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ED 016 054 VT 001 726

COMMUNICATION OF WORK METHODS.

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REPORT NUMBER SPEC-REP-58 PUB DATE JUN 64
EDRS PRICE MF-$0.25 HC-$1.76 42P.

DESCRIPTORS- PROGRAMED INSTRUCTION, *JOB SKILLS, *AUDIOVISUAL COMMUNICATION, *ASSEMBLY (MANUFACTURING), *INDIVIDUAL INSTRUCTION, *EDUCATIONAL EXPERIMENTS, AUTOINSTRUCTIONAL METHODS,

THE ECONOMIC IMPLICATIONS OF PROGRAMED INSTRUCTION FOR WORK TRAINING UNDER CONTROLLED CONDITIONS WERE INVESTIGATED. "WORK TRAINING" REQUIRED THE MEMORIZATION OF PROCEDURES DURING THE TRAINING PERIOD. ONE EXPERIMENT UTILIZED 20 UNSKILLED FEMALES WHO COMPLETED A LAYERED ASSEMBLY BY REFERRING TO A TYPED LIST OR SLIDES OF THE ASSEMBLY WHICH WERE OPERATOR PACED. WITH CRITERIA OF TIME AND ERRORS, THE SLIDES WERE MORE EFFECTIVE. A SECOND EXPERIMENT UTILIZED 20 MALE COLLEGE STUDENTS WHO MADE A LAYERED ASSEMBLY BY REFERRING TO A TYPED LIST ON A SLIDE OR SLIDES OF THE ASSEMBLY, AGAIN OPERATOR PACED. THE ASSEMBLY SLIDES WERE MORE EFFECTIVE THAN THE LIST SLIDES. A THIRD EXPERIMENT UTILIZED 16 UNSKILLED FEMALES WHO MADE A LAYERED ASSEMBLY BY REFERRING TO MULTIPLE SLIDES PER LAYER, SINGLE SLIDES PER LAYER, A TYPED LIST IN A TYPEWRITER, OR TAPED AUDIO INSTRUCTIONS. ALL WERE OPERATOR PACED. BOTH SLIDE METHODS WERE ABOUT EQUALLY EFFECTIVE, AND BOTH WERE MORE EFFECTIVE THAN THE LIST OR AUDIO METHODS. A FOURTH EXPERIMENT UTILIZED 10 MALE COLLEGE STUDENTS WHO MADE A LAYERED ASSEMBLY BY FOLLOWING A TYPED LIST WITH THE FINGERTIP OF THE LEFT HAND, OR USING ONE SLIDE PER LAYER. THE SLIDES WERE MORE EFFECTIVE. A FIFTH EXPERIMENT UTILIZED 12 MALE COLLEGE STUDENTS WHO MADE A SIMULATED ELECTRICAL TERMINAL BOARD BY REFERRING TO A TYPED LIST, COLORED SLIDES OF THE ASSEMBLY, OR AUDIO TAPE RECORDING. ERRORS INCREASED FROM SLIDES TO LIST TO TAPE. IN ALL EXPERIMENTS PICTORIAL PRESENTATION WAS BEST FOR BOTH THE TIME AND ERROR CRITERIA. (EM)

KANSAS STATE UNIVERSITY BULLETIN

SPECIAL REPORT NUMBER **58**

COMMUNICATION OF WORK METHODS*

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* This study was supported in part by a grant from the Research and Educational Committee, American Society of Tool and Manufacturing Engineers, 1964.

KANSAS ENGINEERING EXPERIMENT STATION

MANHATTAN, KANSAS

COMMUNICATION OF WORK METHODS[1]

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[1]Under sponsorship of ASTME Research and Educational Grant, June, 1964.

The authors are greatly indebted to Dr. S. C. Brown, Assistant Professor of Psychology, for his many contributions in the design and editing of this paper.

Interest in programmed learning has increased since Skinner's article "The Science of Learning and the Art of Teaching" in 1954 but most work has been oriented toward academic research rather than work training. A decade later, Schramm (17) compiled 160 papers of original research on programmed learning. Only 18 dealt with work related tasks and more than 80 percent of the 160 experiments used student subjects. We wanted to evaluate the economic implications of the new technique for work training under controlled conditions.

Communication through programmed instruction can be of two types: work instruction, in which the operator always has a detailed procedure before him, and work training, in which the operator is expected to memorize a particular procedure during a training period. Although research in both types of communication is currently in progress in the Industrial Engineering Department at Kansas State University, the remainder of the article will only be concerned with work instruction.

Work done elsewhere

Communication between the engineer and the worker is typically through the visual and/or auditory channels. In general, it has been established that the visual channel is better than the auditory channel for transmitting information (11, 15). Cardozo and Leopold (6) had subjects transcribe letters and numbers. Visual input results in fewer errors than auditory input. Roshal (16) compared the efficiency of presenting information through slides and motion pictures for a knot-tying task and found motion pictures better. However, he stated "For simple tasks, the most important consideration may be the accurate representation of the product of the perceptual motor skill." When the subject tied the knot at the same time as the motion picture was being shown, Roshal noted that this divided attention seemed to produce a conflict. McGuire (13) felt that motion picture portrayals of performance tend to present information faster than the subject's input capacity. If however, the film speed is slowed down so that all operators can follow it, it tends to act as a pacing device for the faster operators. Slides on the other hand can be actuated by the individual operator at his own pace.

Use of the word "visual" is deceiving. Both a typed list of assembly instructions and step-by-step colored pictures of an assembly are visual. Cross, Noble, and Trumbo (7) in a study on controls found that it was more effective to present a picture of what the operator should duplicate (i.e. matching behavior) than to give the operator typed directions on how to move (i.e. move control left 5" and then down 3").

The auditory channel, however, also has its partisans. Goldman and Eisenberg (9) found that auditory input of information on an assembly task was more advantageous than posting a list of instructions in front of the operator. Erlick and Hunt (8) cite as an advantage of using the auditory channel that while visual information generally requires either shifting the operator's head orientation or locating the equipment in an often already crowded work space, auditory information can be presented by equipment located in less critical work areas. Note also that if the operator's eyes are used in the task, this means she reads the information and then performs the task (i.e. works sequentially). Giving information to the operator through the auditory channel allows her to work "in parallel" as she can obtain information and work at the same time. Thus it appears that both channels have their strong and weak points and that any general statement on which is best must be applied with caution.

