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Spatial Stimulus-response (S-R) Compatibility Effect for Hand Controls with Visual Signals on Horizontal Plane

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***Abstract*—Past research studies on spatial compatibility demonstrated that when stimulus and response sets vary along both horizontal and vertical dimensions, the horizontal (right/left) locational cues are found stronger than vertical (above/below) cues, and this phenomenon is known as right/left prevalence effect [1-3]. However, there is no research study in examining the right/left prevalence effect of stimulus and response sets in transverse (right/left) and longitudinal (front/rear) dimensions. The more we have about human performance in different display-control configurations, the better and more effective will be human-machine interfaces designed to allow effective operation. This study explored the spatial compatibility effect of hand controls with visual signals presented on horizontal planes. Results showed salient spatial compatibility effect between visual signals and controls, however, there was no indication of any prevalence effect of right/left dimension over front/rear one. Results were translated into practical recommendations for design of control-horizontal display configuration.**

Keywords: Human-machine interface, Right/left prevalence, Spatial compatibility

I. Introduction

Spatial stimulus-response (S-R) compatibility is an important consideration in human-machine interface design. It refers to the situation where the selection of a response is directly related to the position of the related stimulus. When the relation between stimuli and responses is direct and natural, it is described as compatible, while when the relation is indirect and unnatural, it is described as incompatible [4]. Spatial S-R compatibility between stimulus and response is an important factor to consider when determining equipment designs for enhancing human performance. Basic researches aimed at fundamental understanding of spatial compatibility with visual stimuli has been conducted with simple tasks involving finger pressing of a left or right key in response to a light appearing on the left or right side of a display. Faster responses were obtained when the left and right lights were paired with the left and right buttons, respectively, rather than the reverse assignment of lights to buttons [5]. Likewise, there are also spatial compatibility effects demonstrated for visual stimuli in the vertical (above-below) dimension. Performance is better if top and bottom stimuli were spatially corresponded with upper and lower keys than if not [1, 6]. The compatibility effect of the vertical dimension was of similar magnitude to the effect of the horizontal dimension when they were studied separately. However, when the spatial cue forming the S-R compatibility effect could be interpreted in both the horizontal and vertical dimensions, a stronger compatibility effect was found in the horizontal than in the vertical dimension, indicating a right-left prevalence in spatial compatibility [1-3]. Perhaps, it is because hands, as the effectors, are commonly coded in the anatomical right-left dimension, e.g. on keyboards. Subjects found it easier to assign the effectors by right/left location codes than by above/below ones [7].

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However, at present, no extensive research studies have been conducted to examine the right/left prevalence effect of stimulus and response sets vary in transverse (right/left) and longitudinal (front/rear) dimensions. The more we have about human performance in different display-control configurations, the better and more effective will be human-machine interfaces designed to allow effective operation. This study explored the spatial compatibility effect of hand controls with visual signals in right/left (transverse) and front/rear (longitudinal) dimensions on horizontal planes.

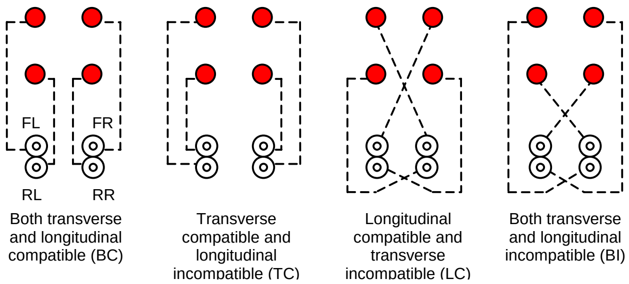
II. Method

A. Subjects

Thirty two Chinese students of City University of Hong Kong (16 males and 16 females) of ages 20 to 28 (mean = 22) participated in this experiment. They were all right-handers as tested with the Lateral Preference Inventory [8]. All of them had normal or corrected-to-normal vision.

