The Effects of Practice and Speed Stress with Different Stimulus-Response Mappings

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Abstract. Stimulus-response (S-R) compatibility refers to better performance with compatible over incompatible S-R mappings. We investigated how a stressor in the form of a time constraint influences performance in choice-reaction tasks with S-R mappings that varied in degree of compatibility. A 600-ms response deadline did increase participants' stress levels as indicated in subject workload reports. Furthermore, the time constraint decreased reaction time and increased error rate more for incompatible (mirror-opposite, mixed and random) mappings compared to compatible mappings. Participants who learned to respond with the incompatible mappings reverted to the more natural, corresponding responses when stressed. However, the effect of the time constraint was reduced when the incompatible mapping was systematic compared to when it was random. Thus, there are benefits of applying systematic rules when designing products for a user population.

Keywords: Stimulus-response compatibility, display-control compatibility, stress, practice effects.

1 Introduction

In everyday life, we are bombarded with stimuli. Whether we choose to respond to a stimulus and how we respond to it depends on natural response tendencies and past experiences. Imagine, for example, walking towards a door for the very first time and seeing a handle on it. Would you pull or push on the handle to open the door? Due to the response affordance of handles, people have developed a response tendency to pull on handles rather than to push on them. However, some doors are designed in a manner that requires a user to push on the handle to open the door rather than to pull on it. Can users interact with this type of door successfully? The answer is "yes" even when the push response does not match users' response tendencies. With practice, people are able to learn that a particular type of door handle requires a push and not a pull response. However, what would happen if a person had to quickly exit a building with handled doors that require push responses? Would the person follow his/her natural response tendencies and pull on the door handle or would s/he follow the learned response to push the handled door? Being able to determine the ways in

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which humans respond to situations under both time constraints and no time constraints can help improve the ability to design systems and interfaces that maximize user's performance and efficiency (low reaction time, RT; low error rate, ER). The aim of the current study is to examine human response tendencies in the laboratory in choice-reaction tasks when speed stress, in terms of a time constraint, is applied compared to when no time constraint is imposed.

Stimulus-response (S-R) compatibility is a topic that has been studied since Human Factors emerged as a field [1]. The S-R compatibility effect refers to the fact that performance is better when (a) the stimulus configuration matches the response configuration than when it does not (set-level compatibility), and (b) when individual stimuli are mapped to their corresponding responses than when they are not (element-level compatibility [2]. Fitts and Seeger [1] demonstrated set-level compatibility by examining performance when three different display configurations were paired with three response configurations. Stimulus set A consisted of eight lights arranged in a circle and the response set A used a response apparatus that consisted of a stylus that could be moved along eight paths of a circle (see Fig. 1). Response sets B and C were arranged in a square or as two lines, one horizontal and one vertical. RT and ER were lower when stimulus set A was mapped to response set A than to response sets B and C because the configurations corresponded. In other words, performance was better when the stimulus set closely matched the response set than when it did not.

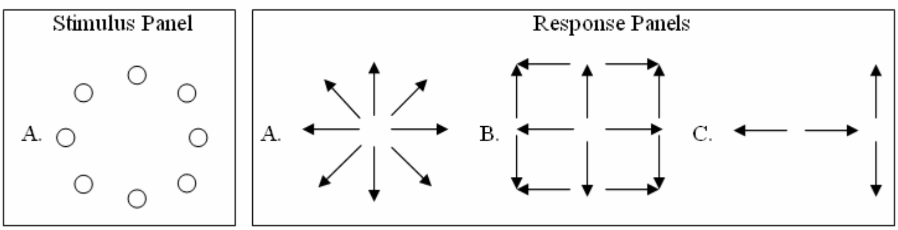

Fig. 1. Illustration of Stimulus Panel A and Response Panels A-C used by Fitt's and Seeger (1953)

Fitts and Deininger [3] illustrated element-level compatibility effects using stimulus set A and response set A. The mapping of stimulus locations to response locations was corresponding, mirror-opposite, or random (see Fig. 2). For the corresponding mapping, the illumination of the top light required the stylus to be moved to the top position of the response apparatus. For the mirror-opposite mapping, the illumination of a light to the right of a vertical midline required the stylus to be moved to the left position of the response apparatus, opposite of what a corresponding response would be. For the random mapping, there was no systematic relationship between the stimulus and response locations, and participants had to memorize the specific S-R pairings. RT was lowest for the corresponding mapping, intermediate for the mirror-opposite mapping, and highest for the random mapping. Thus, there was maximal benefit for maintaining spatial compatibility, but performance also benefited from a systematic S-R rule (e.g., respond with the mirror opposite location to the stimulus location).