The traditional work instruction device is a written or typed list of steps that have been developed by the organization's industrial engineering department. This list is posted in front of the operator. Recently more sophisticated equipment (1) (2) (3) (4) (5) (19) has been used which have tape recorded commentaries in conjunction with color slides. On at least one unit (10) the voice is automatically hushed at the end of the instruction so the operator can hear background music while carrying out the previous instruction. There is very little published evidence of controlled experiments on work method communication, thus the impetus for the following series of investigations.

EXPERIMENT ONE

Task. The task, depicted in Fig. 1, used a pegboard with a 4 x 4 matrix of $\frac{1}{4}$" diameter 3" long wooden dowels on $1\frac{1}{4}$" centers. The columns were labeled A-D and the rows 1-4. Three types of wooden washers were made: one to fit over one dowel (singles), one to fit over two dowels (doubles) and one to fit over three (triples). Since components in many industrial assembly tasks must not only be placed in the proper position but must also have a specific orientation, the washers were colored red on one side of one end of the doubles and triples and white on the other side of the other end. The singles were red on one side and white on the other. Errors, therefore, could be classified four ways: position (on wrong pegs), orientation (on correct pegs but with ends reversed or part upside down), color (on correct pegs but with ends reversed and part upside down), and omission (part omitted). Although we have differentiated between color and orientation errors some readers may wish to combine both categories into a single category of orientation error. Five singles, four doubles and one triple composed a layer of non overlapping washers. Twelve different patterns of layers were designed. For experiment one, these twelve layers were grouped into four tasks of three layers each.

The workstation, shown in Fig. 2, was dèsigned for consistency of method rather than efficiency. Each operator worked only with the right hand.

Subjects. Twenty women were hired from the unskilled labor pool of the Kansas State Employment Service. Each woman worked for four hours and was paid by the hour. Years of schooling ranged from 10 to 17 with an average of 13.0.

Media. Two methods of work communication were investigated: (1.) The conventional typed list shown in Fig. 3. (2.) Picture slides taken from the operator's viewing angle. There were three slides for each layer---one for the singles, one for the doubles and one for the triple. For clarity the "background" components were not shown on the slides. The slides were rear projected on the screen of a Hughes Model 202 Videosonic and were changed by actuation of a footswitch. Thus both media were operator paced. Note that only a small portion of the total information required for the task was available on any specific picture whereas the total task information was available on the list.

Experimental procedure. Each subject used both media and all four tasks. In order to balance practice effects ten subjects were randomly assigned to the list-picture-picture-list (l-p-p-l) sequence and the other half to the p-l-l-p sequence. Each subject completed a total of thirty assemblies (fifteen per task) for the list media and thirty for the picture. The sequence of tasks was randomized with the restriction that each task appeared equally often in each of the four time periods.

While the subject worked, the experimenter timed her with a decimal minute stop watch. Upon completion of an assembly of three layers, the experimenter

