The Worringham and Beringer Visual Field Principle When Responding with the Right or Left Hand

Ken S.S. Man, Errol Hoffmann, Alan H.S. Chan and Liszt C.M. Chan

***Abstract*—There are some conditions where the orientation of an operator is such that the display and its related control are displaced 180 degrees from each other, allowing operation of the control by either hand. The Worringham and Beringer Visual Field principle is a useful design principle that determines the way in which the operator will respond with a control, independent of the position of the control relative to the operator and the display. One condition that has not been tested is when the response may be made using either the left or the right hand. In the following experiment, a design was chosen where the display was located 180 degrees away from the control, allowing the operator to rotate the body so that control may be made using the right or left hand. The results showed that the Visual Field principle is applicable to both horizontal and vertical displays when there is 180 degrees between the locations of display and control, irrespective of which hand is used, when considering a ±10% interval in mean stereotype strength as indicating equivalence of stereotype strength. The practical implication of this finding was discussed.**

***Index Terms* – compatibility, displays and controls, stereotype strength, visual field principle**

I. Introduction

IT is of importance to consider the common expectancy of operation or population stereotype when designing the relationship between controls and displays [1]. For instance, the expectancy of increasing the volume of a radio is to rotate a knob clockwise. An opposite design to this expectancy leads to more errors when changing the volume. Similarly, for a horizontal display with a knob situated below the display, the expectancy of moving the indicator to the left is to rotate the knob anticlockwise. This expectancy is referred to as a control-display stereotype, which is high within many populations [2,3]. Stereotype strength refers to the percentage, or proportion, of majority responses in a given direction [1]. Stereotype strength is robust over long time periods and does not change with extended practice [4]. In this study, stereotype strength refers to the proportion of responses made by participants for a given display-control arrangement that are in the requested direction: for example, the proportion of clockwise rotations of a control knob when moving a display indicator to the right is requested.

In a wide range of work situations, such as aircraft, various complex arrays of displays and controls exist, where workers may be required to make a control action when viewing a display that is not in the same plane as the control [5]. The space limitations of work environment may be one of the reasons for these complex arrays of controls and displays. A very powerful principle was developed by Worringham and Beringer [6] to determine the compatibility between control and display movements when the operator's control is not in the same plane as the display. Given its importance to ergonomics, visual field (VF) compatibility has been called the "Worringham and Beringer principle" in recent literature. Worringham and Beringer developed the principle in experiments where translational controls were located on a vertical surface with displays that were mounted vertically and moved in the horizontal direction. According to the Worringham and Beringer principle, when the motion of the relevant limb segment is in the same direction as that of the display, as seen in the visual field, this is a VF compatible situation. In other words, if a display is in the same frontal plane as a control and moving the display to the left requests the operator seated at the display to make a horizontal control movement to the left, then, when the display is located in another the same horizontal location relative to the operator and with the same display movement, the same relationship between display and control movements exists, irrespective of the display location. The VF principle is applicable not only for translational controls with displays moving horizontally, but also for rotational controls with displays moving horizontally and vertically [7].

However, one condition that has not been tested is when the response may be made as conveniently using either the left or right hand. In the following experiment, we have chosen a design where the display was located 180 degrees away from the control, allowing the operator to rotate the body so that control may be made using either the right or left hand. The specific hypothesis to be tested in this study is that the stereotype strength for a given display location is independent of the hand used to make control responses. This will be tested by means of a test of equivalency of the stereotype strengths for four different types of control using the right or left hand for making a response.

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II. Method

A. Displays and Controls

A 43 cm flat screen monitor was used, on which two displays were shown. Fig. 1 depicts these two displays that were simple line drawings of a display with a neutral indicator at the mid position for the linear displays. Six different control locations used in the experiment are shown in Fig. 2. These controls were used in studies on display-control stereotype strength [7,8]. Three translational controls including Up Translation (UT), Forward Translation (FT) and Right Translation (RT), and three rotational controls including Forward Rotation (FR) Clockwise Horizontal Rotation (CHR) and Clockwise Vertical Rotation (CVR) were tested.

