 29 | 36 |
| Side | 6 | 36 | 34 | 51 | 51 | 2* | 23 | 24 | 25 | 26 | 1 |
| | 12 | 45 | 51 | 62 | 62 | 11 | 30 | 31 | 22 | 23 | 1 |
| | 18 | 53 | 53 | 65 | 74 | 1 | 26 | 45 | 25 | 44 | 25 |
| **Installation** | | | | | | | | | | | |
| Back | 6 | 16* | 0 | 19* | 2 | 14 | 2 | 15 | 18* | 2 | 17 |
| | 12 | 24 | 24 | 15 | 23 | 2/10* | 12* | 1* | 12* | 1* | 10 |
| | 18 | 13 | 25 | 3* | 26 | 14 | 19* | 14 | 37* | 2/10 | 28 |
| Bottom | 6 | 59 | 69 | 69 | 64 | 26 | 26 | 13 | 2/10 | 17* | 18* |
| | 12 | 69 | 79 | 82 | 77 | 31 | 42 | 27 | 16 | 5* | 25* |
| | 18 | 81 | 84 | 80 | 87 | 16 | 5* | 29 | 24* | 16 | 33 |
| Side | 6 | 56 | 71 | 70 | 73 | 34 | 32 | 38 | 3* | 6 | 9 |
| | 12 | 55 | 67 | 73 | 77 | 26 | 46 | 48 | 27 | 30 | 4 |
| | 18 | 69 | 77 | 80 | 81 | 27 | 37 | 39 | 13 | 17 | 4 |

* Represents an inversion—i.e., percents increasing instead of decreasing.

TABLE 14

DIFFERENCE BETWEEN MEANS AS A FUNCTION OF DEPTH (REMOVAL)

| Location | Aperture Size (inches) | Depth (inches) | | |
|---|---|---|---|---|
| | | 6 to 12 | 6 to 18 | 12 to 18 |
| Back | 8 | 6.71 | 23.59 | 16.88 |
| | 10 | 3.64 | 18.44 | 14.80 |
| | 12 | 4.74* | 2.24* | 2.50 |
| | 14 | 0.00 | 10.82 | 10.82 |
| | 16 | 4.67 | 9.72 | 5.05 |
| Bottom | 8 | 7.89 | 123.25 | 115.36 |
| | 10 | 47.41 | 32.34 | 15.07* |
| | 12 | 28.92 | 46.62 | 17.70 |
| | 14 | 10.06 | 49.96 | 39.90 |
| | 16 | 9.53 | 19.77 | 10.24 |
| Side | 8 | 65.01 | 174.87 | 109.86 |
| | 10 | 22.91 | 58.73 | 35.82 |
| | 12 | 9.21 | 56.23 | 47.02 |
| | 14 | 9.61 | 41.36 | 31.75 |
| | 16 | 9.54 | 14.55 | 5.01 |

* Represents an inversion—i.e., performance times decreasing instead of increasing

TABLE 15

PERCENT OF INCREASE OF WORK TIMES AS FUNCTION OF DEPTH (REMOVAL)

| Location | Aperture Size (inches) | Depth (inches) | | |
|---|---|---|---|---|
| | | 6 to 12 | 12 to 18 | 6 to 18 |
| Back | 8 | 12 | 27 | 43 |
| | 10 | 7 | 27 | 36 |
| | 12 | 8* | 5 | 4* |
| | 14 | 0.00 | 21 | 21 |
| | 16 | 10 | 10 | 22 |
| Bottom | 8 | 7 | 98 | 112 |
| | 10 | 65 | 13* | 44 |
| | 12 | 61 | 23 | 98 |
| | 14 | 18 | 61 | 91 |
| | 16 | 20 | 18 | 42 |
| Side | 8 | 47 | 54 | 125 |
| | 10 | 25 | 32 | 65 |
| | 12 | 10 | 47 | 62 |
| | 14 | 14 | 40 | 60 |
| | 16 | 14 | 6 | 21 |

* Represents an inversion—i.e., percents decreasing instead of increasing

TABLE 16

DIFFERENCE BETWEEN MEANS AS A FUNCTION OF LOCATION
(REMOVAL)

| Depth (inches) | Aperture Size (inches) | Location | | |
|---|---|---|---|---|
| | | Back to Bottom | Back to Side | Bottom to Side |
| 6 | 8 | 54.71 | 84.57 | 29.86 |
| | 10 | 21.81 | 38.75 | 16.94 |
| | 12 | 9.83* | 34.09 | 43.92 |
| | 14 | 2.20 | 16.19 | 13.99 |
| | 16 | 2.58 | 23.01 | 20.43 |
| 12 | 8 | 55.89 | 142.87 | 86.98 |
| | 10 | 65.58 | 58.02 | 7.56* |
| | 12 | 23.83 | 48.04 | 24.21 |
| | 14 | 12.26 | 25.80 | 13.54 |
| | 16 | 7.44 | 27.88 | 20.44 |
| 18 | 8 | 154.37 | 235.85 | 81.48 |
| | 10 | 35.71 | 79.04 | 43.33 |
| | 12 | 39.03 | 92.56 | 53.53 |
| | 14 | 41.34 | 46.73 | 5.39 |
| | 16 | 12.63 | 27.84 | 15.21 |

*Represents an inversion—i.e., performance times decreasing instead of increasing.

