Computer Simulated Tests for Lever Controls with Circular Displays

W.H. Chan and Alan H.S. Chan

Abstract — **Using computer simulated tests, this study examined direction-of-motion stereotypes and response times for different configurations of lever controls and circular displays. Quantitative measures of the strength and reversibility of stereotypes were used to analyze the effects of pointer position, direction of turn instruction, and control plane on movement compatibility. The results showed that strong and significantly reversible stereotypes were obtained for horizontal and vertical levers, at the 12 and 9 o'clock pointer positions, respectively. Response times were generally longer when there were no clear movement stereotypes. In the analysis of contributions of component principles to overall stereotypes, the results were explained in terms of a number of common control operating principles. Based on the experimental findings, recommendations for check reading or resetting purposes are that the pointer should be placed at 12 and 9 o'clock positions for the horizontal and vertical levers, respectively. Both the levers and the display should be positioned in the frontal plane. Due to weak response preferences and low reversibility, vertical and horizontal levers were found not suitable for use with other control/display configurations tested here. This study provided useful design guidance for improving the design of control panels used in person-machine interfaces.**

Index Terms— **movement compatibility; circular display, lever control; stereotype, reversibility**

I. INTRODUCTION

The relationship between a control movement and its effect most expected by a population is known as a direction-of-motion stereotype, and such a relationship is said to be compatible. Stereotypes for displays and control movements have been studied for more than fifty years. Nevertheless, apart from the studies of Warrick and Grether [1] on pointers and check reading, and Chan *et al.* [2] on circular displays with thumbwheels, there seems to be very little work on movement compatibility for circular indicators with linear controls. In order to demonstrate the existence of major response preferences or movement stereotypes, Chi-square test of statistical significance between the proportions of different responses is commonly used [3]-[4]. The strength of a stereotype has been measured in terms of the majority proportion of responses (≥ 50%) for a test condition; a value of 50% indicates no choice preference while a value of 100% indicates a perfect stereotype. Other than stereotype strength, the reversibility of stereotype forms another important measure for evaluating interfaces of a human machine system. The term 'reversibility', describes the situation where, for example, a population that turns a rotary knob clockwise for moving a circular display pointer clockwise (CC responses) will turn the knob anticlockwise for moving the pointer anticlockwise (AA responses). Stereotypes are found not always reversible, and an index of reversibility (IR) has been calculated from the sum of the product of the proportions of AA and CC responses, and the product of the proportions of AC (anticlockwise response for clockwise instruction) and CA (clockwise response for anticlockwise instruction) responses [5]. The index may range from zero for absolute non-reversibility to one for perfect reversibility where the preferred response for clockwise pointer movement is opposite to the response for anticlockwise pointer movement.

The present study examined direction-of-movement stereotypes for circular displays and three types of lever controls, viz. horizontal lever, vertical lever, and four-way lever. Unlike many previous studies that have relied solely on paper-and-pencil tests, the tests were conducted with a personal computer and a control box for presenting stimulus materials and collecting responses, respectively. In each stimulus display, a pointer was set at one of the four common cardinal positions (12, 3, 6, and 9 o'clock positions). To determine the contributions of component principles for movement stereotypes, if any, found in this study, the model building and analysis approach proposed by Hoffmann [4] was adopted.

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II. METHODS

A. Experimental Design

The three lever tests were performed in random order. A circular display was shown on the computer screen which was in the frontal plane and the lever control was installed in one of the four planes tested (Fig. 1 and Fig. 2). The subject was given a clockwise or anticlockwise instruction for direction of turn of a pointer which may be at the 12, 3, 6, or 9 o'clock position and then had to use the control box with the up/down/left/right arrow keys for indicating their choices of up/down/left/right movement respectively for moving the pointer to the destination mark. The four control planes, four cardinal pointer positions, and two instructions of turn gave 32 conditions for each type of lever testing. The order of testing of the 32 conditions was randomized and the subjects paced and initiated the presentations. The percentages of responses for left and right, and up and down lever movements were recorded for each control/display configuration. The time between showing the movement instruction and lever manipulation by the subject was recorded as the response time.

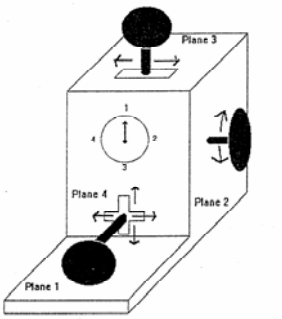


Fig. 1 A schematic diagram showing the three types of levers, four pointer positions, and four control planes tested in the study.