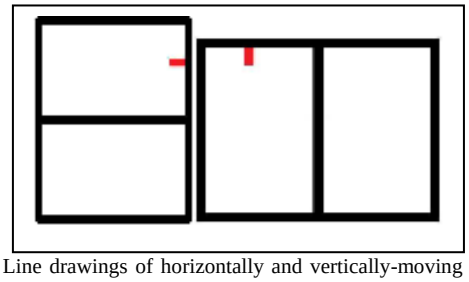

Fig. 1. Line drawings of horizontally and vertically-moving displays. Red lines indicate an experimenter-requested direction of display movement.

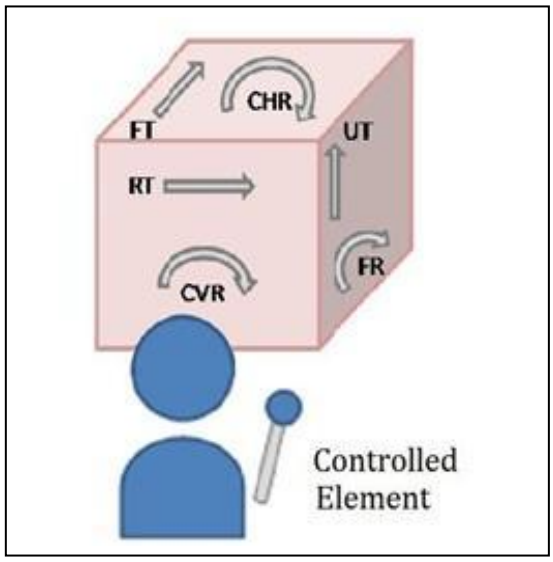

Fig. 2. The six different translational and rotational controls used in the experiment (modified from Wickens et al. [10]).

B. Experimental Arrangements of Display and Control

Fig. 3 shows the locations of displays and controls relative to the operator, including combinations of Right (R), Left (L), Centre Front (CF), and Back (B) of control and display locations. There was a separation of 180 degrees between the locations of display and control. Thus, four different arrangements of control/display were used in this experiment (see Fig. 3). These combinations were used to test whether the VF principle is applicable to all of these four combinations when responding with the right or left hand, despite of the fact that some of them may not be practically important.

In the four experimental conditions of display and control locations relative to the operator, small circle is the control and rectangle is the display. Location code is that first letter is display location (L, CF, R, B); second is control location (L, CF, R, B). For each of these display/control locations, the six control types of Fig. 2 were tested. Participants moved the control with the right or left hands and had to rotate the trunk in the appropriate direction for left and right-hand control, giving comfortable use of the control while observing the display.

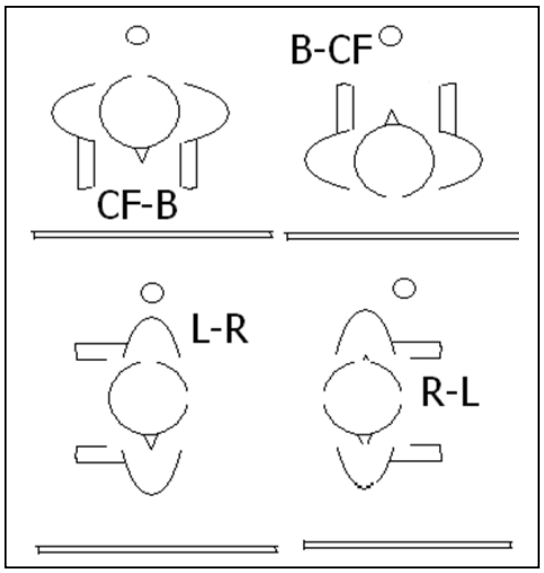

Fig. 3. Experimental conditions of location of display and control relative to the operator. Rectangle is display; circle is control.

C. Participants

This experiment involved forty undergraduate volunteer students of the City University of Hong Kong who were aged between 20 and 24 years and selected to be all right-handed for the purposes of the experiment. The numbers of male participants and females participants were 21 and 19 respectively.

D. Procedure

A Latin square design for the control and the display locations was used to determine the order in which the four experimental conditions were performed. The randomization of the order of the control type within each of the display and control locations was made for each participant. The form of displays and controls that would be presented was shown to participants, along with the requests that would be made in terms of required direction of display movement (moving the display to the up/down/right/left). The task of participants was to move the control so that the display moved in the requested direction. This direction of control movement was recorded as appropriate to the control type (anticlockwise (ACW), clockwise (CW) rotation for the rotary controls or forward/rearward/right/left movement for the translational controls). The indicator always moved in the requested direction, independent of the control movement. In order to make participants understand the procedure correctly, several randomly-chosen cases were provided to them.