TABLE 17

PERCENT OF INCREASE IN WORK TIMES AS A FUNCTION OF LOCATION
(REMOVAL)

| Depth (inches) | Aperture Size (inches) | Location | | |
|---|---|---|---|---|
| | | Back to Bottom | Bottom to Side | Back to Side |
| 6 | 8 | 100 | 27 | 154 |
| | 10 | 43 | 23 | 76 |
| | 12 | 17* | 93 | 59 |
| | 14 | 4 | 25 | 31 |
| | 16 | 6 | 43 | 51 |
| 12 | 8 | 91 | 74 | 232 |
| | 10 | 120 | 6* | 106 |
| | 12 | 45 | 32 | 91 |
| | 14 | 23 | 21 | 49 |
| | 16 | 15 | 36 | 56 |
| 18 | 8 | 197 | 35 | 300 |
| | 10 | 51 | 41 | 114 |
| | 12 | 71 | 57 | 168 |
| | 14 | 65 | 5 | 72 |
| | 16 | 23 | 23 | 51 |

*Represents an inversion—i.e., percents decreasing instead of increasing

TABLE 18

DIFFERENCE BETWEEN MEANS AS A FUNCTION OF DEPTH
(INSTALLATION)

| Location | Aperture Size (inches) | Depth (inches) | | |
|---|---|---|---|---|
| | | 6 to 12 | 6 to 18 | 12 to 18 |
| Back | 8 | 17.94 | 23.52 | 5.58 |
| | 10 | 3.32* | 7.90 | 11.22 |
| | 12 | 3.61 | 6.66 | 3.05 |
| | 14 | 1.14 | 17.88 | 16.74 |
| | 16 | 4.80 | 7.30 | 2.50 |
| Bottom | 8 | 97.58 | 239.51 | 141.93 |
| | 10 | 14.87 | 10.49 | 4.38* |
| | 12 | 6.57 | 15.29 | 8.72 |
| | 14 | 1.78 | 30.71 | 32.49 |
| | 16 | 1.35 | 3.24* | 4.59* |
| Side | 8 | 69.59 | 252.91 | 183.32 |
| | 10 | 32.16 | 46.17 | 13.96 |
| | 12 | 32.61 | 41.86 | 9.25 |
| | 14 | 2.10 | 24.08 | 21.98 |
| | 16 | 5.92 | 26.70 | 20.78 |

* Represents an inversion—i.e., performance times decreasing instead of increasing

TABLE 19

PERCENT OF INCREASE IN WORK TIMES AS A FUNCTION OF DEPTH
(INSTALLATION)

| Location | Aperture Size (inches) | Depth (inches) | | |
|---|---|---|---|---|
| | | 6 to 12 | 12 to 18 | 6 to 18 |
| Back | 8 | 42 | 9 | 55 |
| | 10 | 7* | 24 | 16 |
| | 12 | 8 | 7 | 16 |
| | 14 | 2 | 32 | 35 |
| | 16 | 11 | 5 | 17 |
| Bottom | 8 | 62 | 56 | 153 |
| | 10 | 23 | 6* | 16 |
| | 12 | 14 | 16 | 32 |
| | 14 | 4 | 71 | 65 |
| | 16 | 2 | 8* | 6* |
| Side | 8 | 28 | 57 | 101 |
| | 10 | 29 | 10 | 42 |
| | 12 | 45 | 9 | 57 |
| | 14 | 3 | 28 | 32 |
| | 16 | 9 | 28 | 39 |

* Represents an inversion—i.e., percents decreasing instead of increasing

TABLE 20

DIFFERENCE BETWEEN MEANS AS A FUNCTION OF LOCATION (INSTALLATION)

| Depth (inches) | Aperture Size (inches) | Location | | |
|---|---|---|---|---|
| | | Back to Bottom | Back to Side | Bottom to Side |
| 6 | 8 | 113.60 | 208.64 | 95.04 |
| | 10 | 14.46 | 61.18 | 46.72 |
| | 12 | 4.85 | 30.37 | 25.52 |
| | 14 | 3.23* | 24.68 | 27.91 |
| | 16 | 13.83 | 26.44 | 12.61 |
| 12 | 8 | 193.24 | 260.29 | 67.05 |
| | 10 | 32.65 | 96.66 | 64.01 |
| | 12 | 7.81 | 59.37 | 51.56 |
| | 14 | 6.15* | 25.64 | 31.79 |
| | 16 | 10.38 | 27.56 | 17.18 |
| 18 | 8 | 329.59 | 438.03 | 108.44 |
| | 10 | 17.05 | 99.40 | 82.35 |
| | 12 | 13.48 | 65.57 | 52.09 |
| | 14 | 9.60 | 30.88 | 21.28 |
| | 16 | 3.29 | 45.84 | 42.55 |

* Represents an inversion—i.e., performance times decreasing instead of increasing

TABLE 21

PERCENT OF INCREASE IN WORK TIMES AS A FUNCTION OF LOCATION (INSTALLATION)

| Depth (inches) | Aperture Size (inches) | Location | | |
|---|---|---|---|---|
| | | Back to Bottom | Bottom to Side | Back to Side |
| 6 | 8 | 265 | 61 | 486 |
| | 10 | 29 | 73 | 123 |
| | 12 | 11 | 53 | 71 |
| | 14 | 6* | 59 | 49 |
| | 16 | 33 | 23 | 63 |
| 12 | 8 | 318 | 26 | 427 |
| | 10 | 70 | 81 | 208 |
| | 12 | 17 | 95 | 128 |
| | 14 | 12* | 69 | 49 |
| | 16 | 22 | 30 | 59 |
| 18 | 8 | 496 | 27 | 659 |
| | 10 | 30 | 110 | 173 |
| | 12 | 27 | 83 | 132 |
| | 14 | 14 | 27 | 45 |
| | 16 | 7 | 81 | 93 |

* Represents an inversion—i.e., percents decreasing instead of increasing