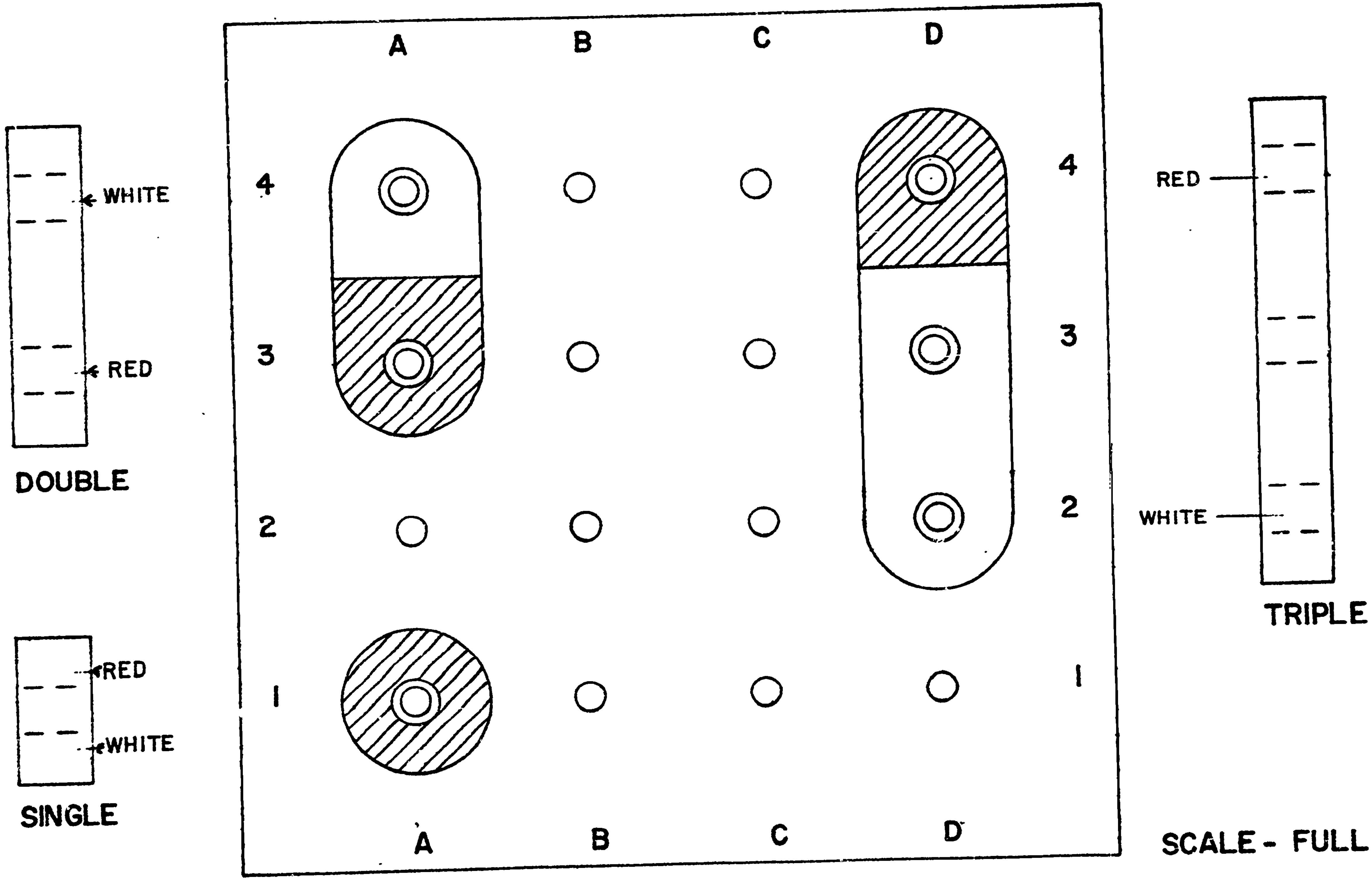

FIG. 1 PEG-BOARD ASSEMBLY CONFIGURATION USED IN EXPERIMENTS ONE, TWO, THREE, AND FOUR.

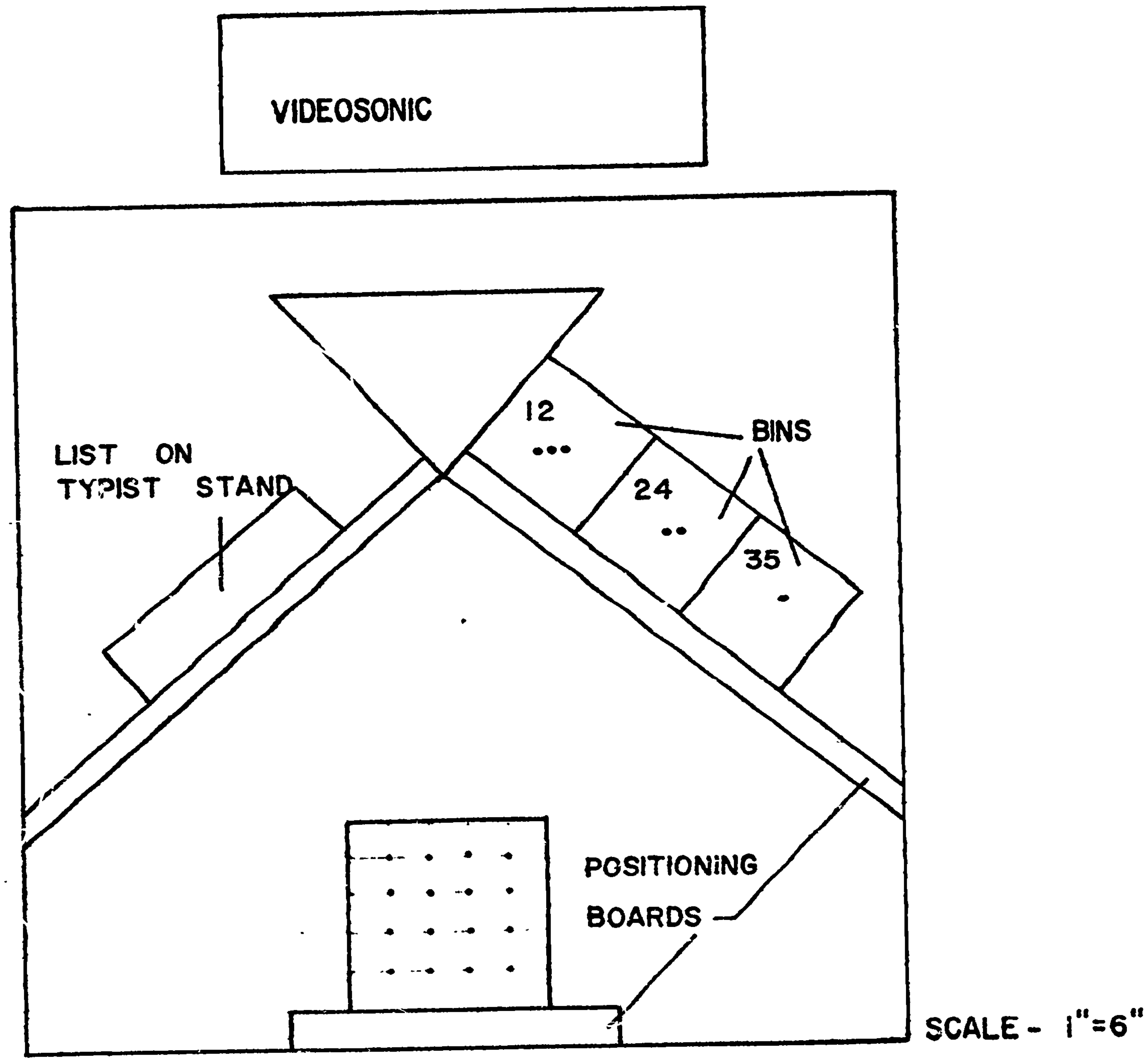

FIG. 2. WORKPLACE LAYOUT.

Fig. 3. Typical instruction list for experiment one.

TASK I

1. Get 5 singles
2. White at A1, C2, D3
3. Red at B4, C3

4. Get 4 doubles
5. White right at B1, C1
6. Red up at B2, B3
7. Red down at D1, D2
8. Red right at C4, D4

9. Get 1 triple
10. White down at A2, A3, A4

11. Get 5 singles
12. White at A4, D1, D4
13. Red at A3, D2

14. Get 4 doubles
15. White down C1, C2
16. White right B4, C4
17. White left A2, B2
18. Red right A1, B1

19. Get 1 triple
20. Red left at B3, C3, D3

21. Get 5 singles
22. White at D3, D4
23. Red at A1, B3, B4

24. Get 4 doubles
25. White up at C3, C4
26. White up at D1, D2
27. Red down at A3, A4
28. Red left at B1, C1

29. Get 1 triple
30. Red right at A2, B2, C2

disassembled the unit and noted the type and frequency of errors. This information was not given to the subject. Although the inspection time varied depending on the number and type of errors, the subject was idle for approximately two to three minutes between each assembly. The subjects were instructed to work "quickly but accurately".

