The Influence of Directional Cues on Operators' Performance in Non-correspondent Spatial S-R Pairing Tasks

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Abstract

This study investigated the effects of directional cues on operators' performance in non-correspondent spatial stimulus-response (S-R) pairing tasks. The experiment used a 2 (spatial cognitive styles) × 3 (directional cue task types) design. Spatial cognitive styles included field-dependent (FD) and field-independent (FI) cognitive styles which were divided by Riding's computer-administered Cognitive Style Analysis (CSA). The experimental tasks consisted of a no-directional cue task (a non-correspondent spatial S-R pairing task without directional cue) and two directional cue tasks. The directional cue tasks consisted of a stimulus directional cue task (a non-correspondent spatial S-R pairing task with stimulus directional cue), and a response directional cue task (a non-correspondent spatial S-R pairing task with directional response cue). The result of significant variance analysis showed that both FD and FI cognitive styles performed significantly better in both directional cue tasks. This implies the important role of directional cues for enhancing the performance of operators of different spatial cognitive styles in non-correspondent spatial S-R pairing tasks. Thus, it is suggested that directional cue can be used in designing the control-display devices with non-correspondent spatial S-R pairing patterns for the operators of different spatial cognitive styles.

Keywords: Individual Spatial Cognitive Styles, Non-correspondent Spatial Stimulus-response Pairing, Directional Cue

Citation: Chen, C., Lee, C., & Huang, S. (2008). The Influence of Directional Cues on Operators' Performance in Non-correspondent Spatial S-R Pairing Tasks. *Journal of Design*, *13*(1), 25-32.

1. Introduction

Spatial stimulus-response (S-R) pairing refers to the physical arrangement in space of controls and their associated displays (Fitts & Seeger, 1953), and is used for mechanisms that people operate in their jobs and daily lives, such as the arrangement of burners and controls on a stove (Chapanis & Lindenbaum, 1959). Spatial S-R pairing patterns can be classified into correspondent and non-correspondent. They are defined as follows: (1) If the stimulus and response codes are consistent (i.e. a left-side response to a left-side stimulus, the compatible condition), the reaction time is shorter. This is referred to as the "correspondent" condition. (2) Conversely, if the stimulus and response codes are inconsistent (i.e. a right-side response to a left-side stimulus, the incompatible condition), the reaction time is longer. This is referred to as the "non-correspondent" condition (Fitts & Seeger).

Correspondent spatial S-R pairing is the most popular pairing pattern used to design safe and efficient control-display devices (Sanders & Mccormick, 1992). However, a non-correspondent spatial S-R pairing pattern is sometimes inevitable, as when the boundary between the non-correspondent spatial S-R pairing pattern and the correspondent spatial S-R pairing pattern are not clear, or when certain essential factors of a design conflict with spatial S-R pairing principles. One example is a layout with vertical controls and horizontal displays. In such a case, a non-correspondent spatial S-R pairing pattern is sometimes inevitable. Moreover, it has been found that those using different spatial cognitive styles, such as field-dependent (FD) and field-independent (FI) cognitive style, can be adversely influenced by spatial S-R pairing patterns (Chen, Lee, & Cai, 2007). This implies the necessity of a well-designed control-display device that can enhance both the FI and FD operator's performance in a non-correspondent spatial S-R pairing task. This problem, however, has seldom been investigated. Thus this study investigates the optimal design for a control-display device with a non-correspondent spatial S-R pairing pattern for field-dependent-independent (FDI) operators.