E. Data Analysis

An analysis of variance (ANOVA) was used to determine the effects of the experimental variables (control/display location, control type and their interactions on the strength of the stereotype). Then, Tukey HSD post-hoc test for the means of stereotype strength was conducted to determine where the significant differences lay between the right and left hand. If the VF principle is valid for right and left hands

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of the operator, it would be expected that there would be no difference in stereotype strength for each of the display locations with the right or left hand. This was tested through post-hoc tests on the hand used x display location interaction. Finally, for the determination of whether the stereotype strengths were equivalent in magnitude, the Dunnett and Gent test [9] was conducted with two different levels of 'inconsequential' difference to see if the confidence interval of the difference in mean values of the stereotype strength lay within this inconsequential difference (the magnitudes are effectively equivalent).

III. Results

A. Horizontal Display

The four cases of control and display were L-R, R-L, CF-B and B-CF. Stereotype strengths are shown in Fig. 4 and Fig. 5 for the effects of hand used on different control types and control locations respectively. ANOVA results showed no significant main effect of whether the left or right hand was used in making the control response [$F(1,211) = .02$, $p = .89$] nor was there a significant interaction between use of the left or right hand and the display location [$F(3,15) = .72$, $p = .56$]. There were significant effects of display location [$F(3,15) = 12.77$, $p < .001$]; control type [$F(5,211) = 28.33$, $p < .001$] and control type x display location [$F(15,15) = 13.51$, $p < .001$]. Tukey HSD post-hoc tests indicated only one significant difference between the left and right hands. This occurred for the UT control, where the left hand had a higher stereotype strength than the right hand.

The data showed that there was no significant interaction between the hand used in responding and the display location. A second important criterion is that, for a given display location, the magnitudes of the stereotype strengths are equivalent for the right and left hands. The method of Dunnett and Gent [9] was used to test this equivalence. In this method, the confidence interval of the difference in mean responses was determined to see whether it lies within an amount that is treated as inconsequential. Using this method, and assuming a ±10% interval as indicating equivalence of stereotype strength, each of the display locations showed equivalence of stereotype strength with the right or left hand. The situation was the same even if a tighter limit of ±5% was assumed as being inconsequential. Thus, with horizontally-moving displays, there is effectively no difference in whether the right or left hand is used in making the control response. There were thus no deviations from the VF principle when using the right or left hands for response. In other words, there was full equivalence of the two hands in their stereotype strength for horizontal display.

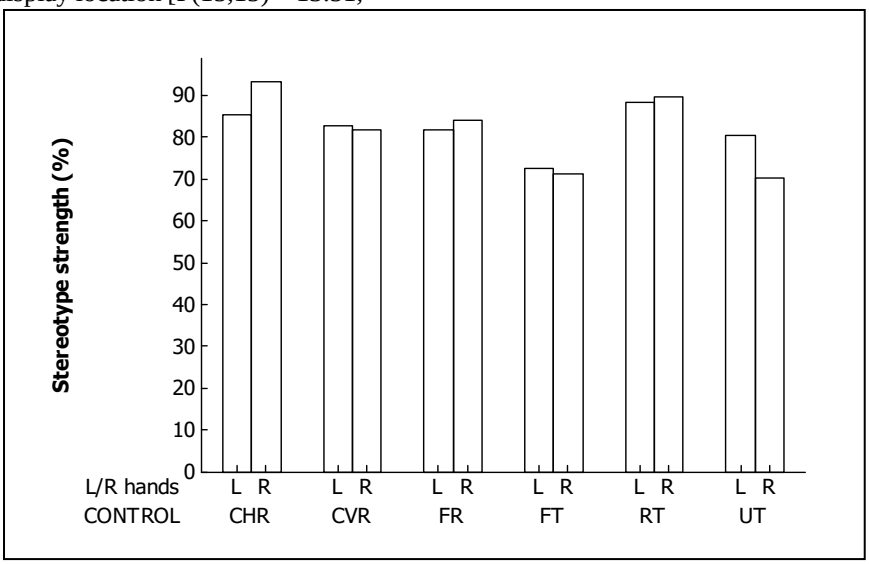

Fig. 4. Horizontal displays: Effect of hand used for control responses on stereotype strength for different control types.