Fig. 2 The physical set up of the computer simulated lever test with a computer screen display and a control box.

B. Subjects

Forty Hong Kong Chinese students (32 males and 8 females) of the City University of Hong Kong with ages ranging from 20 to 26 years took part in the three types of lever testing. All of them were right-handed and manipulated the controls with their right hands.

III. EXPERIMENT 1: HORIZONTAL LEVER

A. Response Preference

The frequency and percentage of responses for different testing conditions are shown in Table 1. Student's t test showed that there was no significant difference between the proportions of left responses (48.0%) recorded and the chance probability of 50% from all subjects for all testing conditions. Chi-square tests on the number of left responses corresponding to the instruction of turn direction showed that while the plane (*P*) effect was non significant, the cardinal position (*C*) ($p < 0.001$) and instruction of turn (*I*) effects were significant ($p < 0.001$). The interactions of *P x C*, *C x I*, and *P x C x I* were also significant (p's < 0.001) (Table 2), indicating that the cardinal position (*C*) effect varied across different planes and the turn (*I*) effect varied across different cardinal position (*C*).

B. Response Time

Average response times for all subjects for each test conditions ranged from 162 to 260 ms (mean 203 ms, standard deviation 26ms). Regression analysis for the preferred (majority) responses (p) for instructions of turn showed that the higher the preferred response proportion, the shorter the mean response time (Fig. 3).

Response time (ms) = 303 – 1.21 * p ($r^2 = 0.511$, n = 32, $p < 0.001$)

It has been hypothesized that this type of compatibility effect is due to the need of less information recoding for configurations of stronger compatibility, which in turns results in faster learning and reduced mental workload [6].

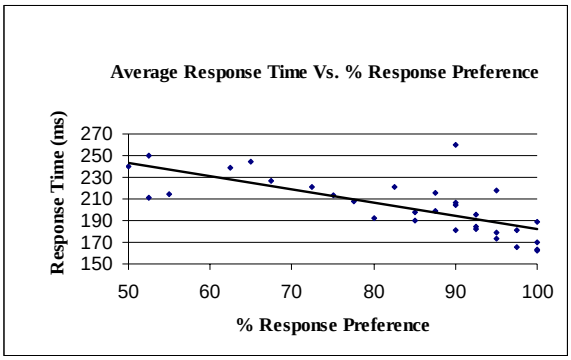
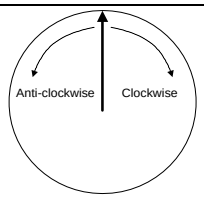
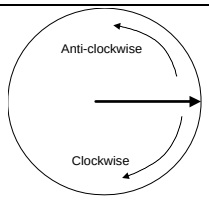
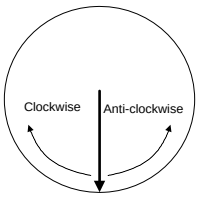
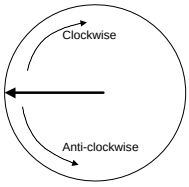


Fig. 3 Average response time vs. % response preference.

Table 1 Analysis of responses made for different pointer positions, instructions, and planes in Simulated Test 1 (Horizontal Lever)

