California State University, Northridge

THE EFFECTS OF PANEL ARRANGEMENT AND
LOCUS OF ATTENTION ON PERFORMANCE

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by

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ABSTRACT

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The use of mirror imaged controls within functionally equivalent control panels has been questioned in various applications, including aircraft control layout, machinery controls, and control room design. The mirror image research has indicated that in some situations mirror imaging may be a superior design in terms of operator performance. One possible variable which may affect mirror imaging of controls is the location at which the operator is focusing attention; external to the panel, or within the panel.

The present thesis addressed the question of how the control panel should be arranged and if the locus of

attention affected performance. A 2 x 2 x 8 factorial design was used. The first factor was locus of attention with two levels, internal and external locations; the second factor was arrangement with two levels, mirror-image and left-right arrangements; the third factor was trial block with eight trial blocks. This design was used to test these variables under usual operating conditions and under a simulated emergency condition.

Subjects were randomly assigned to the four experimental groups. They were trained on one control panel arrangement and then transferred to either a mirror image of that panel or to the same arrangement (left-right). Time and error data were collected for transfer trials. Two time measurements were collected for the emergency condition; response time and completion time. The analysis of variance indicated slower response times for the mirror-image group, as well as a greater number of errors. The effect of trials was significant for both training and transfer data. The interaction for trials by arrangement was significant. For the emergency data, the same results were observed for the time data; both response time and completion time. The error analysis showed that the mirror-image group had significantly more errors than the left-right group. This analysis showed a significant locus by arrangement interaction, with the

mirror-image group improving significantly from the first trial to the last, while the left-right group remained about the same.

Table of Contents

	<u>Page</u>
Approval	ii
Acknowledgement	iii
Abstract	iv
List of Figures	viii
List of Tables	ix
I. Introduction	1
Transfer of Training	15
Research in mirror imaging	18
Hypotheses	29
II. Method	31
Subjects	31
Design	31
Apparatus	34
Procedure	38
Learning Phase	40
Transfer Trials	44
III. Results	46
Response Time Data	47
Learning Data	47
Transfer Data	47
Difference Data	50
Emergency Response Time Data	56
Emergency Completion Time Data	56
Error Data	59
Questionnaire Data	63
IV. Discussion	68
Arrangement of Controls	70
Locus of Attention	72
Emergency Data	73
Generalizability	77
Conclusions	78
Future Research	79
V. References	80
VI. Appendices	
A. Contents of Slide Commands	83
B. Standardized Instructions	88
C. Questionnaire	92

List of Figures

	<u>Page</u>
1. Nuclear power plant control room	2
2. Control panel (A) and its mirror-image (B)	5
3. Flat control panel in mirror-image	6
4. U-shaped control panels in mirror-image (A) and left-right (B)	8
5. Roof bolting machine in mirror-image (A) and left-right (B)	11
6. Four control arrangements used in range studies	20
7. Pigg experimental apparatus in mirror-image (A) and left-right (B)	23
8. Experimental design	33
9. Control panel dimensions	35
10. Control labels for panel in left-right (A) and mirror-image (B)	37
11. Screen positions for internal (A) and external (B) focus conditions	39
12. Experimental conditions for learning and transfer	41
13. Plot of learning and transfer data	49
14. Trials by arrangement interaction (Transfer data)	52
15. Trials by arrangement interaction (difference data)	55
16. Trials by arrangement interaction (emergency reaction time data)	58
17. Trials by arrangement (emergency completion time data)	61
18. Arrangement by focus interaction (error data)	64

List of Tables

	<u>Page</u>
1. Emergency Procedure	43
2. ANOVA Summary Table for Learning Data	48
3. ANOVA Summary Table for Transfer Data	51
4. ANOVA Summary Table for Difference Data	54
5. ANOVA Summary Table for Emergency Response Time Data	57
6. ANOVA Summary Table for Emergency Completion Time Data	60
7. ANOVA Summary Table for Error Data	62
8. Results from Questionnaire	65
9. ANOVA Summary Table for Questionnaire (Question Number 6)	67

Control panels in various forms have become an integral part of daily life. In the home these vary in complexity from the relatively simple control arrangement on the common stove, to the increasingly complex panels on home stereo systems. In the workplace there is also a wide range of complexity, with the extremely complex end of the spectrum perhaps exemplified by the nuclear power plant control room, an example of which is shown in Figure 1. With this level of complexity and the attendant potential for disaster, it is critical that the operators get the information they need and are able to perform the indicated operations in the safest and most efficient manner. Research in the area of control panel and work station design is abundant and accepted human factors specifications are available in the human factors literature (VanCott & Kinkade, 1972; Woodson, 1982). The application of this knowledge, however, seems to be analogous to the rediscovery of the wheel for each new area to which it is applied. A case in point is the design of nuclear power plant control panels and control rooms. The Three Mile Island incident initiated failure analyses of that plant and a general increase in the human factors analyses required within the nuclear power industry (Seminara, et al, 1977; Nureg 0700, 1981).

Figure 1. Nuclear power plant control room.

These analyses often cited the lack of application of human factors specifications in the design of control room panels.

One of the design practices which has been questioned in the design of cockpits (Fitts and Jones, 1947), and mining equipment (Schurick, 1982) as well as nuclear power plant control rooms is the mirror imaging of controls within panels. Mirror imaging involves pattern reversal in the spatial orientation of controls on functionally identical panels. Figure 2 shows this relationship in which panel B is a mirror image of panel A. On panel A control "A1" is on the operator's left and control "A3" is on the operator's right. When the panel is mirror imaged, as in panel B, control "A1" is now on the operator's right and control "A3" is on the operator's left.

The major concern with control panel arrangements using mirror imaging is that they may not match the model the operator uses to remember the location of controls. If the operator uses his body as a reference in associating the location of controls, he would associate control "A1" (Figure 2) with his left side and control "A3" with his right side. When he operates the mirror image of the panel he will have to reverse his model. If the operator uses an external reference to associate the location of controls, he will retain the same model. For example, if the panel being operated is

on the west side of the building and the operator is using a display on the north wall as a reference, when he switches to the mirror imaged panel on the east side of the building, he would not have to alter his model. The display on the north wall would remain on the north wall when the mirror imaged panel was operated and each control within the panel would retain the same spatial relationship to that reference. This would result in control A1 being closest to the reference, control A2 next and so on, as was the case on the first panel.

In nuclear reactor control rooms, mirror imaging of panels usually takes one of two forms; either a flat panel and its mirror image are on opposite walls of the control room or the controls are arranged in a U-shaped panel configuration and its mirror image is located in an adjacent room. Figure 3 shows the operator in relation to a flat control panel placed on opposite walls of the control room. The panel in Figure 3A shows control "1" on the operator's right when he is working on one wall, and on the left when he is working on the opposite wall, but control "1" is always on the west side and control "4" is always on the east side of the panel. With the left-right configuration in Figure 3B, control "1" remains on the operator's left regardless of which wall the operator is working on, however, control "1" is on the west side of one panel and on the east side of the other.

CONTROL PANEL "A"

CONTROL PANEL "B"

Figure 2. Control Panel A and its
Mirror Image B.

A. MIRROR IMAGED PANELS

B. LEFT-RIGHT PANELS

Figure 3. Flat control panel in mirror-image (A) and left-right (B) configurations.