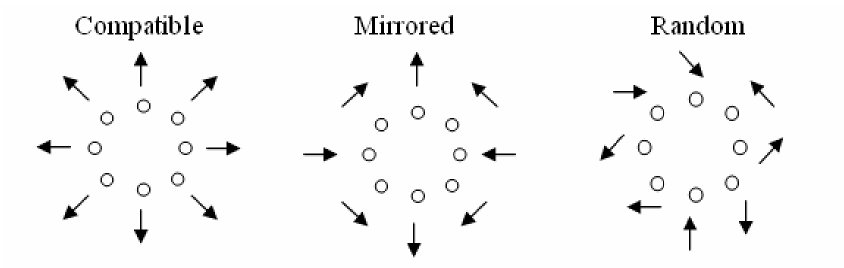

Fig. 2. Illustration of element-level mappings used by Fitts and Deininger [3]. The circles represent stimulus locations, and arrows indicate the direction of the response to be made to the stimulus.

Kornblum, Hasbroucq, and Osman [4] contended that element- and set-level compatibility work together to influence performance. To obtain the shortest RT and lowest ER, both set- and element-level compatibility should be high. Thus, any interface design should take into account both set- and element-level compatibility effects. Morin and Grant [5] illustrated the degree of element-level compatibility by using five different mappings based on a correlation of direct spatial mapping, where $r = 1$ (completely corresponding) represented a direct mapping of a stimulus to a response, and matched participants natural response tendencies. The other four mappings ranged from correlations of $r = .86$ (non-corresponding) to $r = .00$ (completely random). Performance was the best when the mapping was completely corresponding; and was proportional to the correlational level (lower correlation = lower performance) when S-R mappings deviated from the completely corresponding mapping.

Speed stress is one factor that can affect how much time people have to respond to a stimulus event and the errors that people make. Castaneda and Lipsitt [6] presented subjects with a stimulus set of eight lights horizontally aligned and a response set of 8 switches located directly below the eight lights. Half of the lights had corresponding S-R mappings, where the switch below the light turned the light off and the other half had non-corresponding S-R mappings; the switch to turn the light off was adjacent to the lit light, either to the left or to the right. All participants were shown the same stimulus sequence and were placed into either a stressed or non-stressed group. Stress was induced in the form of a 1-s time constraint, where participants had to flip the correct switch within one second. The non-stressed group did not have a time limit for responding to the stimulus.

ERs were calculated for both the corresponding and non-corresponding mappings. Fewer errors were committed with the corresponding mappings than with the non-corresponding mappings. In addition, fewer errors were committed for the corresponding stressed group than for the corresponding non-stressed group. However, the pattern for the non-corresponding group was reversed, with more errors committed in the non-corresponding stress group than in non-corresponding non-stressed group. Based on these findings, Castaneda and Lipsitt [6] concluded that speed stress facilitated performance when the mapping was simple and matched participants' natural response tendencies. However, when the mapping was non-corresponding and complex, the stress interfered with performance. Although, this experiment showed that speed stress could influence compatible and incompatible mappings in different ways, it did not examine performance with S-R mappings that varied in degree of compatibility.

The purpose of the current study was to investigate participants' performance with learned S-R mappings that vary in degree of compatibility, under conditions with and without speed stress. As in Castaneda and Lipsitt's [6] study, the stressor employed was a time constraint. In addition, we investigated the type of errors made within each mapping condition, to determine if they were random or systematic. A random error is an errant key strike, and a systematic error is selecting the key that spatially corresponds to the stimulus location, since it is the most natural mapping. We hypothesized that participants in the compatible mapping condition would yield the shortest RT and be most resistant to the effect of speed stress. For the incompatible mappings, performance should be better and more resistant to speed stress when the S-R assignments are more systematic than when they are not.

2 Method

2.1 Participants

Forty-eight students (18 males; 30 females; *M* age = 19.5 yrs, *sd* = 2.15 yrs) participated in this study for credits toward a Psychology course requirement. All participants reported having normal or corrected-to-normal vision.