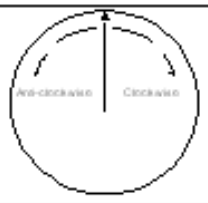
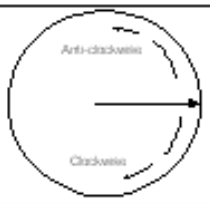
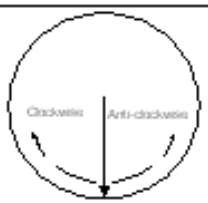
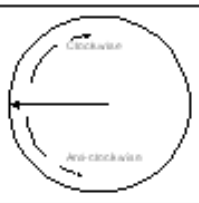
			 Pointer Position 1		 Pointer Position 2		 Pointer Position 3		 Pointer Position 4					
			Instruction														
	Plane	Response	Clockwise		Anticlockwise		Clockwise		Anticlockwise		Clockwise		Anticlockwise		Clockwise		Anticlockwise	
			N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
	1	Left	0[a]	0.0	39	97.5	20	50.0	36	90.0	34	85.0	4[a]	10.0	3[a]	7.5	13	32.5
		Right	40	100	1[a]	2.5	20	50.0	4[a]	10.0	6[b]	15.0	36	90.0	37	92.5	27	67.5
	2	Left	3[a]	7.5	39	97.5	21	52.5	37	92.5	31	22.5	8[c]	20.0	2[a]	5	10[c]	25.0
		Right	37	92.5	1[a]	2.5	19	47.5	3[a]	7.5	9[d]	77.5	32	80.0	38	95	30	75.0
	3	Left	0[a]	0.0	38	95.0	22	55.0	40	100	35	87.5	11[c]	27.5	4[a]	10	14	35.0
		Right	40	100	2[a]	5.0	18	45.0	0[a]	0.0	5[a]	12.5	29	72.5	36	90	26	65.0
	4	Left	0[a]	0.0	38	95.0	19	47.5	35	87.5	33	82.5	4[a]	10.0	6[b]	15	15	37.5
		Right	40	100	2[a]	5.0	21	52.5	5[a]	12.5	7[b]	17.5	36	90.0	34	85	25	62.5
	Total	Left	3	1.87	154	96.25	82	51.25	148	92.5	133	83.13	27	16.87	15	9.37	52	32.5
		Right	157	98.13	6	3.75	78	48.75	12	7.5	27	16.87	133	83.13	145	90.63	108	67.5

[a] significant at the 0.001 level.
[b] significant at the 0.005 level.
[c] significant at the 0.01 level.
[d] significant at the 0.025 level.
[e] significant at the 0.05 level.

Table 2 χ^2 analysis across the number of left responses in the requested directions in Simulated Test 1 (Horizontal Lever)

Component	d.f.	χ^2	Significance
P	3	1.99	
C	3	80.41	< 0.001
I	1	35.28	< 0.001
PC	9	89.63	< 0.001
PI	3	1.05	
CI	3	324.12	< 0.001
PCI	9	337.90	< 0.001
Total	31	870.38	< 0.001

Table 3 The conformance conditions of the clockwise-right (CR), anticlockwise-left (AL), right-clockwise (RC), and left-anticlockwise (LA) principles at the four pointer positions of a circular display

 Pointer position 1			 Pointer position 2			 Pointer position 3			 Pointer position 4		
A. Clockwise Instruction											
CR		+1	CR		-1	CR		-1	CR		+1
RC		+1	RC		+1	RC		-1	RC		-1
B. Anticlockwise Instruction											
AL		+1	AL		+1	AL		-1	AL		-1
LA		+1	LA		-1	LA		-1	LA		-1

C. Discussion

1. Stereotype Reversibility

An index of reversibility (IR) may be calculated from the sum of the product of the proportion of right-clockwise (RC) and left-anticlockwise (LA) responses, and the proportion of the left-clockwise (LC) and right-anticlockwise (RA) responses as follows:

$$IR = p(RC) \times p(LA) + p(LC) \times p(RA)$$

For the 12 o'clock (C_1) and 6 o'clock (C_3) pointer positions, the IRs were 0.945 and 0.719, respectively, demonstrating that the reversibility of stereotypes was strong for the two vertical pointers. Strong LA preference was found for pointers at 3 o'clock (C_2) and strong RC preference for pointers at 9 o'clock (C_4), both were parallel to the lever movement directions. However, the IRs for the horizontal pointer positions were 0.489 and 0.358, respectively, indicating the non-reversibility of stereotypes.

2. Contribution of Component Principles

In exploring the control-display relationships, one plausible hypothesis rests on the possibility that operators may perceive the rotary motion of a pointer in translatory terms [2]. The contribution of the clockwise-right (CR) and anticlockwise-left (AL) principles to the overall strength of stereotype at a pointer position should be considered along with the dominant right-clockwise (RC) and left-anticlockwise (LA) stereotypes observed. Table 3 illustrates conformance of the CR, RC, AL, and LA principles for the four pointer positions.

In analyzing the contribution of component principles towards direction of turn stereotypes here, the proportion, for example, of right response was derived from the linear sum of the strengths of the clockwise-right (CR) and the right-clockwise principle (RC). Mathematically, the measured proportion of right responses can be expressed as $p_r = RC + CR + 0.5$.

Based on the response proportions found in the experiment and the conformance conditions of the RC and CR principles at various pointer positions (Table 3), the following four expressions were then written to solve for the two unknowns in plane 1.