The other panel design that is often mirror imaged in nuclear reactor control rooms is the U-shaped panel. Figure 4 shows this configuration with both mirror imaged and left-right arrangements. As indicated in the other examples of mirror imaged panels, the specific control arrangement for a panel is reversed on its mirror imaged panel. Figure 4 shows the relationship in which control "1" is on the operator's left in panel A and on the operator's right in panel B, its mirror image. For the left-right arrangement, control "1" remains in the same position relative to the operator for each panel. Thus, mirror imaging assumes that the operator adopts an external reference with regard to control operation. That is, the operator expects controls on the east side to remain on the east side, even though the operator turns and faces the opposite direction. Left-right orientation, on the other hand, assumes that the operator adopts a body reference. That is, the operator expects controls on his left to remain on the left, even when the operator turns and faces the opposite direction.

Whenever an operator is required to operate two functionally similar panels, whether on opposite sides of a control console or on opposite walls, the question arises as to which design produces the best performance; mirror imaging or non-mirror imaging. Although the use of mirror imaging in control panel design is cited as an

A. MIRROR IMAGE PANELS

B. LEFT-RIGHT PANELS

Figure 4. U-shaped control panels in mirror-image (A) and left-right (B) configuration.

undesirable design choice (Seminara, et al, 1977), it is often found in nuclear power plants. Seminara et al (1977) offer two reasons for this. First, mirror imaging is "aesthetically pleasing", and second, it is economically desirable due to the necessity of producing only one length of cable for each control location on both panels. There do not seem to be any performance related criteria for using mirror imaging, but at the same time, there exists little empirical support for not using mirror imaging.

Control arrangement is also a concern in aircraft cockpit design. In most aircraft cockpit designs there are two seats which the pilots occupy and pilots often trade off which side of the aircraft they occupy. The controls are configured such that the pilot in the left seat operates the aileron and elevator controls with his left hand and the engine controls with his right hand (Pigg, 1954). The pilot in the right seat operates the same controls with the opposite hands; the aileron and the elevator controls with the right hand and the engine controls with the left hand. The same problem with orientation of controls is experienced in the cockpit as in the control room. The operator adopts a model with which he references the location of controls. As with the control room panel operators, the pilot may reference the controls with respect to his body, in which case he learns that the ailerons are operated with

the left hand and the engine controls are operated with the right hand when he is in the left seat and vice versa for the right seat. He may, on the other hand, reference the controls with respect to an external reference, such as the center of the aircraft and the doors. In this case, no matter which seat the pilot is occupying, the engine controls are always in the center of the aircraft and the aileron controls are always next to the door.

In mining operations the machine used for roofbolting of the mine shaft is configured such that an operator can be on either side of the machine to perform the required operations (Schurick, 1982). The controls are arranged so that they are either mirror imaged or in a left-right configuration. Figure 5 shows the configuration for both arrangements. When the operator is on the left side of the machine the boom control may be closest to the front of the machine. When he moves to the right side of the machine, the mirror imaged arrangement would still place the boom control closest to the front of the machine. For the left-right arrangement, when the operator moves to the opposite side of the machine, the boom control would now be placed in the position farthest from the front of the machine, however, the operator would control the boom with the same hand regardless of which side of the machine he was on.

Figure 5. Roof bolting machine in mirror-image (A) and left-right (B) configuration.

The specific arrangement of controls may have an important influence on the operator's performance, however, the reference the operator adopts may interact with the arrangement to seriously affect the operator's orientation to the panel. Two of the studies surveyed (Pigg, 1954; Schurick, 1982) suggest that the reference the operator uses may determine how the operator orients himself to the panel. For example, if the display for a panel is located in the center of the panel, the operator may develop a cognitive "picture" of how the controls are oriented on the panel with respect to this display. This would be the same as a body reference in which controls "1" "2" "3" would be on the operators left and "4" "5" "6" on the right. If the panel were to change location to the opposite wall, for instance, with the display retaining its position on the panel, the reference would remain the same. If the arrangement of controls on the panel were to be mirror imaged on the opposite wall with this reference, the result may be a temporary degradation in the performance of control panel operations because what the operator pictured on the left (i.e., controls "1" "2" "3") would now be on the right side of the panel. In the left-right arrangement, the controls would remain in the same spatial orientation, thus the established reference would apply no matter which wall the panel was on.

The roofbolter machine discussed with regard to

mining operations (Schurick, 1982), has controls arranged so that the drill control, for example, is closest to the front of the machine. The operator usually holds the drill steel with one hand and operates the other controls on the panel with the other hand. Mirror imaging would result in the panel controls having the same relation to the drill steel and the front of the machine, as shown in Figure 5A, no matter which side the operator was on. Since the operator is focusing his attention on the front of the machine where the functions are being performed, he may be using this point as the reference for orienting himself with respect to the control panel layout. If this is the case, then the mirror imaged arrangement should be more congruent with his mental model.

Depending upon which reference the operator uses for orienting himself with respect to the panel arrangement, the front of the machine or his body, the optimal arrangement may vary. It may be that mirror imaging of panels is a good arrangement for certain applications and not for others.

Various methods for panel design, including mirror imaging, have been used in process control rooms for a number of years. Seminara et al (1977) were able to survey operators with sufficient experience with all of these layouts to obtain preference information. The following quotes are a sample of the opinions gathered

in that survey:

- o Mirror imaging is lousy! You find yourself getting up and turning the wrong way.
- o Units #2 and #3 are mirrored. That's bad news! You get used to one orientation and then get confused--especially when you are new and have just spent 90 days training on the simulator.
- o Mirror imaging is a problem for the first three weeks. Now it isn't a problem.

Operator preference is an important factor in design; however, it does not necessarily indicate the design that will produce the best performance in terms of speed, accuracy and safety.

The final survey comment cited above is of particular interest because it seems to indicate that practice may minimize the problems experienced with mirror imaging. Under normal operating conditions when the stress level is relatively low and the operator is in good physical and mental condition, this may be the case. However, under conditions when the operator is fatigued, ill, under time pressure, or other stress, performance may be adversely affected. In their study of 460 pilot errors, Fitts and Jones (1947) identified one major source of errors as the lack of uniformity in the location of controls. Under normal conditions the pilot is able to adapt to the new control pattern, overriding the old, established habit; however, in a

stress situation the pilot may revert to the old, automatic pattern of response. Chapanis (1965) identified a similar consequence of stress in terms of operator expectancy. Operators often expect certain controls to move in a particular manner. When these expectancies are universal, they are termed population stereotypes. An operator who learns an operation that violates a population stereotype may have no problems operating in the situation under normal circumstances, however, under stress the operator will often revert to the more natural, though incorrect, movement of the control. If this paradigm translates into motor skill acquisition, it would be expected that the operator who had been trained on panel "A" could relearn the new pattern of skills required for panel "B" and perform adequately on that panel. Under stress, however, the operator may produce the behavior pattern associated with the first panel learned, panel "A" in this case, thus an initial degradation in performance would be expected to occur.

Transfer of Training

An important theoretical consideration which applies to the issue of mirror imaging is transfer of training. Transfer of training is concerned with the effect the learning of one behavior has on subsequent learning. This effect can have one of three outcomes in varying degrees: Positive, in which learning of the

second behavior is facilitated by learning the first behavior. Negative, in which subsequent learning is adversely affected by prior learning. Zero effect, in which the primary learning has no effect on subsequent learning. Early transfer of training research dealt primarily with verbal learning, paired-associate tasks in which the subject learned a list of words and their associated pairs (Poffenberger, 1915; Wiltbank, 1919). Holding (1965) summarized the transfer of training literature with respect to task stimuli and response as follows:

- o The same stimuli paired with the same response yields high positive transfer.
- o Different stimuli paired with different responses yield zero transfer.
- o Different stimuli paired with the same response yields positive transfer.
- o The same stimuli paired with different responses yields negative transfer.