In terms of separating information from its context, FD and FI cognitive styles represent two contrasting approaches (Witkin, Dyk, Faterson, Goodenough, & Karp, 1962). FDs usually have a difficulty in separating incoming information from its context in misleading conditions, and are more likely to be influenced by external cues. FIs, on the other hand, rely on internal cues and have no difficulty in such tasks (Baillargeon, Passcual-leone, & Roncadin, 1998; Riding & Cheema, 1991). Moreover, the physiological evidence for different P300 amplitudes of FDIs in a portable rod and frame task (Goode, Goddard, & Pascual-leone, 2002) indicates that a referenced sample indexical cue and a target indexical cue can greatly enhance FDs' performance in an information-separating task. This demonstrates the usefulness of a referenced sample indexical cue (defined as a stimulus directional cue in terms of its indicating stimulus function) and a target indexical cue (defined as a response directional cue in terms of its indicating response function) for FDs in non-correspondent spatial S-R pairing tasks. Thus it can be seen that directional cues can enhance the performances of the FD and FI operators in carrying out non-correspondent spatial S-R pairing tasks. This study investigates the role of both stimulus and response directional cues in the design of a control-display device using a non-correspondent spatial S-R pairing pattern for field-dependent-independent (FDI) operators.

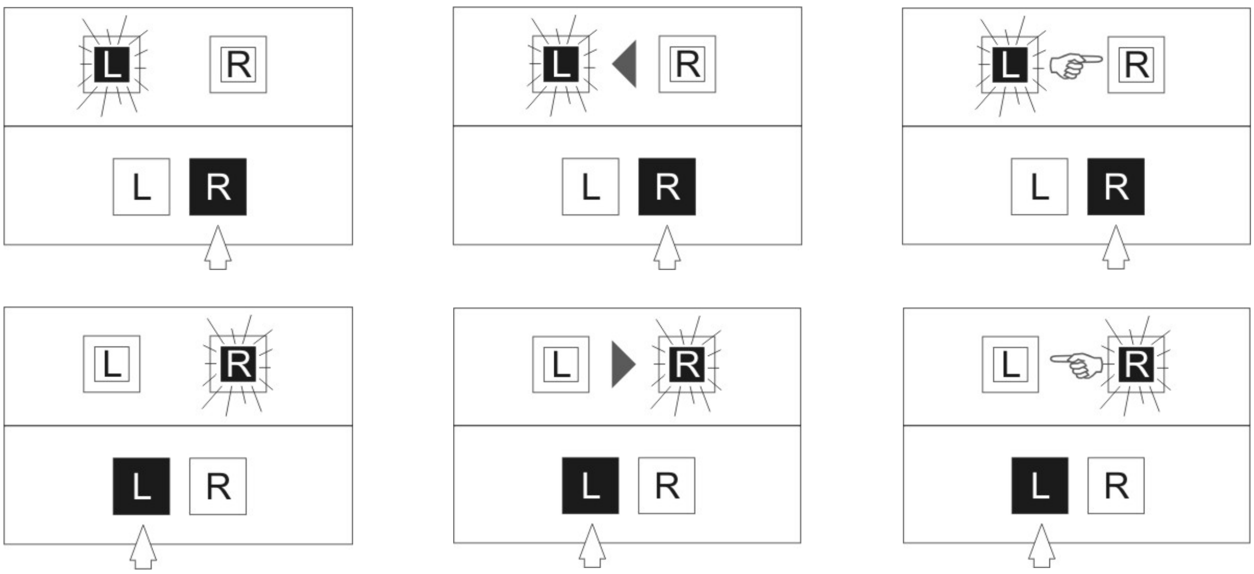
2. Methodology

2-1 Experimental Design

The experiment adopts a 2 (spatial cognitive styles) × 3 (directional cue task types) design. The spatial cognitive style is a two-level independent variable. The directional cue task type is a three-level independent variable.

The spatial cognitive styles included FD and FI cognitive styles measured using Riding and Cheema's (1991) computer-administered Cognitive Styles Analysis (CSA). A CSA score below 1 indicates an FI cognitive style, while a score above 1 indicates an FD cognitive style.