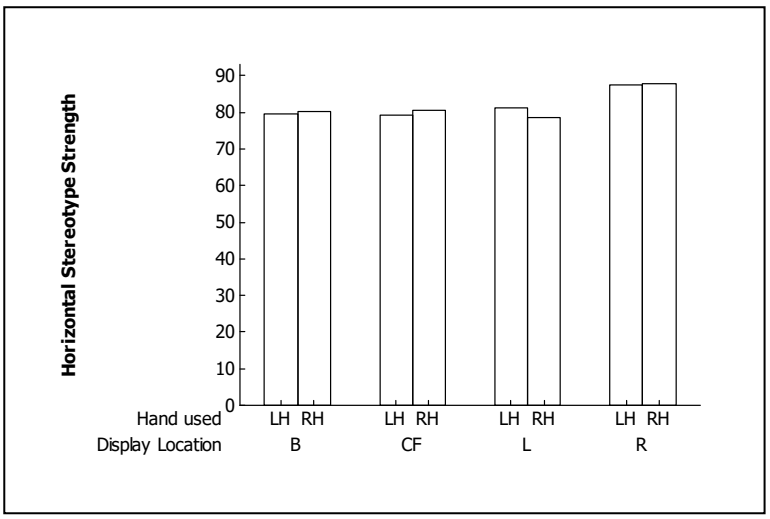

Fig. 5. Horizontal displays: Effect of hand used for control responses on stereotype strength for different display locations.

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B. Vertical Display

With vertically-moving displays (Up/Down), the results of ANOVA showed effects closely identical to those of the horizontally-moving displays. There was no significant main effect of whether the left or right hand was used in making the control response [F(1,211) = .3.83, p = .07] nor was there a significant interaction between the hand used for responding and display location [F (3,15) = 1.47, p = 0.262]. There were significant effects of display location [F3,15) = 5.24, p < .05]; control type [F(5,211) = 25.67, p < .001] and control type x display location [F(15,15) = 7.78, p < .001]. In this case, Tukey post-hoc tests showed no significant difference between left and right hands for any display location or control type (Fig. 6 and Fig. 7). Analyzing the hand-used x display location interaction, the results of Dunnett and Gent test [9] indicated full equivalency of stereotype strength with an 'inconsequential' difference of ±10% in mean stereotype strength for all display locations with the left or right hand. However, with the tighter limit of ±5%, there was no equivalency of stereotype strengths because the confidence intervals exceeded in magnitude the 'non-consequential' differences in mean values of stereotype strengths. Thus, hand used in making the control response may be a significant factor when the response is made to vertical displays.

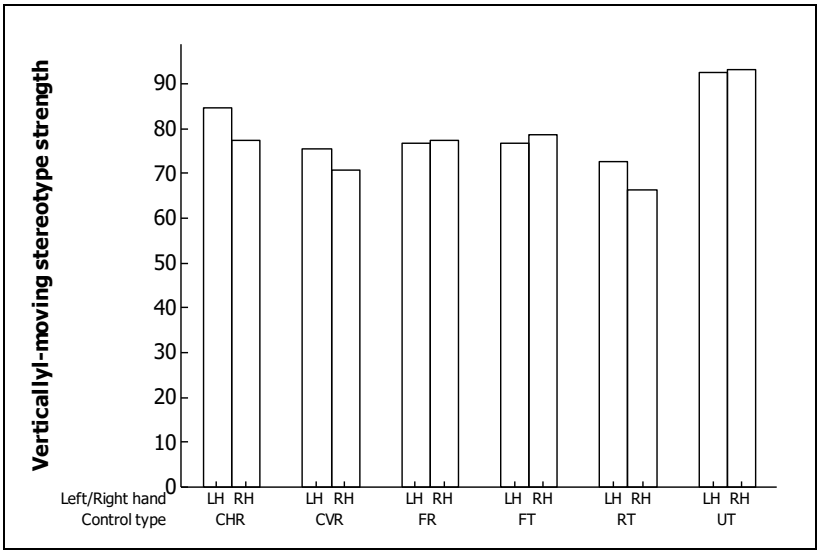

Fig. 6. Vertical displays: Effect of hand used for control responses on stereotype strength for different control types.