Osgood (1949) also illustrated these relationships using a response surface in which he graphically showed this relationship. In terms of control panel design, if the stimulus, for example a warning sound, remains the same and the response, for example, operating a specific control, is opposite from a panel to its mirror image,

it would be expected that negative transfer of training would result. The relationship for motor skill transfer, however, does not seem to be this clear cut. The determination of similarity between stimulus and response is not as easily achieved as with verbal learning tasks for several reasons. Information processing, response selection and execution are more complex for motor skills (Bilodeau, 1969). In a verbal learning task there is usually one correct response, whereas in motor skills such as tracking, a number of possible responses can be considered correct. In transferring skills from a simulator to job performance, it is possible to define similarity in motor performance in terms of "simulation fidelity" (Bilodeau, 1969), however, no systematic relationship between transfer effects and stimulus-response similarity has been established. Bilodeau compared research in verbal learning and motor skill acquisition and concluded that interference and negative effects are much harder than positive effects to produce in motor skills. In the operation of control panels the stimulus may be a display or a previously learned procedure; each of which remain relatively constant from panel to panel. In the case of mirror imaged panels, the response is reversed from panel to panel. As mentioned, however, the reference the operator uses to orient himself to the

panel (e.g., body, display, etc.) may be an influencing factor in the effect of using mirror imaged panels.

Another factor which may influence the results of transfer of training research is the level of learning the subjects receive. Wiltbank (1919) states that the transfer effect is dependent in part on the level of original learning. More effect will be observed when the first task is learned to a high degree of proficiency.

Research in Mirror Imaging

The use of mirror imaging of controls is considered by Seminara et al (1977) to be at the "top of the list" of human factors discrepancies observed in nuclear power plants, however, as previously stated, very little research was found to support this contention. Of the studies that were found, none directly relate to complex control panel design. In the research regarding mirror imaging (Chapanis & Lindenbaum, 1959; Chapanis & Mankin, 1967; Ray & Ray, 1979; Pigg, 1954; Schurick, 1982), the stimulus consisted of either a single row or a single column of controls. The number of controls in these studies ranged from two to five per panel. One group of studies (Chapanis & Lindenbaum, 1959; Chapanis & Mankin, 1967; Ray & Ray, 1979) tested mirror imaging as one of several possible arrangements for stove design. In the majority of these studies the controls were arranged

horizontally on the front surface of a mockup stove. The controls corresponded to a constant arrangement of the four burners. Mirror imaging was defined in these studies as the arrangement of controls such that the leftmost and rightmost controls operated either both back or both front burners. This produced an arrangement in which the two controls on the right mirrored the two controls on the left. Figure 6 shows the four control arrangements used in these studies. Subjects were trained to detect a stimulus light placed in the center of each burner and to activate the corresponding control to extinguish the light. Response time and error data were recorded. The response time data for Chapanis & Lindenbaum (1959) showed that the mirror-imaged arrangement (2) had significantly faster response times for the last 40 trials. Ray & Ray (1979) performed similar research in which they only measured error data. They found the mirror imaged arrangement (2) to produce fewer errors. Preference data indicated a slight preference for the mirrored arrangement, however, previous experience with any of the arrangements was not considered.

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location of the control and its operation since visual feedback is immediately available to the operator. The operator may reference a particular control to the machine, observing that it is the closest to the front of the machine. When the operator switches to the other side of the machine, a mirrored arrangement would result in this control still being in the position closest to the front of the machine. The operator in this situation would be using a machine reference to determine location of controls. Schurick expected that subjects in the mirror-image group would have faster completion times and fewer errors due to the use of a machine reference. In fact, no differences were found between the two groups for either completion time or errors.

In most cases, in the nuclear power control rooms, the operator does not receive direct feedback from a specific location regarding the effect of the controls operated. Feedback is usually in the form of a display of lights, gauges, or similar modes of feedback which are integrated and scattered on the control panel. The location of this display may affect the reference the operator uses to establish associations between controls and their location on the panel. For example, if the signal is centered above the panel, the operator may use the central axis of the panel as a reference; whereas if

the signal is located to the left of the panel, this may become the reference. The location of this signal may determine where the operator references the arrangement of controls and consequently, the panel arrangement may influence performance.

Although Schurick did not find any differences between groups, a possible source of variance which may have been reflected in the wide variability Schurick found in her study was the lack of sufficient training which subjects received on the first control arrangement. In the research on transfer of training there is some disagreement as to the level of training subjects should receive before being transferred. Siipola & Israel (1933) have determined that the differential amounts of training on the learning task may be an important variable in accounting for the resulting amount of transfer observed on the transfer task. In training situations on a roofbolter machine or for licensing in a nuclear power plant control room, the operator would probably be trained to some automatic level of performance or quickly achieve this level through experience with the control panel. It seems, therefore, that training the subject to automaticity would generalize to the actual situation operators experience and would also reduce variability in the data.

The research discussed relating to the question of using mirror imaging in the design of control panels does not clearly generalize to complex control panels. Two variables did emerge from the literature, however, which may have an effect on performance depending upon the design configuration used. The first of these is locus of attention. The effects of mirror imaging may be dependent upon what the operator uses as a reference; where he focuses his attention may determine the reference he uses to locate controls. The second variable is stress and its effect on performance. The use of mirror imaging or other design configurations may have a varying effect upon performance dependent upon the amount of stress the operator is experiencing. Under normal circumstances, the operator may perform adequately with the panel, however, in an emergency situation, performance may be differentially affected.

The intent of the current study was to determine if these variables, coupled with panel arrangement, would have an effect on operator performance. Two levels of control panel arrangement were used; mirror-image and left-right. In the mirror-image group controls were arranged so that control "1" was on the far left of the panel on one side of the room with the same control on the far right on the mirror image of that panel, when located on the other side of the room. On the left-

right panel the controls remained in the same pattern no matter which side of the room they were on. To determine the effect of locus of attention, two levels were used; internal, in which a rear projection screen was placed above and central to the control panel, and external, in which the screen was placed above and to the side of the control panel closest to the room exit (on the north side of the room).

These two independent variables were used to determine their effects on operator performance and also to determine any interactions between them. Mirror imaged controls by themselves may have little effect on the performance of a task, however, coupled with an external or internal reference, performance may be affected. Alternatively, mirror imaging controls may affect performance substantially by itself, however, when it is coupled with an internal or external reference, no effect may be observed.

Subjects were also tested under a stress situation to determine if performance on a particular panel arrangement was affected. Stress was introduced by asking the subject to role play an emergency situation similar to one which may be encountered in a nuclear power plant control room. When a target slide was projected on the screen the subject was asked to perform a learned emergency sequence to prevent a "melt-down"

situation.

As mentioned earlier, operator expectancy may influence operator performance on a particular panel. In a survey given after the experimental trials, subjects were asked if they expected the panel to remain in the configuration which they learned or if they expected the arrangement to change when they were transferred to the opposite side of the room. To determine subject expectancy in an objective manner, subjects were observed during trials at the end of training and at the beginning of transfer in which the

Hypotheses

Arrangement. It was expected that the mirror-image group would have slower response times and produce more errors than the left-right group for transfer trials. control labels were removed.