The experimental tasks consisted of a no-directional cue task (a non-correspondent spatial S-R pairing task without directional cue) and two directional cue tasks. The directional cue tasks consisted of a stimulus directional cue task (a non-correspondent spatial S-R pairing task with stimulus directional cue), and a response directional cue task (a non-correspondent spatial S-R pairing task with response directional cue). In the no-directional cue task (Fig. 1a), the participant was told to press an inconsistent response key to respond the stimulus; i.e., he/she responded to a left stimulus by pressing the key on the right. In the stimulus directional cue task (Fig. 1b), the participant pressed an inconsistent response key to respond to the stimulus in accordance with the stimulus directional cue, which appeared before the stimulus to indicate where the stimulus would appear. Moreover, in the response directional cue task (Fig. 1c), a participant pressed an inconsistent response key to respond to the stimulus in accordance with the response directional cue task, which appeared before the stimulus to indicate which response key should be used.



(a) (b) (c)

Figure 1. Three experimental tasks: (a) no-directional cue task; (b) stimulus directional cue task; (c) response directional cue task

2-2 Participants

A total of 48 undergraduate and graduate students (24 participants per cognitive style) from National Yunlin University of Science and Technology participated in the experiment. Their mean age was 23.2 years (*SD*=2.4). They were all healthy and right handed. Each participant's cognitive style pattern was measured with CSA. The FI participants' mean CSA score was 0.73 (*SD*=0.11), and FD participants' mean CSA score was 1.5 (*SD*=0.32).

2-3 Materials and Equipment

The experimental tasks were performed on a personal computer. The subjects used a two-key control unit (Lumina LP-400) to respond to the stimulus shown on the display (Viewsonic 17-in VA702). The distance between the display and the subject's eye was 40 cm. The visual angle was 3.6 degrees.

The experimental tasks were programmed in Visual Basic. The screen background was black. The stimulus appeared inside two 2.5 cm × 2.5 cm white squares in the center of the screen, with a distance of 5cm between the two squares. The stimulus was a 2.0 cm × 2.0 cm yellow square, which randomly appeared six times in each task. Totally, each participant would have six responses in each task. Moreover, both a stimulus directional cue (a red triangle, Fig. 1b) and a response directional cue (a finger symbol, Fig. 1c) appeared 0.1 second before the stimulus. Each stimulus randomly appeared one second after the response key was pressed.

2-4 Procedure

The experimental procedure encompassed two steps. In the first step, the participants were selected. In the second step, the three experimental tasks were performed. In the first step, 48 students (24 participants per cognitive style) at the National Yunlin University of Science and Technology were randomly chosen and measured with CSA.

Before the experiment, a brief introduction was made to ensure that the subjects understood the experimental procedure. The participants processed the experimental tasks only with their right index fingers. Each participant placed his/her right hand on the control unit and pressed the ENTER key to do the experimental tasks. Each participant completed a three-task trial experiment. In each task the participant responded six times to six randomly appeared stimuli. The three experimental tasks were randomly assigned to each participant.

2-5 Dependent Measures and Data Analysis

The participant's performance was defined as the average of six reaction times in each task. The reaction time was defined as the period of time between the appearance of the stimulus and the pressing of the response key. The significant analysis of variance in participants' performances in three experimental tasks was conducted to examine the effect of FDI Cognitive Style on a participant's performance. If the FD and FI participant's performance is better in directional cue task than in no-directional cue task, the directional cue assumptions of this study can be verified.

3. Results and Discussion

3-1 ANOVA Analysis of Two Independent Variables

This study was done to investigate the effect of directional cue on the performance of a non-correspondent spatial S-R pairing task. Two independent variables---spatial cognitive style and directional cue task type---were utilized. The results of ANOVA (Table 1) indicate that both spatial cognitive style and directional cue task type influenced the participants' performances. The interaction between the spatial cognitive style and the directional cue task type also influenced the participants' performances. These results demonstrat the effect of directional cue on the operators' performances in a non-correspondent spatial S-R pairing task.