Results. Five of the subjects took so long when using the list that they would not have been able to complete 15 assemblies of each of the four tasks within the four hour experimental session. For example, subject 17 used the list for her first task and was still taking over three minutes per assembly after 12 assemblies. At that point, the experimenter transferred her to the second task and pictures. She completed 15 assemblies of the second task and 12 assemblies of the third task using slides. She was able to complete 15 assemblies of the fourth task using the list before the four hour limit. The data beyond the minimum number completed for any one of the four tasks was not used. Thus for subject 17 we used only the first 12 cycles of the four tasks.

There was an average of .060 errors per layer when using the pictures and .380 errors per layer when using the list; it required an average time of .383 minutes per layer for pictures and .815 minutes per layer for the list. More detailed information can be found in Tables 1-5. The statistical significance of total errors, position errors, orientation errors, color errors, omission errors and time was tested with the non-parametric Wilcoxon Matched Pairs Signed Ranks test (18). The differences between media for each of the above criteria were significant ($p < .01$).

Tables 1 through 5 indicate that there might be a layer effect. There seem to be considerably more errors for the middle and top layers which must

Table 1. Position errors on experiment one.

Media	Layer Top	Middle	Bottom	Total	Total/ layer
List--1st series	25	26	3	54	
2nd series	24	25	1	50	
Total/1668 layers	49	51	4	104	.062
Pictures--1st series	1	0	2	3	
2nd series	5	3	1	9	
Total/1668 layers	6	3	3	12	.007

Table 2. Orientation errors on experiment one.

Media	Layer Top	Middle	Bottom	Total	Total/layer
List--1st series	69	62	57	188	
2nd series	50	64	20	134	
Total/1668 layers	119	126	77	322	.193
Pictures--1st series	9	8	13	30	
2nd series	8	5	6	19	
Total/1668 layers	17	13	19	49	.029

Table 3. Color errors on experiment one.

	Layer				
Media	Top	Middle	Bottom	Total	Total/layer
List--1st series	24	32	16	72	
2nd series	14	27	11	52	
Total/1668 layers	38	59	27	124	.074
Pictures--1st series	3	5	2	10	
2nd series	2	3	4	9	
Total/1668 layers	5	8	6	19	.011

Table 4. Omission errors on experiment one.

Media	Layer Top	Middle	Bottom	Total	Total/layer
List--1st series	29	28	8	65	
2nd series	8	9	3	20	
Total/1668 layers	37	37	11	85	.051
Pictures--1st series	3	3	3	9	
2nd series	10	1	2	13	
Total/1668 layers	13	4	5	22	.013

Table 5. Total assembly time (min.) for experiment one.

Media	Layer Top	Middle	Bottom	Total/1668 layers	Min./ layer
List--1st series	268.80	259.18	226.18	754.16	
2nd series	210.22	208.27	187.07	605.56	
Total	479.02	467.47	413.25	1359.74	.813
Pictures--1st series	110.44	109.44	110.95	331.38	
2nd series	101.67	100.55	104.49	306.71	
Total	212.11	210.54	215.44	638.09	.383

be assembled against a background of parts than for the bottom layer which is assembled with an "empty" background. This was tested with another non-parametric test, Friedman's two-way analysis of variance (18). Both time and position errors had a chi-square value that could have occured by chance less than one time in one hundred so it was concluded that the background did affect position errors and time. The probabilities of the chi-square occuring by chance for omission errors, orientation errors, and color errors were approximately 10 percent, 20 percent and 20 percent respectively, so these three are considered to have occured by chance.

Next the effect of the educational level of the subject was determined. The average errors and time per layer were calculated for each subject. The difference between the errors for each media for each subject was plotted against the subject's educational level. A similiar procedure was followed for times. The resulting Spearman rank correlation coefficient (18) was -.494 for errors and -.721 for times. Both are significant at $p < .05$. Thus, although every woman had more errors and more time for the list than the pictures, the difference was inversely related to the educational level and those with less formal schooling benefitted most from the pictures.

After the experiment, the subjects were asked which media they preferred and why. Nineteen of the twenty preferred the pictures. One preferred the list because "it is more of a challenge".

Discussion. It was felt that the requirement of "a complex operation with a long cycle time" before it was profitable to change from the conventional typed list (9) was incorrect. McCormick (12) states that in performing any type of work a person engages in essentially three kinds of functions: 1. Obtaining information 2. Making decisions 3. Acting upon the decisions.

It was felt that visual instruction would reduce the time for obtaining information and making decisions but probably would not change the time to carry out the decision (eg. soldering time and the time necessary to select the parts and assemble the components). Thus the tasks were designed with a high information and decision content and relatively low motor work content.

The data indicates that pictorial presentation is more effective than a typed list. Educational level also is a variable with subjects with less education benefitting more from pictures. Adding a component against a complex background seems to affect some types of errors.

In order to verify some of these results, a second experiment was run which used college students as subjects. Since in experiment one there may have been too much information being presented at one time, an attempt was made to equate the information content of the two media. Both media were presented by means of the Videosonic unit to remove any novelty effects of the machine.

EXPERIMENT TWO

Task. Five assemblies of the same type as in experiment one were used, but with each assembly consisting of only two layers each instead of the three layers per assembly of experiment one.

Subjects. Twenty male undergraduate and graduate students in industrial engineering served without pay.

Media. In this experiment, the typed instructions from the list were photographed and presented on a slide for each layer. The pictures were also on a one slide per layer basis instead of the three slides per layer of experiment one. The viewing time for both media was under the control of the subject.

Experimental procedure. Ten subjects used the list slides and ten used the picture slides. The five assemblies were arranged in five different sequences to balance sequential effects between tasks. Two subjects used each sequence with each media. One of these two subjects had layer one on the bottom and layer two on top while the other had two on the bottom and one on top. Thus the five tasks and sequences composed a 5 x 5 Latin square. A ten second rest interval was given between each layer with a 30 second interval between tasks. The subjects were told "errors and time are equally important."