For the emergency trials, the mirror-image group was expected to have slower time measures for both response time and completion time.

Locus. The external reference group was expected to have slightly slower response times caused in part by the movement time required by the subjects to turn from the screen to the control panel, however, this was not expected to be significant.

Arrangement by Locus Interaction. It was expected that the interaction between Locus and Arrangement would

be significant. The external locus/mirror-image group was expected to have faster response times and fewer errors due to the anticipated use of the screen as a reference with which to associate the control arrangement. It was also expected that the internal reference group would have faster response times and produce fewer errors than the external reference for the left-right condition because they were expected to use their body to reference the location of controls.

METHOD

Subjects

A total of 40 students from California State University, Northridge were used in this study. Thirty introductory psychology student volunteers were given course credit for their participation. Of these, 15 were female and 15 were male. Ten additional subjects; two males and eight females, were obtained through an advertisement in the University newspaper and were paid \$4.00 for their participation. All subjects were randomly assigned to experimental conditions, resulting in two paid subjects in each of two of the cells and three paid subjects in each of the other two cells of the experiment. Six left-handed subjects participated in the study. Of these, five were in the left-right group and one was in the mirror-image group. Subjects were tested individually.

Design

The design of the study was a $2 \times 2 \times 8$ factorial experiment. The three factors were panel arrangement, locus of attention and trial blocks. Panel arrangement was a between subject factor with mirror-image and left-right arrangements as the two levels of arrangement. Locus of attention was also a between subject factor with internal locus consisting of a rear projection screen being placed above and central to the control

panel, and external locus consisting of the rear projection screen being placed to the side of the control panel. Trial block was a within subject variable and consisted of eight blocks of trials obtained after the subject was transferred to the second side of the panel. Each trial block was a mean score, produced by combining 10 trials, unless an emergency score was included in the trial block, in which case the trial block was composed of nine trials. Figure 8 presents the design in this study. The dependent measures collected in this study were response time, emergency completion time, and errors. Response time consisted of the time from the onset of the stimulus, the instruction slide, to the operation of the indicated control by the subject. Emergency completion time consisted of the time from the onset of the emergency trial to the completion of the final operation in the learned sequence. Collection of the error data consisted of the experimenter observing each subject's approach movement to each control following the presentation of the instruction slide. If the subject's hand approached either the incorrect control or the incorrect side of the board, an error was recorded. This error data included operation of incorrect controls as well. No error data were collected during the learning trials or during the emergency trials. The

Figure 8. Experimental design.

dependent variable measured during the learning phase of the study was response time. During the transfer trials measurements were taken for response time, emergency response time and emergency completion time. Error data was collected only for transfer trials.

Apparatus

A symmetrically arranged control panel was used to simulate general control panel operations. The panel contained three rows of controls. The top and bottom rows had six controls each and the central row had eight controls. The top and bottom rows consisted of continuous rotary controls with corresponding dials having values ranging from "0" to "6". The central row consisted of four toggle switches with "ON" and "OFF" locations and four push buttons. The two sides of the panel were separated by 36.83 cm at the center of the panel to exaggerate the arm movements the subjects needed to make to reach controls, thereby exaggerating error movements. Figure 9 shows the control panel and its dimensions.

The labels for the panel were constructed using black Helvetic medium, 18 point letters on white posterboard. The labels were 33.65 cm by 3.18 cm. The labels were attached to the panel using Velcro strips. The labels were attached so that the control name was

Figure 9. Control panel dimensions.

directly below the appropriate control. There were two sets of labels; one for the left-right condition and one for the mirror-image condition. The labels for the panel and its mirror image are shown in Figure 10.

The control panel was placed on a desk 71.12 cm high. The subject was seated in front of the panel at what each subject determined to be a "comfortable" distance from the table. The work space envelope was determined for the fifth percentile female (Churchill et al, 1977).

Two LaFayette digital stop clocks (Model 54030) were used to collect time data. The timers were activated by a toggle switch manually controlled by the experimenter. The first timer (A) was stopped by the subject through the operation of any control on the panel. The second timer (B) was stopped by the experimenter through the operation of a control toggle switch. Timer A was used to collect response time data. Timer B was used to collect task completion time for the emergency task.

A rear projection system was used to present the instructions to the subjects. A set of 80 slides contained a single command per slide. The slides contained commands such as "Temperature D-3 to 4", "Pump-1 ON", and "Pressure B-1 to 5" (Appendix A

TEMPERATURE A-1	TEMPERATURE A-2	TEMPERATURE A-3		PRESSURE C-1	PRESSURE C-2	PRESSURE C-3	
PUMP 1	RESET 1	RESET 2	PUMP 2	PUMP 3	RESET 3	RESET 4	PUMP 4
TEMPERATURE B-1	TEMPERATURE B-2	TEMPERATURE B-3		PRESSURE D-1	PRESSURE D-2	PRESSURE D-3	

A. ORIGINAL ARRANGEMENT

PRESSURE C-3	PRESSURE C-2	PRESSURE C-1
-----------------	-----------------	-----------------

PUMP 4	RESET 4	RESET 3	PUMP 3
-----------	------------	------------	-----------

PRESSURE D-3	PRESSURE D-2	PRESSURE D-1
-----------------	-----------------	-----------------

TEMPERATURE A-3	TEMPERATURE A-2	TEMPERATURE A-1
--------------------	--------------------	--------------------

PUMP 2	RESET 2	RESET 1	PUMP 1
-----------	------------	------------	-----------

TEMPERATURE B-3	TEMPERATURE B-2	TEMPERATURE B-1
--------------------	--------------------	--------------------

B. MIRROR IMAGE ARRANGEMENT

Figure 10. Control labels for panels in original (A) and mirror-image (B) arrangements.

contains the complete list of instruction slides used.). The presentation order of slides was randomized for each subject. The 40 random orders were determined using a table of random numbers. The slides were grouped into blocks of ten slides per block. The commands were grouped into four categories depending upon the type of control to which they were associated. The four groups were: Temperature, Pressure, Pump, and Pushbutton. Each of the control commands was associated with a particular control on the board; some on the left side and some on the right side. The presentation orders were established using an equal number of slides from each category as well as an equal number from each side of the panel.

The projection system was either centered in front of the subject, above the top of the board for the internal locus condition, or at the north end of the table for the external locus condition (see Figure 11). The screen was placed approximately 140 cm above the floor and approximately 70 cm in front, or to the side of the subject, depending upon the locus condition to which the subject was assigned.

Procedure

Each subject was assigned to a condition according to a pre-determined random order, constructed using a

A. SCREEN POSITION FOR INTERNAL FOCUS.

B. SCREEN POSITION FOR EXTERNAL FOCUS.

Figure 11. Screen positions for internal (A) and external (B) locus conditions.

table of random numbers. The starting side was alternated for each subject with half starting on the east side and half starting on the west side of the room. The starting panel configuration was also alternated for every other subject. This consisted of having subjects begin their training with either the mirror-image labels or the left-right labels. Figure 12 illustrates the learning and transfer configurations for each group of subjects.

Learning Phase

The experimenter read a set of standardized instructions (See Appendix B) while the subject read silently. Any questions were answered at this time. All subjects received the same procedure in the learning phase except that the side of the room and the label configurations were alternated for each consecutive subject. Subjects were instructed to monitor the screen and perform the indicated operation following the experimenter's verbal signal "Ready Go". As the experimenter gave this signal, the timer toggle switch was placed in the "ON" position and the slide projector was automatically advanced to the next slide in the sequence. Upon the activation of any control on the panel, timer A stopped and the experimenter manually recorded this value. The timer switch was placed in the

Figure 12. Experimental conditions for learning and transfer.