Table 1. ANOVA analysis of FDI cognitive styles and directional cue task types

Independent variables	*df*	*SS*	*F*	*Sig.*
Spatial cognitive styles (A)	1	5611371.361	161.628	.000
Directional cue task types (B)	2	1131032.250	32.578	.000
A × B	2	332929.000	9.590	.000

3-2 The Effect of Spatial Cognitive Style on the Participants' Performance

Figure. 2 shows that FDs spent much more time performing the three experimental tasks than FIs. It can also be seen that FD subjects spent much more time performing the no-directional cue task. These results indicate the effect of FDI cognitive style on performance in a non-correspondent spatial S-R pairing task. In accordance with these findings, this study recommends that individual spatial cognitive style should be taken into account when designing control-display devices that must use a non-correspondent spatial S-R pairing pattern. An example is when restricted space necessitates an arrangement consisting of vertical displays and corresponding horizontal controls.

3-3 The Effect of Directional-Cue Task Type on Participants' Performance

Figure. 2 and Table 2 also show that in both directional cue tasks, both FD and FI participants performed better in the directional-cue task than in the no-directional cue task. Particularly, both FD and FI participants performed significantly better in the response directional cue task. These results indicate the important role of directional cue, particularly the response directional cue, in enhancing performance in a non-correspondent spatial S-R pairing task. Thus this study's hypothesis was supported. Therefore, it would be suitable to apply such a directional cue to the design of a control-display device using a non-correspondent spatial S-R pairing pattern, since such a directional cue evidently enhances the performance of both the FD and FI cognitive styles.

Most spatial control-display device studies (Bayerl, Millen, & Lewis, 1988) recommend an optimal spatial S-R pairing pattern regardless of directional cue for the spatial control-display device. For instance, Bayerl et al. investigated the optimal spatial pairing pattern of function keys and their corresponding labels on a screen. However, if the control-display device must be designed using non-correspondent spatial S-R pairing pattern, this will influence the FD operators' performances (Chen et al., 2007). This indicates the need to investigate a way to design a control-display device that uses a non-correspondent spatial S-R pairing pattern for the benefit of both FD and FI operators. In this study, directional cues, especially the response directional cue, were found to enhance most FD and FI operators’ performances in non-correspondent spatial S-R pairing tasks. Thus it is reasonable to recommend a designer the directional cue for designing the control-display devices for most operators varying with different spatial cognitive styles, while the control-display device is inevitably with a non-correspondent spatial S-R pairing pattern. For instance, in designing a control-display device with a non-correspondent spatial S-R pairing pattern, such as Chapanis and Lindenbaum’s (1959) four-burner stove, a small light can be employed to indicate which control to use.

Table 2. Multiple comparative analysis of two cognitive styles in three experimental tasks

FD cognitive style	**no-directional cue**	>	**stimulus directional cue**	>	**response directional cue**
	●				●
			●		●
FI cognitive style	**no-directional cue**	>	**stimulus directional cue**	>	**response directional cue**
	●				●

Note.“ > ”: larger; “● ”: groups who had significant differences in their performances