Results. Table 6 gives a parametric analysis of variance of the time and error scores. Errors were not broken into categories as in experiment one. There was an average of .32 errors per layer with the list and .12 errors per layer with the pictures. The average time scores were .884 minutes per layer with the list and .472 minutes per layer for the pictures. Both of these effects were statistically significant; errors at $p < .05$ and time at $p < .01$.

The significant display x practice interaction for errors can be attributed to the large number of errors committed by the list group on the first task. After the first assembly the errors were distributed fairly evenly over the remaining tasks. The average error scores for the first two layers for the picture were .05 errors per layer and .75 errors per layer for the listing. For the last two layers the pictures were .15 errors per layer while the listing were .20 errors per layer.

The subject's time scores decreased with practice to give a significant practice effect. Also practice x top-bottom, and display x practice effects were significant for time scores. The significant display x practice reflects the fact that the picture times started low and decreased only slightly while the list times decreased more rapidly. The average time for the first two

Table 6.

Summary of Analysis of Variance
for Assembly Times and Error Scores

Source	d.f.	Time Scores M.S.	Time Scores F	Error Scores M.S.	Error Scores F
Between Subjects	19				
Display (D)	1	8.4914	46.707**	2.000	4.348*
Blocks (B)	4	.2446	1.345	.930	2.022
D x B	4	.2341	1.287	.450	.978
Error	10	1.8175			
Within Subjects	180				
Practice (P)	4	.3555	44.438**	.718	2.124
Target (T)	4	.0185	2.312	.080	.237
Order (TB)	1	.0103	1.287	.020	.059
P x TB	4	.0688	8.600**	.258	.763
T x TB	4	.0103	1.287	.045	.133
D x P	4	.1708	21.350**	.913	2.701*
D x T	4	.0166	2.750*	.275	.814
D x TB	1	.0134	1.675	.021	.059
B x TB	4	.0063	.788	.620	1.834
D x TB x T	4	.0012	.150	.020	.059
D x B x TB	4	.0119	1.487	.270	.799
D x TB x P	4	.0071	.887	.283	.837
Error	138	.0080		.338	

*$p < .05$
**$p < .01$

layers for the picture group were .513 minutes and for the listing were 1.154 minutes. The average time for the last two layers were .439 minutes for the picture and .775 minutes for the listing. The significant practice x top-bottom interaction reflects the failure for all bottom layers to take longer than the associated top layers. That is, initially the bottom layer took longer than the top layer, but after the initial learning period the top was taking longer than the bottom. The reason for the top taking longer than the bottom was probably due to the confusing background while building the top layer which was not present while building the bottom layer.

Discussion. From the time scores we see that the listing started out considerably higher than the pictorial and remained so through the five assemblies; however, there were indications that the difference between the media may converge. Also the data indicated that the error scores will converge much sooner than the time scores.

The results of this experiment show that even with the information content of the media equated and with removal of any novelty effects the pictorial display remains superior. To make a more direct comparison, experiment three was designed to compare the effect of changing the information content per presentation. The effect of the use of the audio channel of presentation was also investigated.

EXPERIMENT THREE

Task. The four assemblies of experiment one were repeated.

Subjects. Sixteen women were hired from the unskilled labor pool of the Kansas State Employment Service. Each woman worked approximately four hours and was paid by the hour. Average years of schooling completed was 12.75.

Media. Four different media were used: (1.) Three picture slides per layer of experiment one. (2.) One picture slide per layer similiar to those in experiment two. (3.) The list of experiment one. However, the list was placed in a typewriter which permitted the subject to keep track of her place as she turned the roller. (4.) Audio instructions. These were given through the tape recorder portion of the Videosonic with the letters given as the words "able", "baker", "charlie", and "dog". The instructions were the same as those on the list. After the instruction to get the part, there was a pause of 1.8 seconds before the position instructions were given. There was another pause of 1.2 seconds at the end of the position instruction before the new get instruction. If desired, the tape could be stopped by depressiing a footswitch so this media as well as the others was operator paced. The running times for the tapes if they were not stopped were 2:37, 2:35, 2:35, and 2:45 minutes for tasks 1, 2, 3, and 4.

Experimental procedure. Each subject used each of the media for 15 consecutive assemblies. The four media and the four tasks composed a 4 x 4 Graeco-Latin square of subjects by sequence. Subjects 5-8 and 9-12 used different squares but subjects 13-16 repeated the same square as subjects 1-4. The subjects were instructed to work "quickly but accurately".

Results. Error categories are shown in Tables 7 to 10 with an average of .290 errors per layer when using the list, .592 when using audio instruction, .071 when using one picture per layer, and .103 when using three pictures per layer. Using a two tail Wilcoxon test for comparing these errors, the difference between the one picture per layer and three pictures per layer was significant at $p < .05$ and the differences between three pictures and list and between list and audio were significant at $p < .01$.

Table 7. Position errors in experiment three.

Media	Layer: Top	Middle	Bottom	Total	Total/720 layers
One picture/ layer	4	3	3	10	.014
Three pictures/ layer	7	4	7	18	.025
List	47	19	8	74	.103
Audio	87	82	42	211	.293

Table 8. Orientation errors in experiment three.

Media	Layer			Total	Total/720 layers
	Top	Middle	Bottom		
One Picture/ layer	10	4	12	28	.039
Three Pictures/ layer	12	10	22	44	.061
List	27	30	26	83	.115
Audio	34	37	19	90	.125

Table 9. Color errors on experiment three.

Media	Layer Top	Middle	Bottom	Total	Total/720 layers
One Picture/ layer	3	4	0	7	.010
Three Pictures/ layer	4	5	2	11	.015
List	20	15	15	50	.069
Audio	43	34	9	86	.119

Table 10. Omission errors on experiment three.

Media	Top	Layer Middle	Bottom	Total	Total/720 layers
List	0	2	0	2	.003
One Picture/ layer	3	1	2	6	.008
Three Pictures/ layer	5	3	1	9	.012
Audio	12	18	10	40	.055

For position errors alone (Table 7) the difference between the one picture per layer and three pictures per layer was not significant, but both the differences between three pictures per layer and the list, and between the list and audio were significant at $p < .01$. Therefore, the difference between one picture per layer and the list is also significant.