"Off" position and was cleared. This procedure was repeated for each of the first 49 training slides. The presentation order for these learning trials was the same as for the transfer conditions. Slide number fifty for the training session was an orange slide which indicated an emergency situation.

Upon presentation of the orange emergency slide the subject was taught a six-step emergency procedure (See Table 1). The subject was instructed that during the experiment an emergency situation would occur. At this time the subject was to perform the emergency procedure to avoid a hypothetical disaster. Subjects were asked to role play and perform as if it were a real emergency situation. Subjects were given five minutes to practice the procedure on the panel at their own pace. Upon completion of this training, the subjects were given ten practice emergency trials. Timer A was operated in the same manner as for the general trials. Timer B was stopped by the experimenter when the subject operated the final control in the emergency procedure. Time data from both timers were recorded.

The remaining 28 training slides were presented to the subject following the emergency training. At location 75 an emergency training slide was again presented. Following the presentation of these 78

TABLE 1

Emergency Procedure

1. PRESSURE A-1 TO 5
2. TEMPERATURE C-2 TO 6
3. RESET-1 PUSH
4. PUMP-4 ON
5. RESET-2 PUSH
6. TEMPERATURE D-3 TO 6

training slides, the labels were removed from the panel and the subjects were presented with 15 more slides without labels. These trials were termed blind trials. The blind trials were given to determine if the subject's observable approach to each control was correct and if the response times were fairly consistent.

After completion of the blind trials the subjects were given a five minute break outside of the experimental room while the experimenter transferred the panel to the opposite side of the room and placed the projector in the appropriate location.

Transfer Trials

After the break the subjects were given ten additional trials with the labels removed to determine if they had any expectation as to the panel arrangement after the panel had been transferred. The labels were then replaced in either the mirror-image or the left-right configuration, depending on the experimental group the subject had been assigned to. The subject was then given 78 test trials with emergency slides presented at locations 25, 50, and 75 in the slide presentation order.

Upon completion of the testing the subject was given a short questionnaire to determine demographic,

preference, and expectancy data (Appendix C). Each subject was verbally informed of the nature of the study and given a written explanation of the experiment.

Each subject required approximately one hour to complete the experiment.

RESULTS

During data collection one subject's performance was so poor that these data were eliminated and the next subject was assigned to the same treatment conditions to replace these data.

The original data collection proposal included an equal number of males and females in each of the four cells, however, due to the difficulty in obtaining subjects, an unequal number of males and females in each cell resulted.

Data screening procedures were performed on the data to determine if the assumptions of the analysis of variance were met by these data. Normality was tested using the Shapiro-Wilk statistic. For all data sets this statistic ranged from .925 to .979, indicating that each was within the acceptable limit for normality.

Outliers were tested using the SAS (1979) Box Plot procedure. One data point in the left-right/external group and one data point in the mirror-image/external group were distant, however, according to this procedure they were not extreme points (within the 25th and 75th interquartile range). These data points were, therefore, included in the analyses.

The F MAX test was used to determine homogeneity of variance. This statistic was not significant for any of

the dependent variables ($p < .05$).

Response Time Data

Learning Data. The last 30 trials on the learning data were divided into 3 blocks of 10 trials (nine trials were combined if the block contained the emergency slide). These three scores were analyzed to determine if there were any initial differences between the four groups prior to transferring the panel to the opposite side of the room. The only significant difference indicated by an analysis of variance was for the main effect of trials ($F(2,72)=3.35$, $p > .05$). The results of this analysis are shown in Table 2. Figure 13 shows a graph of the learning data plotted with the results of the transfer data. A post hoc comparison of the three trials (Mean Trial 1 = 3.08; Trial 2 = 3.01; Trial 3 = 2.97) using the Tukey test showed a significant difference between trials 1 and 3 only ($p < .05$).

Transfer Data. A total of 78 response measures were taken after the control panel was placed on the opposite side of the room following the learning phase. These measures were combined to produce eight trial blocks of 10 trials (9 scores if an emergency trial fell within the block of 10 scores). An analysis of variance was performed on these data.

The effects for both Locus and Arrangement, as well

Table 2

ANOVA Summary Table for Learning Data

Source	SS	df	MS	F	p
Locus	1.83	1	1.83	1.43	.238
Arrange	.44	1	.44	.35	.567
Locus x Arrange	3.78	1	3.78	2.95	.091
Error (between)	46.08	36	1.28		
Trials	.25	2	.13	3.35*	.038
Locus x Trials	.03	2	.02	.39	.685
Arrange x Trials	.08	2	.04	1.03	.362
L x A x Trials	.05	2	.03	.67	.515
Error (within)	2.73	72	.04

Figure 13. Learning and transfer data.

as the interaction of Arrangement by Locus were not found to be significant as shown in Table 3. A significant effect was found for the within subject factor of trials ($F(7,252)=12.59$, $p<.001$). A Tukey post hoc comparison of the eight trials indicated a difference between trial 1 and trials 5, 6, 7, and 8 ($p<.05$).

The interaction between Trials and Arrangement was also found to be significant ($F(7,252)=2.74$, $p<.01$). Figure 14 presents a graph of this interaction. An F test for simple effects showed a significant improvement for only the mirror image group from Trial 1 to Trial 8 ($F(7,252)=12.35$, $p<.05$). A Tukey test was performed on the differences between the mirror-image group and the left-right group for each trial. The results showed a significant difference for Trials 1, 2, 3, and 4 with the mirror-image group having longer response times on each of these trials ($p<.05$).

Difference Data. This data set was generated by producing a mean score for the last 30 trials of the learning data for each subject and subtracting this from each of the transfer trials used in the transfer data analyses. A positive score indicated a longer response time for the transfer data than for the learning data.

Table 3

ANOVA Summary Table for Transfer Data

Source	SS	df	MS	F	p
Between Subject	40.97	39			
Locus	1.12	1	1.12	1.18	ns
Arrange	2.29	1	2.29	2.42	ns
Locus x Arrange	3.52	1	3.52	3.72	ns
Error (between)	34.04	36	.95		
Trials	2.38	7	.34	12.59*	.001
Locus x Trials	.07	7	.01	.41	ns
Arrange x Trials	.54	7	.08	2.74*	.01
L x A x Trials	.30	7	.04	1.54	ns
Error (within)	6.96	252	.03

Figure 14. Trials by arrangement interaction
(transfer data)

A negative score indicated that the transfer response time was shorter than the learning mean response time. This procedure is analogous to using the learning data as a covariate on the analysis of the transfer data. This analysis produced a change in the results from those observed in the uncorrected transfer data analysis. Table 4 shows these results. A significant effect for Arrangement ($F(1,36)=12.60, p<.001$) with the mirror-image group having a smaller difference score (Mean = $-.06$) than the left-right group (Mean = $-.28$) showing a greater improvement in response time for the left-right group after transfer than for the mirror-image group.

The effect for Trials was significant ($F(7,252)=10.024, p<.001$). A post hoc comparison using the Tukey test showed a significant difference between trials 1 and 7 and trials 1 and 8 ($p<.05$).