2.2 Apparatus and Stimuli

The stimuli were presented on a personal computer using the Micro Experimental Laboratory (MEL) program. The responses were keypresses on a traditional QWERTY keyboard. This study employed a four-choice reaction task with four different S-R mappings (see Fig. 3). For the compatible mapping, a spatially corresponding mapping was employed, where each stimulus was mapped to its corresponding response. For the mirror-opposite mapping each stimulus was mapped to it mirror-opposite response. For the mixed mapping condition the left pair of stimuli was mapped to their corresponding responses and the right pair to mirror-opposite responses. For the random mapping, there was no rule that guided overall response selection, and participants had to remember each of the four S-R assignments.

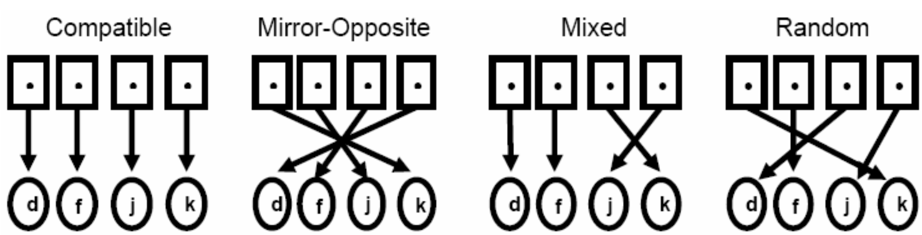

Fig. 3. Illustration of the Four Mapping Conditions Used in the Present Study

Past research has shown that a time constraint decreases performance [7]. The time constraint will induce speed stress because the participants know that they have a short amount of time to respond to the stimulus. To gauge the amount of stress perceived, participants completed a subjective workload rating scale, the NASA Task Load Index (TLX) [8] after each block. At the end of study participants also filled out stress and personality questionnaires. These questionnaires were filled out for exploratory purposes that will not be discussed in the present paper.

2.3 Procedure

The study took place in a laboratory in the Psychology building at California State University Long Beach. Participants were tested individually in a single session lasting approximately two hours. Each participant read and signed a consent form before the experiment began, and were then seated in a room in front of a computer screen.

Participants in all conditions were given written and verbal instructions about the task, assigned mapping, and hand placement on the keyboard. The stimulus was a white circle presented on a black background that appeared in one of four white boxes aligned horizontally. Participants were told that the stimulus would appear in one box and to make the response assigned to the particular stimulus based on their mapping condition. A standard QWERTY keyboard was used for responding, in which the middle and index finger on the left hand were placed on the D and F keys, respectively, and the middle and index finger on the right hand were placed on the K and J keys, respectively.

Once the participant read the instructions, he/she pressed the space bar to begin the first phase of the experiment, which consisted of 1,600 trials. In this learning phase, participants had two seconds to respond to the stimulus. This allowed them enough time to respond without feeling any speed stress. If a response was not made in two seconds or a wrong choice was selected, an error tone sounded, and the next trial was presented. The intertrial interval was set at 1 s. After the first 800 trials, a message informed the participant to see the experimenter to fill out a questionnaire (the NASA TLX) prior to taking a break. After the 5-min break, participants returned to the room to complete the remaining 800 learning trials and to fill out another NASA TLX scale.

After the learning phase was completed, participants took a 10-minute break prior to performing the experimental phase. The experimental phase employed the same mapping as the training phase, but was divided into three parts: 300 trials with the 2-sec response time deadline, 600 trials with the 600-ms deadline, followed by 300 more trials with the 2-sec deadline. The NASA TLX was given at the end of each part along with five-minute breaks. After the experimental phase concluded, participants filled out a demographics questionnaire, a stress inventory, and a personality inventory.

3 Results

3.1 NASA TLX

As a manipulation check, a repeated measure ANOVA was performed on the composite NASA TLX scores. NASA-TLX scores range from 0 (no workload) to 100 (high workload). There was an effect of stress, $F(2,98) = 71.43$, $p < .001$. Workload ratings in the first experimental block ($M = 44$) increased when the 600-ms deadline was imposed ($M = 68$) and returned to pre-stress levels when it was removed ($M = 45$).

3.2 Practice Session

RT less than 200 ms and trials where participants did not respond within the given time frame (2 s or 600 ms) were excluded (less than 2% of all trials). Mean correct RT and ER for each participant were submitted to a 4 (mapping condition: corresponding, mirror-opposite, random, mixed) x 16 (practice blocks of 100 trials) mixed ANOVA, with mapping condition as the between-subjects variable.