For orientation errors alone (Table 8) the difference between the one picture per layer and three pictures per layer was not significant, and neither was the difference between three pictures per layer and the list. However, the difference between three pictures per layer and audio was significant ($p < .05$) as was the difference between the one picture per layer and the list ($p < .01$).

For color errors alone (Table 10) the differences between the list, one picture per layer, and three pictures per layer were not significant, but the difference between three pictures per layer and audio was significant ($p < .05$).

The possible layer effect (ie. the effect of a confusing background) indicated in Tables 7-10 was tested with Friedman's two way analysis of variance (18). For position errors (Table 7), the layer effect was significant ($p < .05$) only for the audio and list media. For orientation errors (Table 8), the layer effect was not significant for any of the media. For color errors (Table 9), the layer effect was significant only for the audio media. For omission errors (Table 10), the layer effect was not significant for any of the media.

The time per layer for the three picture per layer group was .47 minutes, for one picture per layer was .50 minutes, for the audio was 1.01 minutes, and for the list was 1.08 minutes. The difference between the .47 and .50, and 1.01 and 1.08 were not significant but the difference between the .50 and 1.01 was significant ($p < .01$).

The errors made by each subject while using the one picture per layer was subtracted from the errors she made while using the list. The difference was correlated in the expected direction with education but the correlation ($r = -.240$) was not statistically significant. The differences between the list and three pictures per layer had a correlation of -.200, the differences between the audio to the one picture per layer had a correlation of -.378, and the differences between the audio and three pictures per layer had a correlation of -.354. These three correlations are also in the expected direction but not statistically significant. The correlation between differences in time between the list and three pictures was significant (-.515) but the differences in time between audio and three pictures per layer was not significant.

Each subject was asked to indicate which media was "best" and which "worst". Best was scored at "+1" and worst as "-1". When the scores for the media were totaled for the sixteen subjects, the three pictures per layer had a score of 8, one picture per layer had 4, audio was 0, and the list was -12.

Discussion. The results of experiment three show some small differences between the one and three pictures per layer groups. However, this difference is probably small enough to neglect in an actual work situation. Audio presentation seems to be a very poor way of giving work instructions regardless of whether time or error scores are used as a criterion. Listing, however, proved to be only slightly better than the audio. A possible reason for the poor performance when using audio is referability. When the subject used the tape she either understood it the first time or it was lost and no reference was possible. With the pictures the subject could refer back within a specific instruction although not to previous instructions while with the list she could refer back as far as she wished.

Position errors were shown to be significantly affected by a confusing background in both experiment one and three when a list is used although presenting information through pictures did not bring out this problem. In the following experiment we wished to investigate both the layer effect and referability in more detail.

EXPERIMENT FOUR

Task. Two six layer assemblies were formed by combining task one and two, and task three and four of experiment one.

Subjects. Ten male undergraduate students were paid by the hour. Average years of education completed was 14.5. All subjects were right handed.

Media. Two media were used: (1.) The typed list of experiment one. The subjects, however, were told to keep their place on the list with a finger of their left hand. (2.) The one picture slide per layer of experiment three. Both media were operator paced.

Experimental procedure. Each subject used each media for eight assemblies. The experiment was counterbalanced by having subjects 1-5 assemble four units for each condition using the sequence: List-Task 1, Picture-Task 2, Picture-Task 2, and List-Task 1. Subjects 6-10 followed the sequence P-1, L-2, L-2, P-1. They were instructed to work "quickly but accurately".

Results. The error scores are given in Table 11. Using a Wilcoxon test, the position and omission errors were not statistically different across media, but the difference in color errors was significant ($p < .05$) while orientation errors and total errors were significantly different ($p < .01$). The average time of .72 minutes per layer for the list was significantly ($p < .01$) different from the .41 minutes for the picture. The effect of background (ie. layer effect) was not significant for either media.

Table 11. Errors for experiment four.

Media	Layer	Type of error Position	Orientation	Omission	Color	Total
List	Bottom	0	8	1	3	12
	2	6	10	0	5	21
	3	0	7	0	2	9
	4	5	9	0	1	15
	5	6	6	1	8	21
	Top	15	5	0	9	29
Total errors/ 480 layers		32	45	2	28	107
Average errors/layer		.066	.094	.004	.058	.223
Picture	Bottom	0	2	1	2	5
	2	1	4	0	1	6
	3	0	0	1	1	2
	4	0	2	0	1	3
	5	4	4	0	2	10
	Top	1	4	1	0	6
Total errors/ 480 layers		6	16	3	7	32
Average errors/layer		.013	.033	.006	.015	.067

Discussion. Refer to Table 12 for a comparison of the error rates and time scores for the different media for the previous experiments. Average errors per layer ranged from .060 to .133 for pictures while the list varied from .222 to .380 per layer and the audio had .592 errors per layer. Average times per layer ranged from .38 to .50 for pictures while the list varied from .72 to 1.08 and the audio had 1.01 minutes per layer. Thus, in general, pictures would be preferred over the list which would be preferred over the audio.

A closer look at the types of errors in interesting. The advantage of a place keeping device for the list seems to result in a decrease in omission errors and orientation errors while color errors decrease only slightly and position errors even seem to increase. Audio orientation errors are approximately three times greater than one picture orientation errors, but omissson errors are seven times greater, color errors are twelve times greater and position errors are fourteen times greater.

Another example of how changes in media affect errors was observed in the color errors for experiment four. There were five singles per layer, 48 layers per subject per media, and ten subjects of a total of 2400 opportunities for errors on singles. The four doubles and one triple per layer also afforded 2400 opportunities for error. The subjects made 15 color errors on singles when using the list and 6 (40 percent of the list) when using the pictures. However, they reduced the color errors on doubles and triples from 13 with the list to only one (8 percent of the list) when using the pictures. Thus even different types of parts are differentially affected by changes in media.

Experiment five was designed to further analyze three of the media

Table 12. Comparison of the average error and time scores per layer for experiments one through four.