The interaction between Trials and Arrangement was also found to be significant ($F(7,252)=3.18, p<.005$). This interaction is shown in Figure 15. A simple effects test indicated that only the mirror-image group's performance significantly improved from trial 1 to trial 8 ($F(7,252)=11.64, p<.05$). A Tukey post hoc comparison between the Arrangement groups for each trial showed a significant difference for trials 1, 2, and 3

Table 4

ANOVA Summary Table for Corrected Data

Source	SS	df	MS	F	p
Locus	.004	1	.004	.01	.919
Arrange	31.97	1	31.97	12.60*	.001
Locus x Arrange	.044	1	.044	.02	.865
Error (between)	91.375	36	2.54		
Trials	2.077	7	.297	10.02*	.001
Locus x Trials	.12	7	.017	.59	.768
Arrange x Trials	.660	7	.094	3.18*	.003
L x A x Trials	.205	7	.029	.99	.438
Error (within)	7.461	252	.030

Figure 15. Interaction for arrangement by trials (difference data)

($p < .05$).

Emergency Response Time Data. An analysis of variance on the response time measures for emergency trials indicated a significant main effect for Locus ($F(1,36)=4.75$, $p < .05$) with the internal treatment group having a faster response time (Mean = 2.70) than the external group (Mean = 3.15). Table 5 shows these results.

The main effect for Arrangement was significant ($F(1,36)=25.72$, $p < .001$) with the mirror-image group having slower response times (Mean = 3.46) than the left-right group (Mean = 2.39). The main effect of Trials was also found to be significant ($F(2,72)=15.25$, $p < .001$). A Tukey post hoc comparison showed there to be a significant difference between trials 1 and 2 and trials 1 and 3 ($p < .05$).

A significant difference was found for the Trials by Arrangement interaction ($F(2,72)=6.90$, $p < .002$). Figure 16 shows this interaction. An F test for simple effects indicated that only the mirror-image group improved their performance ($F(2,72)=21.49$, $p < .001$) with mean values on trials ranging from 4.69 on trial 1 to 2.59 on trial 3. For each of the three trials, the Tukey test indicated a significant difference between the mirror-image group and the left-right group ($p < .01$).

Emergency Completion Time Data. The analysis of

Table 5

ANOVA Summary Table for Emergency Response Time Data

Source	SS	df	MS	F	p
Locus	18.84	1	18.84	4.75*	.034
Arrange	102.05	1	102.05	25.72*	.001
Locus x Arrange	6.49	1	6.49	1.64	.207
Error (between)	142.86	36	3.97		
Trials	34.24	2	17.12	15.25*	.001
Locus x Trials	2.20	2	1.10	.98	.383
Arrange x Trials	15.50	2	7.75	6.90*	.002
L x A x Trials	1.06	2	.53	.47	.632
Error (within)	80.87	72	1.12

Figure 16. Trials by arrangement interaction (emergency response time data)

variance performed on the emergency completion time data, shown in Table 6, indicated a significant effect for Arrangement ($F(1,36)=51.52$, $p<.001$) with the mirror-image group having a significantly slower completion time (Mean = 12.35) than the left-right group (Mean = 6.55).

The main effect for trials was found to be significant ($F(2,72)=30.87$, $p<.001$). A Tukey test indicated that there was a significant difference between all trials ($p<.01$).

The interaction between Arrangement and Trials was significant ($F(2,72)=16.08$, $p<.001$). Figure 17 shows this interaction. An F test for simple effects indicated that only the mirror-image group's reference significantly changed over trials ($F(2,72)=45.76$, $p<.001$). A Tukey comparison between the mirror-image and left-right groups within each of the completion trials showed a significant difference between groups for each trial ($p<.01$).

Error Data

An analysis of variance on the error data indicated a significant difference between the number of errors produced by the Arrangement groups ($F(1,36)=23.62$, $p<.001$) with the mirror-image group having a larger number of errors (Mean = 2.80) than the left-right group (Mean = 1.49). Table 7 shows these results. There was

Table 6

ANOVA Summary Table for Emergency Completion Time Data

Source	SS	df	MS	F	p
Locus	48.05	1	48.05	.82	.375
Arrange	3027.95	1	3027.95	51.52*	.001
Locus x Arrange	.46	1	.46	7.79	.891
Error (between)	2116.01	36	58.78		
Trials	425.21	2	212.60	30.87*	.001
Locus x Trials	15.09	2	7.54	1.10	.341
Arrange x Trials	221.44	2	110.72	16.08*	.001
L x A x Trials	8.00	2	4.00	.58	.567
Error (within)	495.88	72	6.89

Figure 17. Arrangement by trials interaction
(emergency completion time data)

Table 7

ANOVA Summary Table for Error Data

Source	SS	df	MS	F	p
Between	428.23	39			
Locus	21.54	1	21.54	3.73	ns
Arrange	136.51	1	137.51	23.62*	.001
Locus x Arrange	62.11	1	62.11	10.75*	.005
Error (between)	208.07	36	5.78		
Trials	15.15	7	2.16	1.67	ns
Locus x Trials	15.81	7	2.26	1.75	ns
Arrange x Trials	13.39	7	1.91	1.48	ns
L x A x Trials	9.39	7	1.34	1.04	ns
Error (within)	326.13	252	1.29		

also a significant effect for the Arrangement by Locus interaction ($F(1,36)=10.75$, $p<.005$). Figure 18 shows this interaction.

The observations of subjects during the blind transfer trials, when the control labels were removed, showed that each subject manipulated the controls on the panel as if the panel was still arranged as it had been in that subject's learning trials. This was consistent across all subjects in each group.

Questionnaire Data

The data for questions 4 and 5 were compiled by frequency and will be reported in terms of percentages. Table 8 shows these results. Question 6 was interpreted as being interval scale data and was analyzed using an analysis of variance. Data from Questions 1 through 3 are not presented in this section because the results dealt with subject demographics.

Question 4: The fourth question asked subjects, "When you changed sides of the table, were the controls laid out the way you expected?" It is interesting to note that the total number of yes's and no's were equal, however, there were 17 yes's in the left-right group and 17 no's in the mirror-image group. Eighty-five percent of each Arrangement group responded similarly to this question.

Question 5: The fifth question asked subjects to

Figure 18. Arrangement by locus interaction (error data)

TABLE 8

Results from Questionnaire

	LE	LI	ME	MI	Total	%
Expectation						
YES	8	9	2	1	20	50
NO	2	1	8	9	20	50
Reference:						
Body	8	9	5	6	28	53
Alpha-numeric	2	2	3	3	10	19
Screen	3	3	4	3	13	24
Experimenter	1	0	1	0	2	4

identify any reference which may have helped to locate controls on the panel. Subjects could choose more than one reference. Fifty-three percent of the responses, across all four groups, used a body reference. Twenty-four percent used a screen reference, with approximately equal numbers in each cell choosing this reference.

Question 6: Subjects were asked if they found the control panel difficult to learn. They were given a likert-type scale ranging from 1 to 6 (see Appendix C) with point 1 anchored by the words "Very Difficult" and point number 6 anchored by the words "Very Easy". An analysis of variance on these data showed no significant differences between the groups. Table 9 shows these results.

Table 9

ANOVA Summary for Questionnaire Item 6

Source	SS	df	MS	F	p
Locus	2.03	1	2.03	1.62	ns
Arrange	.63	1	.63	.50	ns
Locus x Arrange	.03	1	.03	.02	ns
Error (between)	45.11	36	1.25		

DISCUSSION

There were two primary objectives to this study. The first was to determine if the spatial arrangement of controls in two different room locations affected performance. The control arrangements were either mirror imaged or remained in the same pattern when the panel was moved to the opposite side of the room. The second objective of this study was to determine if manipulation of the point at which the subject focused their attention would affect performance by itself and through interaction with the control panel arrangement.