Reaction time. The main effects of practice block, $F(15,660) = 13.14$, $p < .001$, and mapping condition $F(3,44) = 19.38$, $p < .001$ were significant. However, these effects were modified by a 2-way interaction between practice block and mapping condition, $F(45,660) = 2.19$, $p < .001$, see Fig. 4. RT decreased across the learning phase, and there was a benefit for compatible over incompatible mappings. However, RT decreased more for the incompatible mapping conditions than for the compatible mapping.

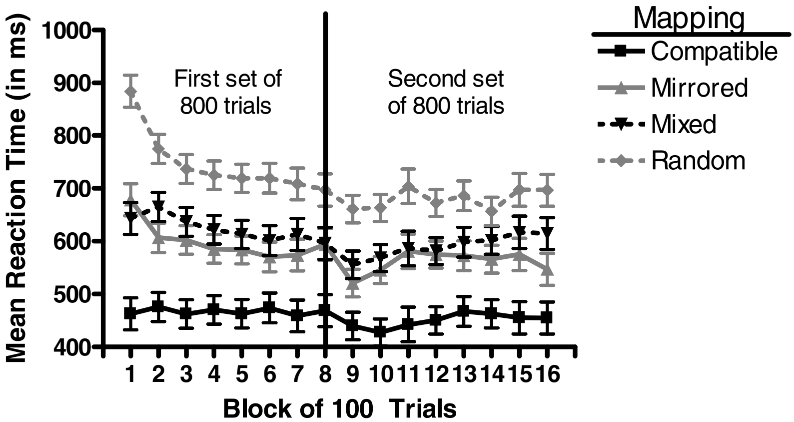

Fig. 4. Mean RT (in ms) for the Four Mapping Conditions as a Function of Practice

Error rate. An error was counted if participants did not respond within the given time frame (2 seconds for the no stress or 600 ms for the stress condition) or if they selected an incorrect response. As with RT, the main effects of block, $F(15,660) = 14.13$, $p < .001$, and mapping condition, $F(3,44) = 12.09$, $p < .001$, were significant. These effects were modified by a 2-way interaction of the two variables, $F(45,660) = 4.17$, $p < .001$. Similar to the RT analysis, the decrease in ER with practice was larger for the incompatible (Mean Difference, *MD,* = 12.59% for random, 5.89% for mirror-opposite and 4.6% for mixed) mapping conditions than for the compatible (*MD* = .26%) one.

3.3 Experimental Session

A 2 (stress, no stress) X 4 (mapping condition: corresponding, mirror-opposite, random and mixed) X 6 (blocks of 100 trials) mixed ANOVA was performed on RT and ER.

Reaction time. The main effect of stress, $F(1,220) = 75.43$, $p < .001$, showed that RT was shorter when the response deadline was applied than when it was not. The main effect of trial block, $F(15,660) = 13.14$, $p < .001$, showed a practice effect. The main effect of mapping, $F(3,44) = 19.38$, $p < .001$, showed that RT was shortest for the compatible mapping, intermediate for the mirror-opposite and mixed mappings, and longest for the random mapping.

Mapping condition entered into two-way interactions with stress, $F(3,220) = 5.53$, $p < .05$, and trial block, $F(15,220) = 7.74$, $p = .001$, and a three-way interaction with stress and block, $F(15,220) = 2.61$, $p = .001$ (see Fig. 5). In general, with no stress, RT decreased more for incompatible mapping conditions than for the compatible mapping condition. When the stress was applied; however, RT was relatively constant across blocks.

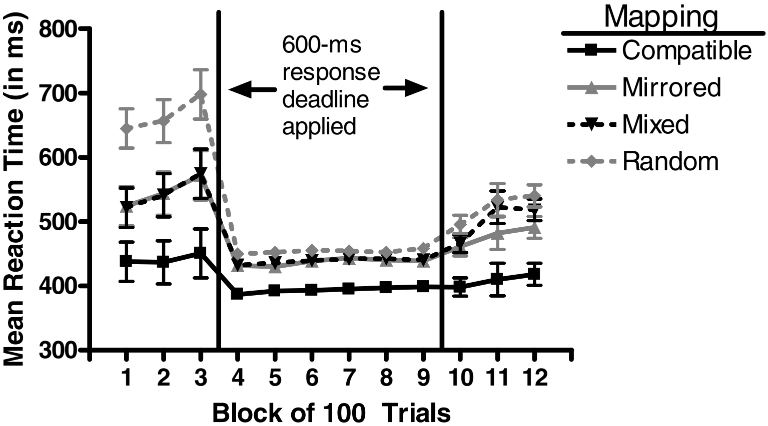

Fig. 5. Mean RT (in ms) for the Four Mapping Conditions as a Function Trial Block and Stress