B. Design

In a trial, one of the four visual signals at the front-left, front-right, rear-left, and rear-right positions of an imaginary square on a horizontal plane was presented to the subjects. A control box with four keys was provided for inputting responses. The keys were at front-left, front-right, rear-left, and rear-right positions on the top plane of the box. The front-left and rear-left keys were operated by middle and index fingers of left hand respectively, while the front-right and rear-right keys were operated respectively by middle and index fingers of right hand. With the given signals and input positions, there were four spatial stimulus-response (S-R) mapping conditions as follows: Both transverse and longitudinal Compatible (BC), Transverse Compatible and longitudinal incompatible (TC), Longitudinal Compatible and transverse incompatible (LC), and Both transverse and longitudinal Incompatible (BI). Each of these conditions was tested for all subjects (Figure 1). For example, in the BC mapping condition, the visual stimuli and corresponding response keys were arranged congruously in both longitudinal and transverse orientations so that subjects would respond by pressing the front-right key (FR) to the front-right (fr) visual signal, front-left key (FL) to the front-left (fl) signal, rear-right key (RR) to the rear-right (rr) signal, and rear-left key (RL) to the rear-left (rl) signal. The 32 subjects, divided into four groups with equal number of males and females, were tested in different sequences with the four blocks of S-R mapping conditions in a counterbalanced order. Each block contained eight practice trials and thirty two testing trials.



C. *Apparatus and Stimuli*

This experiment was carried out with the use of a personal computer (Pentium® 4 CPU, 2.80 GHz). Visual Basic 6 was employed for stimulus preparation and display, and response data collection. The control box installed with the computer software and interfaced with the hardware was placed on a 650 mm high working table, which allowed subjects to respond to the corresponding visual signals. Four response keys were separated by 2.5 cm from each other to ensure subjects' ease and comfort during manipulation. For visual stimulus presentation in a trial, only one of four 30-mm diameter red circles, situated at the four corners of an imaginary 120-mm side square in a prostrate 17-in LCD monitor. A green 10-mm diameter circle was shown at the centre of the screen serving as a warning signal and fixation point.

D. *Procedure*

During the test, subjects sat at a distance of 500 mm directly in front of the display. They were asked to position their hand on the control box with a posture convenient for pressing the devices. Each trial started with the display of a green circle at the centre of the screen to serve as a warning signal and fixation point. After a delay of 1 to 4 seconds, one of the four visual stimuli, chosen at random, was light up. In response to the signal, subjects then pressed the appropriate key according to the compatibility condition being tested. No feedback on the accuracy was given.

III. Result

A total of 4,096 (32 subjects x 4 conditions x 32 trials) responses were collected in this study. Overall, 64 (1.56%) responses were incorrect. Altogether 98 outliers (2.39%) beyond the upper and lower control limits (±3s limits) of 820 ms and 196 ms, respectively were discarded from analysis. A total of 3,934 (96%) responses were thus scrutinized for further analysis. The mean and standard deviation of reaction times (RTs) for the 3,934 correct responses were 508 ms and 104 ms, respectively. The results showed that the effects of response key position, foreperiod, and S-R mapping condition were significant ($p < 0.0001$), while reaction time was not significantly influenced by the signal position and gender factor ($p > 0.05$).

The order of mean RTs across the four response key positions was RR (495 ms), RL (508 ms), FR (513 ms) and FL (515 ms). A post hoc pairwise comparison (The Least Significant Difference - LSD) was performed to examine the difference in RTs between the responses for the four response key positions. The RT for RR key was classified as one set while those for FL, FR and RL keys were in another set, which shows that the response by right index finger was the fastest and there was no difference in reaction times for the responses given by the other three fingers. The significant foreperiod effect indicated that subjects' RTs varied with the duration between the occurrence of warning signal and stimulus presentation. It was found that subjects took the longest time to respond when the foreperiod was at the shortest one-second condition. RT then decreased with an increase of foreperiod duration. Regarding the significant interaction of S-R mapping conditions, the order of mean RTs across the four S-R mapping conditions was BC (437 ms), TC (528 ms), BI (530 ms) and LC (538 ms). Responses were fastest for the BC condition in which correspondence existed for the signal and hand response key positions in both orientations, and slowest for the LC condition in which there was light-key correspondence in the longitudinal but not the transverse orientation. The pairwise comparisons (LSD) classified the reaction times of different S-R mapping conditions into two subsets. The RT for BC was significantly different from the rest while the RTs for TC, LC and BI were found to be not significantly different from each other.