Position 1	1 =	RC	+	CR	+ 0.5
Position 2	0.5 =	RC	-	CR	+ 0.5
Position 3	0.15 =	-RC	-	CR	+ 0.5
Position 4	0.925 =	-RC	+	CR	+ 0.5

The average values, the CR and RC were 0.319 and 0.106, respectively. Similar calculations were done for the other three planes and the resulting overall average of CR and RC were 0.274 and 0.135, respectively. The CR component principle was the strongest, contributing 55% (0.274/0.5) to the total effect. The sum of strength values of the RC and CR principles contributed 82% (0.409/0.5) to overall stereotype strength, justifying the previous assumption made on the contribution of the RC and CR principles towards the direction of turn stereotypes.

Similarly for the anticlockwise instruction, it was assumed that the proportion of left response was derived from the linear sum of strengths of left-anticlockwise (LA) and anticlockwise-left (AL) principles such that,

$p_l = LA + AL + 0.5$ where p_l is the measured proportion of left responses.

With the same method of evaluation, the average AL and LA strengths were found to be 0.444 and 0.011, respectively, contributing a high level of 0.455 (91%) to the overall stereotype strength. The two principles considered here did not function simultaneously at C_2, C_3 and C_4 and therefore C_1 was the best pointer positions for the horizontal lever tested here.

3. Summary

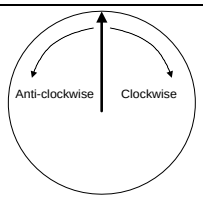
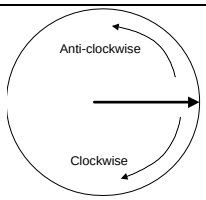
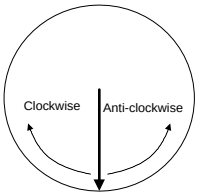
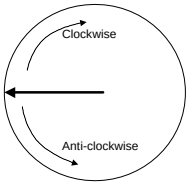
There were strong and reversible RC and LA relationships at vertical pointer position C_1, and strong and reversible RA and LC relationships at vertical pointer position C_3 in planes 1, 3, and 4. Overall, strength of stereotypes and indexes of reversibility were weaker than those found previously for a rotary knob [5]. Lack of dominant direction of movement stereotypes for the horizontal pointers (C_2, C_4) showed that as compared to the rotary control, the horizontal lever did not work satisfactorily with a circular display. Analyses of component principles quantified the respective contributions of RC and CR at C_1 and LA and AL at C_3, and showed that C_1 was the best pointer position for the horizontal lever with a circular display. The negative correlation of preferred responses with time showed that clear stereotypes appear to reduce mental workload.

IV. EXPERIMENT 2: VERTICAL LEVER

A. Response Preference and response time

The frequency and percentage of responses for different testing conditions are shown in Table 4. Student's t test showed that there was no significant difference between the proportions of left responses (50.1%) recorded and the chance probability of 50% from all subjects for all testing conditions. Chi-square tests on the up responses (Table 5) showed that instruction of turn (*I*) and cardinal position (*C*) effects were significant (p's < 0.001) but plane (*P*) effect was non significant. The interactions of *P x C*, *C x I*, and *P x C x I* were also significant (p's < 0.001).

Table 4 Analysis of responses made for different pointer positions, instructions, and planes in Simulated Test 2 (Vertical Lever)

			 Pointer Position 1		 Pointer Position 2		 Pointer Position 3		 Pointer Position 4							
			Instruction															
	Plane	Response	Clockwise		Anticlockwise		Clockwise		Anticlockwise		Clockwise		Anticlockwise		Clockwise		Anticlockwise	
			N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
	1	Up	13	32.5	5 [a]	12.5	5 [a]	12.5	33	82.5	31	77.5	28	70.0	37	92.5	1 [a]	2.5
		Down	27	67.5	35	87.5	35	87.5	7 [b]	17.5	9 [d]	22.5	12	30.0	3 [a]	7.5	39	97.5
	2	Up	11 [c]	27.5	9 [d]	22.5	7 [b]	17.5	34	85.0	35	87.5	31	77.5	36	90.0	2 [a]	5.0
		Down	29	72.5	31	77.5	33	82.5	6 [b]	15.0	5 [a]	12.5	9 [d]	22.5	4 [a]	10.0	38	95.0
	3	Up	9 [d]	22.5	4 [a]	10.0	9 [d]	22.5	32	80.0	35	87.5	28	70.0	35	87.5	3 [a]	7.5
		Down	31	77.5	36	90.0	31	77.5	8 [c]	20.0	5 [a]	12.5	12	30.0	5 [a]	12.5	37	92.5
	4	Up	13	32.5	10 [e]	25.0	5 [a]	12.5	31	22.5	36	90.0	33	82.5	37	92.5	3 [a]	7.5
		Down	27	67.5	30	75.0	35	87.5	9 [d]	77.5	4 [a]	10.0	7 [b]	17.5	3 [a]	7.5	37	92.5
	Total	Up	46	28.8	28	17.5	26	16.3	130	67.5	137	85.6	120	75.0	145	90.6	9	5.6
		Down	114	71.2	132	82.5	134	83.7	30	32.5	23	14.4	40	25.0	15	9.4	151	94.4