Although, from a training perspective, it may seem intuitively obvious that negative transfer may result from training a subject on one panel arrangement and then transferring them to another arrangement while expecting them to perform the same operations, the literature concerning mirror imaging of controls does not bear this out as conclusively as would be expected. Pigg (1954) found that, for a bilateral transfer of training paradigm, subjects both preferred a mirror imaged panel arrangement and performed better on at least the first few trials after being transferred. Since the current study was not concerned with bilateral transfer, the applicability of these results is questionable. The important point, however, is that mirror imaging of controls may be advisable in some

situations.

Schurick (1982) discussed the possibility that mirror imaging of controls would be more desirable than a left-right arrangement when the operator could directly observe the machine response to control activation. Her study did not find any difference between the mirror-image and left-right arrangements, however, the visual reference was not manipulated in this study.

The present study used a task in which the subject viewed a screen which presented written instructions for operating one of twenty controls on the panel. After the learning sequence was completed, subjects were transferred to the opposite side of the room. After transferring the panel, the arrangement either remained the same or was changed to reflect a mirror imaged arrangement of controls. The screen which presented the instructions for each trial was used to direct the subjects attention to either the center of the panel, for the internal condition, or to the left or right of the panel, for the external condition, depending on which side of the room the panel was on.

It was also the intent of this study to observe the effects of the arrangement of controls and the focus of attention on emergency situations as well as regular transfer trials. This was accomplished by training each

subject to perform a six-step emergency procedure. The subjects were given a scenario in which they were to assume the role of nuclear control room operators and, in the course of their work, an emergency situation was signaled by an orange slide in the presentation order. In order to avert a disaster, they were to perform the emergency procedure as quickly as possible. This emergency procedure was intended to determine if there would be a difference in performance between normal operation and stress situations.

Arrangement of Controls

The hypothesis that the mirror-image group would require longer response time than the left-right group was supported by the data collected during transfer.

The significant interaction for Trials by Arrangement indicate that the mirror-image group significantly improved in performance from trial one to trial eight but the left-right group did not. The two groups were significantly different for the first four trials, with the mirror-image group being slower. The two groups were equivalent on all remaining trials. For subjects who were transferred to a mirror-image configuration, performance degraded for at least the first few trials. The results of the learning data analysis, particularly the main effects of Arrangement and Locus, indicated that the groups were at equivalent

levels prior to transfer, therefore, mirror imaging of the control panel does appear to degrade performance, at least on initial performance. Of particular interest concerning this result is the observation that it is the opposite of what Pigg (1954) found in his study. He found that the mirror-image group had shorter response times for the first few trials after transfer. This suggests a difference between the use of mirror imaged panels when bilateral transfer is required and when it is not. This seems to be the only situation suggested by the results of the current study and the Pigg study in which a case for mirror imaging of control panels could be made.

The analysis for the difference data, in which the mean score for the last three learning trials for each subject was subtracted from each of the transfer trials for that subject, produced somewhat different results than the transfer data. When the level of learning for each subject was removed from each transfer trial, a significant effect for Arrangement emerged. This result showed that the mirror-image group, regardless of which Locus condition they were exposed to, performed the operations more slowly than the left-right group. All other results for the difference data replicated those for the transfer analysis.

The error data results also support the hypothesis

that mirror imaging causes a degradation in performance as compared to a left-right configuration. The mirror-image group made significantly more errors than the left-right group. These errors included both movements to the wrong control within the side of the panel on which the correct control was located, and movements to the side of the panel in which the correct control was not located. The Locus by Arrangement interaction showed that the mirror-image group produced a significantly larger number of errors in the internal condition than in the external condition. The left-right group remained fairly constant for both levels of Locus. This result supports the hypothesis that the mirror-image group would perform better with an external reference, although the reference did not seem to affect the left-right group. It was interesting to note that the errors committed in this study were composed only of incorrect control movements. Subjects would make movements toward an incorrect control but would not actually activate incorrect controls. The response time measure, therefore, was increased to reflect this movement and may have been a more sensitive measure of performance than the error data.

Locus of Attention

The hypothesis that manipulation of the point at which the subject focused attention would help the

subject to spatially locate the specific controls on the panel was not supported by these data for normal operating conditions, except for that mentioned in the previous discussion on error data. For emergency conditions, the main effect for Locus was significant, with the internal group having faster response times than external group. No significant differences were found for time performance between the internal and external groups for the transfer trials. This result may indicate that, in fact, there is no effect of locus of attention or it may indicate that the subject does not develop a reference for spatial location of controls based upon the location at which the subject focuses attention. There is also the possibility, which will be discussed later, that the subject may not have learned the panel to an automatic level of behavior.

Emergency Data

During normal operating sequences in the control room time is not necessarily a critical factor, however, during an emergency situation time may become critical. The analysis of the emergency data, both the response times and completion times, indicated that when the operator was transferred to the mirror image of the learning panel, the operator requires more processing time to select the correct control. This is true for all of the data collected; the transfer trials, and the

emergency trials, however, the amount of time required was not statistically significant.

In some cases subjects in this study performed the required tasks on the mirror imaged panel effectively, however, commented that the mirror imaged panel required a greater amount of concentration in order to perform the tasks accurately. This increased concentration resulted in complaints of neck strain and fatigue. Comments by subjects included such statements as:

- o "The first side was very easy to learn, however, operating the mirror image was much more difficult. I never felt as though I had learned it."
- o "Mirror imaging was confusing at first."
- o "Needed more concentration to operate the mirror imaged side."

Some of the subjects performed the transfer trials well on the mirror imaged side, however, when an emergency slide was presented, they had difficulty in completing the sequence. The first emergency sequence was a problem for many of the subjects in the mirror-image group. They either took an extremely long time to complete the task or they could not complete the sequence at all. None of the subjects in the left-right group were unable to complete the first emergency trial while three of the mirror-image group could not complete it.

As indicated by the significant effect for trials, the subject's response and completion times improved from the first to the second and from the second to the third emergency trials. Although the performance of the mirror-image group did improve from the first emergency trial to the final emergency trial, they never reached the performance level of the left-right group on these emergency trials.

A major difficulty with this type of research, as discussed by Schurick (1982), lies in being assured that the subject has actually learned the system, in this case the control panel, to an automatic level of behavior. In application-oriented mirror imaging research, such as the current study and the Schurick (1982) study, it seems to be important to train the subject to an automatic level of behavior during the learning phase so that any negative transfer effects resulting from the mirror imaging can be maximized. The results of the learning trials analysis shows a significant main effect for trials. This effect suggests that the subjects did not learn the panel to an asymptotic level of behavior prior to transferring them. The lack of an Arrangement or an Arrangement by Trials interaction, however, indicated that the groups were at comparable levels of performance during learning.

The difficulty in this research seems to lie in

trying to determine when the subjects have learned the apparatus to an automatic level of behavior. Pilot work for this study indicated that subjects seemed to know the panel well after the first 50 learning trials, as determined by the reduced variability in successive response times per trial. At this point the subjects learned the emergency sequence, which further helped them to reinforce the location of controls. As suggested by the learning data, all groups were performing at approximately the same level prior to transfer. Observations during the blind trials also seem to support the contention that the subjects had learned the panel to an automatic level of behavior. Performance was not found to visibly degrade during the blind trials, suggesting that the subjects did have an adequate knowledge of the location of controls.