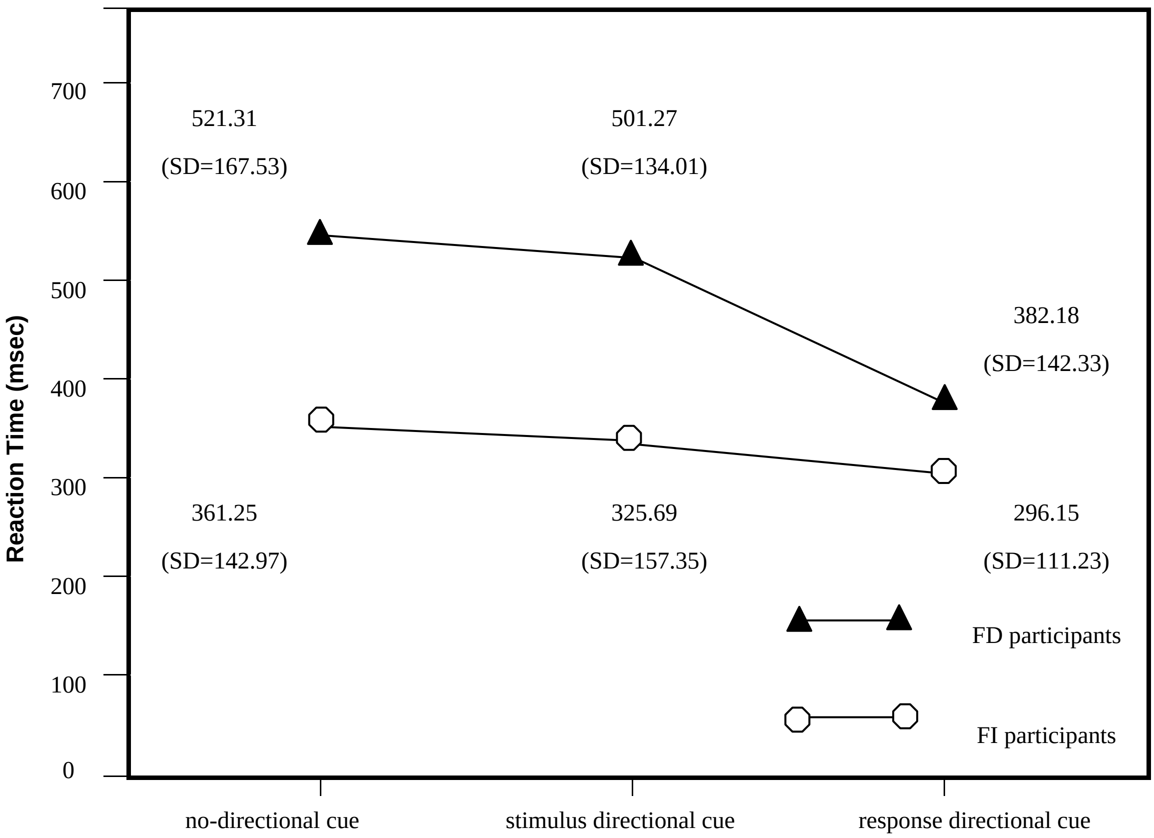


Figure 2. The reaction time of FDI cognitive styles in three experimental tasks

4. Conclusion

The experimental results show that FD and FI participants’ performances were much better in the directional cue task than in the no-directional cue task. Thus it is recommended that the directional cue can be taken into account when designing control-display devices with a non-correspondent spatial S-R pairing pattern.

Therefore, a designer can use a directional cue, such as the response directional cue, to design control-display devices when it is necessary to utilize a non-correspondent spatial S-R pairing pattern. For future work, an inclusive design case study of a real control-display device with a non-correspondent spatial S-R pairing pattern directional cue for the operators of different spatial cognitive styles will be demonstrated to support the findings of this study.

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指示性線索對空間認知風格者之非一致性選擇反應作業績效之影響

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摘　要

本研究之目的，旨在探討指示性線索形式對空間認知個別化差異者的空間刺激反應作業績效的影響。本研究之實驗採用 2 (空間認知風格) × 3 (指示性線索作業形式) 之設計。空間認知風格以 Riding 之電腦化 Cognitive Styles Analysis (CSA) 測驗所判定之場地獨立 (field-independent) 與場地依賴 (field-dependent) 等兩認知風格型態定義之。實驗任務則包含無指示性線索(no-indexical cue)、刺激指示線索(stimulus directional cue)與反應指示線索(response directional cue)等三個作業。實驗結果顯示：在含有指示性線索的任務中，兩種空間認知風格之作業績效均明顯變快。其中，場地依賴認知風格者在反應指示線索作業中的作業績效增進情況，尤其顯著。此顯示，反應指示線索最有助增進各種空間認知風格者在空間刺激反應作業中的作業績效表現。因此，本研究建議使用反應指示線索設計非一致性空間刺激反應裝置，以維持各種空間認知個別化差異者的作業安全。

關鍵字：空間認知風格、非一致性刺激反應配對、指示性線索