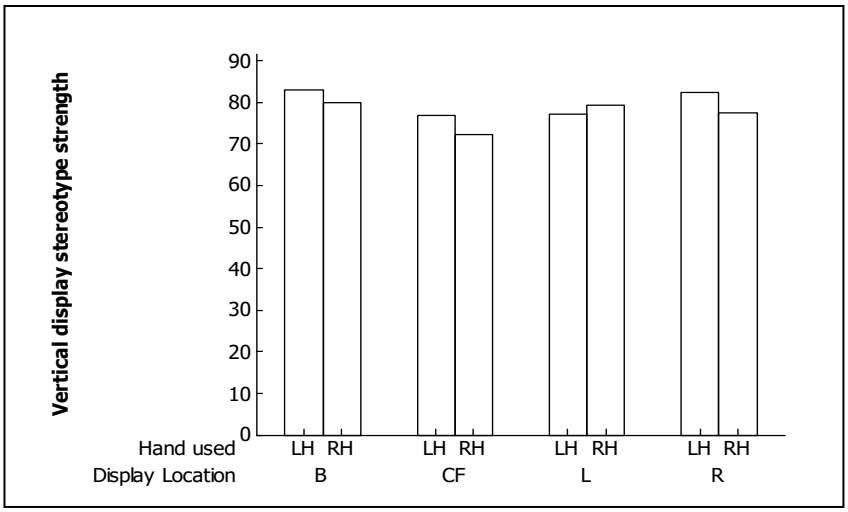

Fig. 7. Vertical displays: Effect of hand used for control responses on stereotype strength for different display locations.

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IV. Discussion

When designing complex arrangements of displays and controls, the Visual Field principle of Worringham and Beringer [6] is one of the most powerful principles. These complex arrangements include, but are not limited to, aircraft, power stations, and space ships. Prior to this study, the Visual Field principle of Worringham and Beringer [6] has been tested in many circumstances [7,8]. However, no studies tested the Worringham and Beringer Visual Field principle [6] when responding with the right or left hand.

In the test for the validity of the Worringham and Beringer Visual Field principle, the equivalency of the stereotype strengths for each of the four display locations with the use of left or right hand was determined. For horizontal displays, using the Dunnett and Gent [9] test and assuming a ±10% interval in mean stereotype strength as indicating equivalence of stereotype strength, each of the display locations showed equivalence of stereotype strength with the right or left hand. Even with the assumption of a tighter limit of ±5%, the equivalence still held as being inconsequential. In other words, with horizontally-moving displays, there is effectively no difference in using the right and left hand when making the control response. The validity of the Worringham and Beringer Visual Field principle for horizontal displays was fully supported irrespective of whether the right or left hand was used to make the control response. With regard to vertical displays, the results of the test of Dunnett and Gent [9] with the assumption of a ±10% interval in mean stereotype strength as indicating equivalence of stereotype strengths showed full equivalency of stereotype strengths for all display locations with use of the left or right hand. However, with a tighter limit of ±5%, there was no equivalency of stereotype strengths as the confidence intervals exceeded in magnitude the 'non-consequential' differences in mean values of stereotype strengths. Thus, hand used in making the response may be a significant factor when the response is made to vertical displays.

Given the results of this study, it was clear that the Worringham and Beringer Visual Field principle [6] can be applied to both horizontal and vertical displays when there was a separation of 180 degrees between the locations of display and control irrespective of which hand was used when considering a ±10% interval in mean stereotype strength as indicating equivalence of stereotype strength. The practical application of the results is that when designing a complex display/control arrangement where the space of work environment is limited and there are 180 degrees between the display and control locations, using either right or left hand to make an appropriate control response can lead to equivalent stereotype strengths for different display locations. Therefore, a "convenient" hand that depends on the location of control, should be used under such complex display/control arrangement. More specifically, for example, when the control is located on the left of the operator, the left hand is most convenient to be used to make a control response under the abovementioned display/control arrangement.

V. Conclusion

In summary, the Visual Field principle of Worringham and Beringer [6] is applicable to both horizontal and vertical displays when there is a separation of 180 degrees between the locations of display and control irrespective of which hand is used for response, when considering a ±10% interval in mean stereotype strength as indicating equivalence of stereotype strength. The stereotype strength for each of various display locations is relatively constant, independent of the hand used. The practical implication of this finding is that the designer can select a "convenient" hand for an operator to make the control response under a complex display/control arrangement where the workspace is limited and there is a large angle between the display and control locations.

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