Experiment	Media	Types of Errors: Position	Orientation	Omission	Color	Average errors/ layer	Average min./ layer
One	List	.062	.193	.051	.074	.380	.813
	Three Pictures	.007	.029	.013	.011	.060	.380
Two	List on Slide	---	---	---	---	.320	.880
	One Picture	---	---	---	---	.120	.470
Three	List (typewriter)	.103	.115	.003	.069	.290	1.080
	Three Pictures	.025	.061	.012	.015	.133	.470
	One Picture	.014	.039	.008	.010	.071	.500
	Audio	.293	.125	.055	.119	.592	1.010
Four	List (finger)	.066	.094	.004	.058	.222	.720
	One Picture	.013	.033	.006	.015	.067	.410

previously studied (list, picture, and audio) but with a different type of assembly.

EXPERIMENT FIVE

Goldman and Eisenberg (9) showed that for a task involving selecting, bending leads, and installing 15 resistors in a terminal board, recorded auditory work instructions were significantly better (standard time was reached in less time) than use of a printed list. Several factors were influential in the decision to replicate their experiment; the results of experiment three, their use of the sole criterion of number of cycles to reach standard rather than average time per cycle or errors per cycle, and the opportunity to compare our results vs. results obtained by another experimenter operating under different conditions.

Their experiment was modified in the following ways: 1. Another media, colored pictures presented on slides, was added to their two media. 2. Each subject served in each condition rather than their independent groups type of experiment. 3. The number and type of errors was recorded. 4. College freshmen were used instead of industrial workers. 5. The experimental task was modified slightly.

Task. A maple board with 63, 5/32 inch diameter holes arranged in the pattern shown in Figure 4 was painted flat black. The 1/8 inch high numbers were made from green pressure-sensitive plastic tape. One hundred standard IBM permanent-type plugged wires were substituted for the resistors. Each wire was 2½ inches long and had a 7/8 inch long plug on each end. These gray wires were hand-painted with three bright enamel stripes to correspond to the resistor colors. Either end of the wire could be placed in either hole so there were no orientation errors. Groups of five wires of each of the ten color codes were

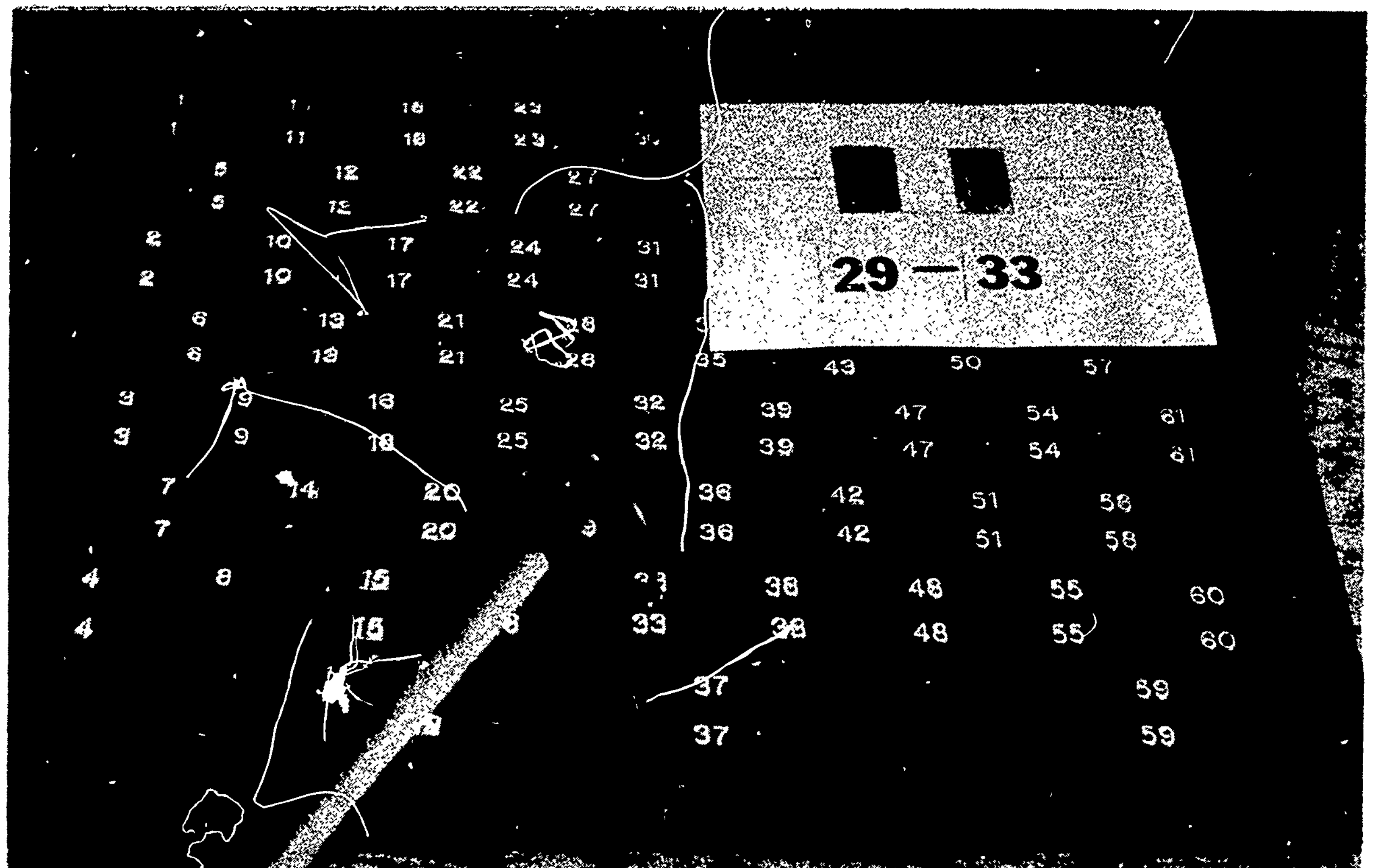

Fig. 4. Pictorial instructions for experiment five.

placed in an unpainted pine parts board having 3/8 inch holes one inch apart in a 10 x 10 matrix. Thus there were 100 holes for the 50 wires. Three highly similar tasks were used, Task A, Task B, and Task C. Task B used the same sequence of color codes as Task A but the hole locations were mirror images of those in Task A. Task C was Task A in reverse order.

Subjects. Twelve male freshmen who were not color blind were paid by the hour.