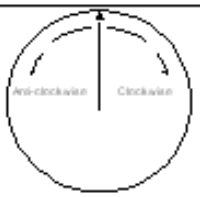
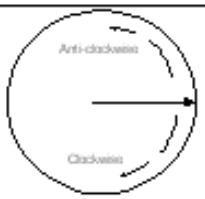
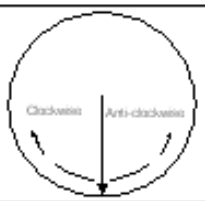
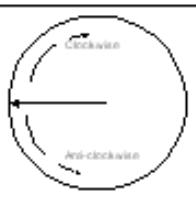
[a] significant at the 0.001 level.
[b] significant at the 0.005 level.
[c] significant at the 0.01 level.
[d] significant at the 0.025 level.
[e] significant at the 0.05 level.

Table 5 χ^2 analysis across the no. of responses in the requested directions in Simulated Test 2 (Vertical Lever)

Component	d.f.	χ^2	Significance
P	3	1.02	
C	3	105.36	< 0.001
I	1	7.02	< 0.01
PC	9	107.37	< 0.001
PI	3	1.62	
CI	3	325.72	< 0.001
PCI	9	296.95	< 0.001
Total	31	845.05	< 0.001

P: Plane (1, 2, 3, 4); C: Pointer cardinal position (12, 3, 6, 9 o'clock);
I: Instruction of turn (anti-clockwise, clockwise)

Table 6 The conformance conditions of the down-clockwise (DC), up-anticlockwise (UA), clockwise-down (CD) and anticlockwise-up (AU) principles at the four pointer positions of a circular display

 Pointer Position 1			 Pointer Position 2			 Pointer Position 3			 Pointer Position 4		
A. Clockwise Instruction											
DC		0	DC		+1	DC		0	DC		-1
CD		+1	CD		+1	CD		-1	CD		-1
B. Anticlockwise Instruction											
UA		0	UA		+1	UA		0	UA		-1
AU		-1	AU		+1	AU		+1	AU		-1

Moderately strong up-anticlockwise (UA) (67.5%) and down-clockwise (DC) (83.8%) preferences were found for the 3 o'clock pointer position, and strong up-clockwise (UC) (90.6%) and down-anticlockwise (DA) (94.4%) preferences were found for the 9 o'clock position. For the 12 o'clock position, downward movement was preferred for both turn instructions with strengths of 71.3% and 82.5% for DC and DA, respectively. For the 6 o'clock position, opposite result as that for the 12 o'clock position was demonstrated. Upward movement was preferred for both turn instructions with strengths of 85.6% and 75.0% for UC and UA, respectively. Regression analysis for preferred responses (p) for different turn instructions showed that response times reduced with increased strength of stereotype in a manner comparable to that for the horizontal lever.

*Response Time (ms) = 366 – 2.05 * p* (r^2 = *0.533, n = 32, p < 0.001)*

B. Discussion

1. Stereotype Reversibility

The IRs evaluated with the DC, UA, UC, and DA stereotypes at pointer positions 1 and 3, 0.362 and 0.320 respectively, were low. With the pointer at positions 2 and 4 and perpendicular to the lever motion axis, higher IRs of 0.711 and 0.861 respectively were found.