Errors. Only trials in which participants selected the incorrect response were counted in the error analysis, see Fig. 6. The main effects of stress, $F(1,220) = 58.79$, $p < .001$, block $F(5,220) = 15.99$, $p < .001$, and mapping condition, $F(3,44) = 9.85$, $p < .001$, were significant. The only other significant effect was the interaction of stress and mapping condition, $F(3,220) = 9.91$, $p < .001$. ER between the stress and the no stress blocks increased by the smallest amount for the compatible mapping, by an intermediate amount for the mirror-opposite and mixed mappings, and by the largest amount for the random mapping. That is, when the stress was applied, the ER increased more for the incompatible than for the compatible mappings, especially for the random mapping.

Table 1. Types of Errors (%) Made in No Stress, and Stress Blocks by Mapping Condition

	No Stress blocks		Stress blocks	
Condition	Corresponding	Other (ind*)	Corresponding	Other (ind*)
Corresponding	N/A	47 (15.7)	N/A	53 (17.7)
Mirrored	18	23 (11.5)	29	30 (15)
Random	25	16 (8)	37	22 (11)
Mixed	23	25 (12.5)	42	10 (5)

*Percent of time that one of the possible alternative “other” responses would be selected

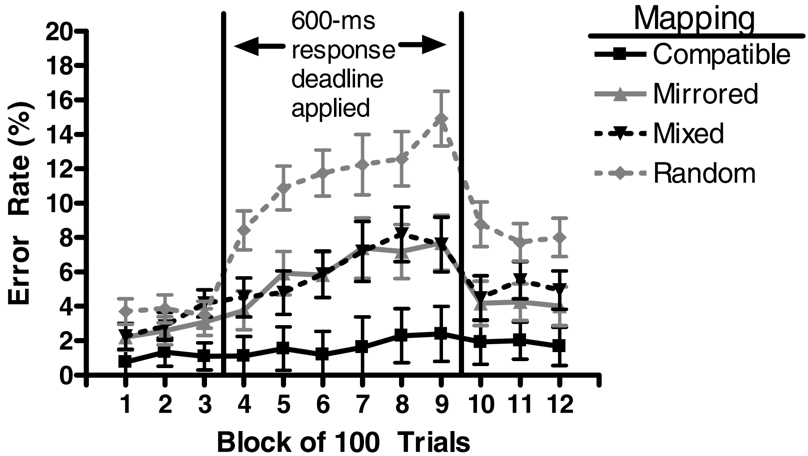

Fig. 6. Mean error rate for the Four Mapping Conditions as a Function Trial Block and Stress

To investigate the types of errors participants made, the percentage of errors involving a corresponding response versus other errors was calculated (see Table 1). In the no stress blocks, participant made corresponding errors more often than other errors. The same pattern was seen in the stress blocks, but the effects were enhanced.

4 Discussion

Previous research has investigated the S-R compatibility effect with mappings that varied in degree of compatibility [2, 5] and with time-constraint stressors [7], but few, if any, have combined both approaches as in the present study. Our results showed that with practice, RT for the incompatible mapping conditions decreased more than for the compatible one. This indicates a larger room for improvement for incompatible mappings [see also 2]. In addition, when a time-constraint stressor was added, the RT for the incompatible mappings decreased to the level of the compatible one. However, the ER data from the stress blocks shows a different story, where the ER increases instead of decreasing. Thus, in the stress blocks, there appears to be a tradeoff between speed and accuracy for the incompatible mapping conditions, but not for the compatible one.

For all incompatible mapping conditions, participants tended to revert back to responding with the compatible response under stress. However, the time-constraint stressor exerts differential impact on performance for the three incompatible mapping conditions. The mirror-opposite and mixed mappings yielded lower RT and ER, and were more resistant to stress, than the random mapping. Moreover, performance may be more impacted by the systematic nature of the S-R mappings rather than by the number of rules employed. Performance for the mirrored and mixed conditions was similar, even though the former conforms to one rule and the latter to two rules.

In general, display-control interfaces should be designed in a manner that is compatible with users' natural response tendencies. However, if a design cannot match users' natural response tendencies, due to design limitation or space constraints, then a systematic mapping rule should govern the mapping of display to control elements in the design. Moreover, when an interface is designed to be used under conditions where rapid responding is required and has a non-corresponding mapping, the interface should be tested under speeded conditions using different display-control configuration.

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