Media. Three media were used. Figure 5 gives the typed instruction list for Task A. Subjects could use their non-preferred hand (they could use only their preferred hand to assemble) to keep their place on the list but this was not suggested to them.

The instructions from the typed list were read verbatim onto a tape as quickly as possible while still remaining intelligible. The average time per instruction was three seconds with a 1.2 second pause between instructions. This speed, which was satisfactory for experienced operators, was too fast for beginners, so they used their non-preferred hand to manipulate the on-off switch of the tape recorder. They were not permitted to reverse the tape to repeat a missed instruction.

An example of the colored slides taken for each instruction is given in Figure 4. Each picture showed only the wire to be inserted with no "background" components except the board itself. A red-tipped yellow pencil was used to indicate the location of the holes on the board. An oversized replica of the wire color code and the pertinent hole numbers appeared in one corner of the picture. The slide was projected on a screen directly in front of the operator by a Kodak Carousel projector. The subject controlled the indexing of the slides with a remote hand switch and was permitted to back up to the previous slide if he wished.

Fig. 5. Typical instruction list for experiment five.

TASK A

Green-Brown-Red	to	20-26
Orange-White-Brown	to	43-50
Red-White-Orange	to	30-34
Brown-Black-Orange	to	7-8
Blue-Gray-Orange	to	22-24
Yellow-Violet-Orange	to	13-17
Brown-Green-Red	to	44-45
Red-White-Orange	to	55-60
Yellow-Violet-Orange	to	18-23
Green-Blue-Red	to	3-9
Orange-White-Orange	to	42-47
Orange-White-Orange	to	29-33
Red-White-Brown	to	11-12
Blue-Gray-Orange	to	51-58
Brown-Black-Orange	to	2-5

Experimental procedure. Every subject always worked through 15 assemblies of Task A, B, and C in that order. The three media (picture, audio, and list) have six possible sequences. Two subjects used each of these sequences in an experimental design which required each media to occur first, second, and third equally often for each task.

Each subject was given a demonstration of how to complete one assembly of Task 1. In addition, brief demonstrations of how to use the slide projector and tape recorder were given before starting the task requiring those media. The subjects were given no rest between assemblies and five minutes between tasks. As the subject worked, the experimenter quickly replaced wires used in the previous assembly on the parts board used in the previous assembly and then recorded the types of errors as they occurred. At the end of an assembly he recorded assembly time, removed wires from the assembled board, and gave a new parts board to the subject. Meanwhile, the subject prepared the media for the next cycle. The subject was given no feedback on time or errors, although they requested it.

Results. A Dixon criterion (14) was used to test for outliers; subject seven had a long average assembly time and subject ten had considerable errors but neither subject could be eliminated.

Errors are shown in Table 13. The position errors were significantly ($p < .01$) less for the picture when comparing them with the tape, but the list was not significantly different from the picture or tape. Omission errors were significantly ($p < .01$) less for the picture than for both the tape or the list, but the difference between the tape and the list was non-significant. None of the differences in color errors between the media were significant. When all errors were combined the pictures were significantly ($p < .01$) better than the tape, and the list was significantly better ($p < .05$) than the tape, but the difference between the picture and the list was non-significant.

Table 13. Errors for experiment five.

	Type of Error			
Media	Position	Omission	Color	Total
List	19	21	35	75
Picture	4	1	43	48
Tape	24	59	62	145

The average time for 15 assemblies when using the tape was 24.85 minutes, for pictures was 29.19 minutes and for the list was 31.16. Using Wlicoxon tests with two tails, the tape was significantly better than both the picture and the list but the picture was not significantly different than the list. It is quite likely that the 59 omitted wires when using the tape (approximately 2% of the 2500 assembled when using the tape) contributed to the lower time for the tape.

DISCUSSION

The primary objective of the paper was to investigate the differences between forms of work instruction. The most obvious result of these experiments was that pictorial presentation is the best using either a time or an error criterion.

The types of errors committed with the different media are also interesting. Experiments three, four, and five demonstrated that media do not affect all types of errors equally. For example, in experiment five there were almost five times as many position errors when using the list as when using the picture. This did not mean, however, that there would be five times as many color errors. There actually were more color errors for the picture than with the list, therefore, making it extremely hard to generalize.

Visualization also seems to be an important consideration. If a subject either made a mistake or suspects he made a mistake when using the picture, he merely looked at the picture and matched what he saw in the picture with what he had assembled. When using the list, he had to decode the written words and form a mental picture and compare this mental picture with his actual assembly. When using audio instructions, visualization was not merely necessary as with the list but also required a good memory. Experiment three and four when contrasted with experiment one, demonstrated that keeping your place on a list (either with your finger or the typewriter carriage) decreased orientation and omission errors although it did not decrease color or position errors.

When using pictures, there seems to be an information content per message effect. That is, it may be that too much information is being presented on a picture. This was noticeable when the same information was presented in experiment three on either one slide or three separate slides. More slides for a given amount of information means the subject has less searching and interpreting to do. Fewer slides for a given amount of information means less indexing time between slides, possibly better referability since more information is available for reference, and of course fewer slides.

Audio presentation of material seems to be the poorest method from both a time and error viewpoint. One problem is the lack of referability. Another problem is that the audio seems to act as a pacing device. The subject improves only up to the pace of the tape and then maintains the pace of the tape. A slow tape sometimes frustrates the subject because he feels he is being held back. On the other hand, it was noticed (especially in experiment five) that the tape performs a feedback function in that it gives some knowledge of results to the subject as he works. In experiment five the subjects counted the number of times they had to stop the tape or counted the number of wires positioned before stopping the tape for the first time. Since not all characteristics of the tape are bad, it may be very useful when used in conjunction with other media.

The longest time any individual operator was studied was four hours in experiment one and even in this experiment only two hours were spent in any one media. Certainly longer term studies need to be made to see at what number of cycles the media become equivalent. Since synchronization of a tape and slides is expensive, investigation of other methods of presenting complex material as well as just tape and slides are in progress. Although these experiments have demonstrated differences in work instruction media in a series of controlled university experiments, it is felt that much work remains to be done.

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