IV. Discussion

In the transverse and longitudinal orientations of visual signals responding with hand controls, subjects responded faster with the right hand than the left hand, and they responded fastest with the right-index fingers, which is in support of the findings of [9] that right-handers showed significant right-hand and right-foot performance advantage. For the significant foreperiod effect, subjects took the longest time to respond when the foreperiod was at one second, and RT then reduced significantly with an increase of foreperiod, which demonstrating that the foreperiod prior to the onset of signal did influence the speed of response. The longest RT found in the one-second foreperiod condition was believed to be related to the incompleteness of preparation in the foreperiod. Therefore a foreperiod of at least two to three seconds is recommended for this type of four-choice reaction task with hand controls in order to ensure relatively better performance. The significant interaction of visual signal position and hand response key position revealed the existence of a spatial S-R compatibility effect. An improvement of 95 ms in RT was achieved when there was correspondence between the stimulus and response key as compared to when there were non-correspondent S-R mappings, supporting the hypothesis that better human performance would be achieved in compatible mapping condition/orientation than in the incompatible one. The non significant difference among incompatible S-R mappings of TC, LC and BI was noted, indicating that there was no evidence of stronger effect of transverse light-key relation over the longitudinal relation in affecting reaction time.

V. Conclusion

The spatial stimulus-response compatibility effect for hand controls with visual signals on horizontal planes was investigated in this study. The following results were obtained and some ergonomics recommendations are formulated to help improve the efficiency and performance of human-machine systems.

a. The relative positions of horizontally arrayed visual signals and hand response keys should be spatially compatible for the best human-machine system performance. Control-display configurations designed so that there is compatibility in both the transverse and longitudinal orientations will lead to the best performance in terms of response times and response errors.

b. Compatibility is higher (though non significant) in the right/left dimension than in the front/rear dimension. This suggested that situations where spatial compatibility cannot be built concurrently in both orientations, compatibility for the transverse orientation should be given the higher priority.

c. Responses with right hand are faster than that with left hand for right-handed subjects. This suggested that, for right handed operators, response hand keys for critical and immediate actions should be positioned on the dominant right hand side.

d. A foreperiod of at least 2 to 3 seconds is recommended in a four-choice foot controls reaction task for ensuring sufficient recuperation period for subjects.

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References

[1] Nicoletti, R. and Umilta, C. (1984). Right-left prevalence in spatial compatibility. Perception and Psychophysics, 35(4), 333-345.

[2] Vu, K. P. and Proctor, R. W. (2001). Determinants of right-left and top-bottom prevalence for two-dimensional spatial compatibility. Journal of Experimental Psychology: Human Perception and Performance, 27, 813-828.

[3] Chan, A. H. S. and Chan, K. W. L. (2004). Design implications from spatial compatibility on parallel and orthogonal stimulus-response arrays. Asian Journal of Ergonomics, 5(2), 111-129.

[4] Proctor, R. W. and Vu, K. –P. L. (2006). Stimulus-Response Compatibility Principles. Taylor & Francis Group: Boca Raton, Florida.

[5] Proctor, R. W. and Reeve, T. G. (Eds.) (1990). Stimulus-response compatibility: An integrated perspective. Amsterdam: North Holland.

[6] Chan, K. W. L., Chan, A. H. S., and Courtney, A. J. (2001). Spatial stimulus-response compatibility in vertical dimension for Chinese: Implication for interface design. Proceedings of the 6th Pan-Pacific Conference on Occupational Ergonomics, Beijing, 31-36.

[7] Umilta, C. and Nicoletti, R. (1990). Spatial stimulus-response compatibility. In R. W. Proctor and T. G. Reeve (Eds.), Stimulus-response compatibility: An integrated perspective (pp. 86-116). Amsterdam: North-Holland.

[8] Coren, S. (1993). The lateral preference inventory for measurement of handedness, footedness eyedness, and earedness: Norms for young adults. Bulletin of the Psychonomic Society, 31(1), 1-3.

[9] Annett, M. (2002). The right shift theory of handedness. In M. Annett (Ed.), Handedness and brain asymmetry: the right shift theory (pp. 48-71). New York: Taylor and Francis.