Interestingly, according to the results of survey question number six, there were no differences between groups in the perceived difficulty in learning the locations of controls on the panel. The wording in the question, "Did you find the control board difficult to learn ?", however, did not require the subject to make a comparison between the learning and the transfer panel. Subjects were required only to report on the difficulty of the learning panel. Comments made on question four, "When you changed sides of the table, were the controls

laid out the way you expected?", indicated that subjects perceived difficulty with the mirror imaged panels. The following are examples of these comments:

- o "I expected them to be reversed."
- o "I would have expected the A and B side to say at my right."
- o "It was difficult for me to adjust."
- o "I was still expecting the lowest numbers on the left, not the right."

The response to this question resulted in 85 percent of the mirror-image group saying "no" and 15 percent of the left-right group saying "no" to this question. This result, together with the observations on the blind trials, in which the labels were removed and subjects were required to perform the operations from memory, suggested that subjects did expect the control panel to be laid out in a left-right arrangement. During the blind trials, after being transferred, virtually all of the subjects performed as if they expected the transfer panel to be laid out in a left-right configuration; identical to the way it had been during training.

Generalizability

The question of whether the results of the current study can generalize to an actual application in a control room or on equipment control panels may be

raised. In a typical control room situation the operator would go through extensive training in a simulated control room. This training would require learning the locations of hundreds of controls and learning extremely complex procedures. Most control panels in control rooms are far more complex than the one used in this study and each control room may contain hundreds of these panels. For this reason, there may not be as large a disparity between training a subject to perform simple operations on one relatively simple control panel for a short period of time and training an operator to perform complicated, multiple-step procedures in a complex control room.

Conclusions

It appears that the use of mirror imaged controls in the design of control panels does degrade performance, especially during the first few trials, when compared to a left-right control panel arrangement. Subjects take more time to complete operations and make more errors in the process of completing these operations. Performance in emergency situations is particularly degraded on the mirror-image panels, especially in the initial trials.

Performance on the mirror imaged panels seems to require greater concentration than for the left-right panels, resulting in reports of strain and fatigue.

In a high stress environment, as would be found in a nuclear control room, emergency situations occur fairly frequently during day to day operations. Since the results of this study indicate that performance is degraded during emergency sequences, it is not recommended that mirror imaged control panels be used in high stress environments. Since there are no urgent engineering reasons for this practice and since performance does seem to be affected adversely, other design practices should be followed.

Future Research

In terms of process control room design, the use of actual operators in an experimental paradigm similar to the one used in the present experiment may be advisable. This would probably result in higher levels of automatic behavior on the part of the operators due to their extensive training, and would, therefore, magnify any differences between panel designs. The use of this homogeneous population may reduce the variability between and within subjects, thus would also magnify any differences found between the mirror-image and the left-right panels. The use of this population would more readily generalize to control room applications, with the results possibly being more acceptable to design engineers.

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Appendix A. Contents of Commands Slides

Slide Commands

Temperature A-1 to 1

Temperature A-1 to 2

Temperature A-1 to 3

Temperature A-1 to 4

Temperature A-1 to 5

Temperature A-1 to 6

Temperature A-2 to 1

Temperature A-2 to 2

Temperature A-2 to 3

Temperature A-2 to 4

Temperature A-2 to 5

Temperature A-2 to 6

Temperature A-3 to 1

Temperature A-3 to 2

Temperature A-3 to 3

Temperature A-3 to 4

Temperature A-3 to 5

Temperature A-3 to 6

Temperature B-1 to 1

Temperature B-1 to 2

Temperature B-1 to 3

Temperature B-1 to 4

Temperature B-1 to 5

Temperature B-1 to 6

Temperature B-2 to 1

Temperature B-2 to 2

Temperature B-2 to 3

Temperature B-2 to 4

Temperature B-2 to 5

Temperature B-2 to 6

Temperature B-3 to 1

Temperature B-3 to 2

Temperature B-3 to 3

Temperature B-3 to 4

Temperature B-3 to 5

Temperature B-3 to 6

Pressure C-1 to 1

Pressure C-1 to 2

Pressure C-1 to 3

Pressure C-1 to 4

Pressure C-1 to 5

Pressure C-1 to 6

Pressure C-2 to 1

Pressure C-2 to 2

Pressure C-2 to 3

Pressure C-2 to 4

Pressure C-2 to 5

Pressure C-2 to 6

Pressure C-3 to 1

Pressure C-3 to 2

Pressure C-3 to 3

Pressure C-3 to 4

Pressure C-3 to 5

Pressure C-3 to 6

Pressure D-1 to 1

Pressure D-1 to 2

Pressure D-1 to 3

Pressure D-1 to 4

Pressure D-1 to 5

Pressure D-1 to 6

Pressure D-2 to 1

Pressure D-2 to 2

Pressure D-2 to 3

Pressure D-2 to 4

Pressure D-2 to 5

Pressure D-2 to 6

Pressure D-3 to 1

Pressure D-3 to 2

Pressure D-3 to 3

Pressure D-3 to 4

Pressure D-3 to 5

Pressure D-3 to 6

Reset 1 PUSH

Reset 2 PUSH

Reset 3 PUSH

Reset 4 PUSH

Pump 1 ON

Pump 2 ON

Pump 3 ON

Pump 4 ON

Appendix B. Standardized Instructions

Instructions

In this study we will simulate the training procedure of a nuclear power plant control room operator. You will be asked to learn the locations of 20 controls on the panel in front of you. You will be given single instructions on the projector screen and will be asked to follow these instructions as quickly and as accurately as possible. Your time to respond to each slide will be recorded, however, it is equally important that you learn the correct location of controls, minimizing errors.

After you have completed the training procedure, you will be given a 5 minute break. When you return you will be tested on the panel.

To begin: Place your hands on the designated place.

When I say "ready--go" a slide will be presented.

Please perform the indicated operation as accurately and quickly as possible.

Return your hands to the designated place to prepare for the next slide.

This procedure will be repeated until all slides have been viewed.

The labels will be removed for the last trials.

Emergency Procedure

In this procedure you are asked to assume that you are operating a control panel in an actual nuclear power plant. When an orange slide is viewed in the projector you will do the following to avoid a nuclear disaster:

1. Pressure A-1 to 5
2. Temperature C-2 to 6
3. Reset-3 Push
4. Pump-1 ON
5. Reset-2 Push
6. Temperature D-3 to 6

Transfer Trials

You will now go through the same procedure as before. The labels will be removed for the first trials. Please work as quickly and accurately as possible.

Left-right

You will continue the procedure as before. When you view the orange slide, please assume that this operation is critical in averting a disaster. You will continue the procedure until all slides have been viewed.

Mirror-image

You will notice that the controls have been changed. This panel is a mirror image of the first panel. This means that the controls which were on the right are now on the left and the controls which were on the left are now on the right.

Appendix C. Questionnaire

QUESTIONNAIRE

1. Your sex is M F
2. What is your major? _____
3. Which is your dominant hand? Left Right
4. When you changed sides of the table, were the controls laid out the way you expected? Yes No

Explain:

5. Did you use any of the following to help you locate the controls on the board?

_____Your body (left side, right side)

_____The screen

_____The experimenter's position

_____The door to the room

_____Other, explain:

6. Did you find the control board difficult to learn?

1	2	3	4	5	6
Very					Very
Difficult					Easy