2. Contribution of Component Principles

Table 6 illustrates conformance of the DC, CD, UA, and AU principles for the four pointer positions. The methodology illustrated in III.C was used here to analyze component principles for the vertical lever. It was assumed that the proportion of down response was derived from the linear sum of the strengths of the down-clockwise (DC) and clockwise-down (CD) principles,

i.e. DC + CD + 0.5 = p_d where p_d is the measured proportion of down responses

Similar calculations as in III.C were done for the four planes and the overall averages for DC and CD were 0.052 and 0.284, respectively. The major component was CD which contributed 57% (0.284/0.5) to the total effect. The sum of strength values of the two principles was 0.336 (67%).

Similarly, it was assumed that the proportion of up response was derived from the linear sum of the strengths of up-anticlockwise (UA) and anticlockwise-up (AU) principles,

i.e. UA +AU + 0.5 = p_u where p_u is the measured proportion of up responses

Using similar methodology, the overall UA and AU computed were 0.100 and 0.288, respectively. The sum of all the strengths (0.388, 78%) was comparatively larger than that for the down response.

3. Summary

For the vertical lever there were down-clockwise (DC) and up-anticlockwise (UA) preferences at pointer position C_2, and strong up-clockwise (UC) and down-anticlockwise (DA) preference at position C_4, but the strength and reversibility of stereotypes were generally weaker than those for the horizontal lever, especially for the vertical pointers. The strongest stereotype (DA, 97.5%) occurred at pointer position C_4, with an average strength of 94.4% for all planes. However, care must be exercised in using the C_2 and C_4 positions concurrently, because the contradictory stereotypes involved may jeopardize operator decision making. Also, it is important to note that for the horizontal lever, stereotype strength and reversibility were greater for vertical pointers (C_1, C_3), but the results here showed that stereotype strength and reversibility were greater for horizontal pointer positions (C_2, C_4). The sum of strengths of the DC, CD, UA, and AU principles found here were comparatively weaker than those found for the horizontal lever.

V. EXPERIMENT 3: FOUR-WAY LEVER

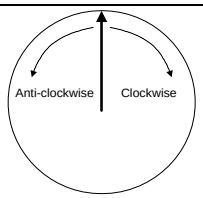
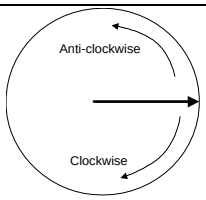
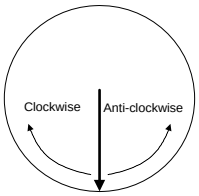
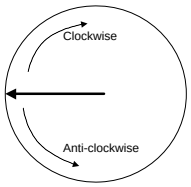
A. Response preferences and response time

The frequency and percentage of responses for different testing conditions are shown in Table 7. Student's t test showed that there were no significant differences between the proportion of up (25.5%), down (25.5%), left (24.7%) and right (24.4%) responses recorded and the chance probability of 25% from all subjects for all testing conditions. Chi-square tests on the response preference (Table 8) showed that while the plane effect was non significant, both the cardinal position ($p < 0.001$) and instruction of turn effects ($p < 0.025$) were significant. The interactions of *P x C* and *C x I* were significant (p's < 0.001), indicating that both the plane and instruction of turn effects varied across different cardinal positions. The interaction of *P x C x I* was also significant ($p < 0.001$).

The four-way lever was a more versatile device than the horizontal and vertical levers, allowing movements in the transverse and longitudinal orientations. Strong response preferences were found for all pointer positions and, in most cases, the subjects seemed to ignore the clockwise and anticlockwise instructions and responded to the up, down, left, or right associated translatory pointer movement. Regression analysis for the preferred responses percentage (p) for different instructions showed that the absolute magnitude of the coefficient for p (-3.02) here was greater than those for the other two levers.

*Response Time (ms) = 443 - 3.02 * p* (r^2 = *0.497, n = 32, p < 0.001)*

Table 7 Analysis of responses made for different pointer positions, instructions, and planes in Simulated Test 3 (Four-way Lever)

			 Pointer Position 1				 Pointer Position 2				 Pointer Position 3				 Pointer Position 4			
			Instruction																	
	Plane	Response	Clockwise		Anticlockwise		Clockwise		Anticlockwise		Clockwise		Anticlockwise		Clockwise		Anticlockwise	
			N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
	1	Up	2	5.0	0	0.0	4	10.0	29[a]	72.5	3	7.5	1	2.5	39[a]	97.5	1	2.5
		Down	1	2.5	3	7.5	34[a]	85.0	5	12.5	4	10.0	2	5	0	0	36[a]	90.0
		Left	0	0.0	36[a]	90.0	1	2.5	6	15.0	33[a]	82.5	1	2.5	0	0	1	2.5
		Right	37[a]	92.5	1	2.5	1	2.5	0	0.0	0	0.0	36[a]	90	1	2.5	2	5.0
	2	Up	2	5.0	0	0.0	2	5.0	34[a]	85.0	4	10.0	2	5	35[a]	87.5	0	0.0
		Down	4	10.0	4	10.0	33[a]	82.5	2	5.0	1	2.5	2	5	1	2.5	35[a]	87.5
		Left	2	5.0	36[a]	90.0	3	7.5	2	5.0	34[a]	85.0	1	2.5	0	0	1	2.5
		Right	32[a]	80.0	0	0.0	2	5.0	2	5.0	1	2.5	35[a]	87.5	4	10	4	10.0
	3	Up	3	7.5	1	2.5	6	15.0	32[a]	80.0	5	12.5	2	5	33[a]	82.5	0	0.0
		Down	3	7.5	5	12.5	24[a]	60.0	3	7.5	0	0.0	2	5	1	2.5	36[a]	90.0
		Left	0	0.0	34[a]	85.0	2	5.0	5	12.5	35[a]	87.5	1	2.5	1	2.5	2	5.0
		Right	34[a]	85.0	0	0.0	8	20.0	0	0.0	0	0.0	35[a]	87.5	5	12.5	2	5.0
	4	Up	1	2.5	0	0.0	2	5.0	35[a]	87.5	5	12.5	7	17.5	35[a]	87.5	1	2.5
		Down	4	10.0	4	10.0	34[a]	85.0	3	7.5	0	0.0	0	0	2	5	38[a]	95.0
		Left	2	5.0	36[a]	90.0	3	7.5	2	5.0	34[a]	85.0	2	5	0	0	0	0.0
		Right	33[a]	82.5	0	0.0	1	2.5	0	0.0	1	2.5	31[a]	77.5	3	7.5	1	2.5
	Total	Up	8	5.0	1	0.6	14	8.8	130	81.2	17	10.6	12	7.5	142	88.8	2	1.3
		Down	12	7.5	16	10.0	125	78.1	13	8.1	5	3.1	6	3.7	4	2.5	145	90.6
		Left	4	2.5	142	88.8	9	5.6	15	9.4	136	85.0	5	3.1	1	0.6	4	2.5
		Right	136	85.0	1	0.6	12	7.5	2	1.3	2	1.3	137	85.6	13	8.1	9	5.6

[a] significant at the 0.001 level.

Table 8 χ^2 analysis across the no. of responses in the requested directions in Simulated Test 3 (Four-way Lever)

Component	d.f.	χ^2	Significance
P	9	14.48	
C	9	783.92	< 0.001
I	3	9.56	<0.025
PC	27	799.32	< 0.001
PI	9	9.52	
CI	9	2514.64	< 0.001
PCI	27	2495.00	< 0.001
Total	93	6674.40	< 0.001

P: Plane (1, 2, 3, 4); C: Pointer cardinal position (12, 3, 6, 9 o'clock);
I: Instruction of turn (anti-clockwise, clockwise)

B. Discussion

It is interesting to note that, although there were more choices and degrees of freedom of lever movement associated with a pointer turn direction, the stereotype strengths for all planes and pointer positions were much higher than those found for the horizontal and vertical levers. Also, average response time for the four way lever was faster than those for the two-way levers. The subjects clearly had to do less mental work with the manipulation of four-way lever where strong stereotypes existed even though there were more choices. As there were more than two choices of movement directions available for each test trial, the IRs could not be evaluated for the four-way lever.

VI. CONCLUSION

The results of these three tests provided useful ergonomic recommendations for the industrial design of control panels used in human-machine interfaces for improved human performance. Below is a list of design implications formulated from the findings of this study.

a) Translatory levers are not as good as rotational controls for working with the circular displays.
b) A four-way lever works better than horizontal or vertical levers with circular displays as reflected from the stronger response preferences exhibited by the four-way lever.
c) If a two-way lever must be used with a circular display then to ensure stronger stereotypes:
    i. the pointer should be positioned at 12 o'clock position for a horizontal lever;
    ii. the pointer should be positioned at 9 o'clock position for a vertical lever.
d) Analyses of strengths of component principles in determining of direction of turn stereotypes gave a good account of the data obtained from the three controls.
e) In general, response times were longer when there were no clear movement stereotypes.

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