Effects of Report Order on Identification on Multidimensional Stimulus: Color and Shape

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Abstract. Two experiments were conducted to investigate the effects of order of report on multidimensional stimuli under between-subject and within-subject designs. The two orders of report were Order Color/Shape and Order Shape/Color. Eighteen participants responded according to the instructed one of the two orders of report in between-subject study. Results showed that response time for Order Color/Shape was significantly shorter than Order Shape/Color. Order Color/Shape, fit the Chinese "adjective then noun" grammar, is more appropriate if people report stimulus attributes in ways consistent with their long-standing language habits. However, another group of eleven participants were required to respond according to task cue alternately in within-subject study. Results showed that switch cost as indicated by response times increase was greater for Order Color/Shape than Order Shape/Color (97 msec. vs. 41 msec. for response time for the first stimulus dimension; 95 msec. vs. 28 msec. for response time total). Such results didn't support the hypothesis that the switch cost would be greater for Order Shape/Color than for Order Color/Shape. The order in which the color attribute should be considered very clearly.

Keywords: report order, multidimensional stimulus identification, task switch, color coding.

1 Introduction

The problems in designing displays have been among the most important topics in human factors engineering. Compacting information into a single multidimensional stimulus can be an effective way of utilizing limited display space and reducing clutter [1]. It may also facilitate integration of information [2] and reduce mental workload [3] [4].

1.1 Report Order

If operators search the dimensions in a particular order, it implies the discriminability of two symbols is determined by the specific order in which features are examined [5]. To develop an optimal symbol set the designer must take into account the order of the search through the dimensions. Likewise, the order of reporting dimensional values

D. Harris (Ed.): Engin. Psychol. and Cog. Ergonomics, HCII 2009, LNAI 5639, pp. 307–316, 2009.
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may play an important role in the accuracy and speed of identifying targets. Shieh and his colleagues [6] [7] investigated the effects of order of report on the speed and accuracy of identifying multidimensional stimuli. They found that subjects responded faster and more accurately if there was a natural language-appropriate order of reporting the dimensional attributes. The stimuli they used were a subset of the Naval Tactical Display System symbols [8] (stimulus set see Fig.1). Two dimensions were attached to each symbol. The first dimension was Shape. The second dimension was Part. They found that the order of reporting dimensional values affected the speed and accuracy of identification. Subjects responded faster and more accurately if the order of reporting stimulus-dimension values was appropriate. The appropriate order of report is the order in which long-standing habits based on a standard word order are not violated. Reporting the Part dimension first then the Shape dimension is more consistent with the "adjective then noun" habit of native speakers of American or Chinese. For example, reporting a whole circular shape by "full circular" is more natural than reporting it by "circular full," hence giving effects of order of report. Such results were consistent with the finding of Harris and Haber [9] that performance based on "adjective then noun" order is better than that based on the reverse order. But this report-order behavior effects was failed to replicate in another study [10] [11], suggesting that this may be not a robust finding.

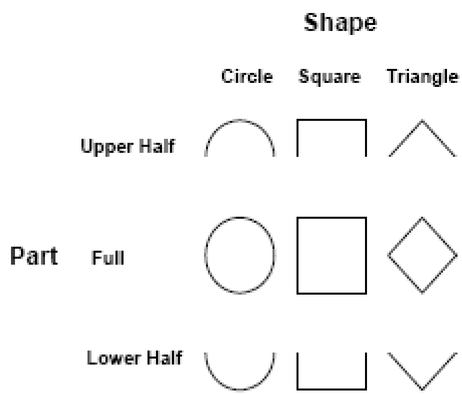

Fig. 1. Nine symbols defined by part and shape dimensions. Each dimension had three values.

1.2 Compatibility

The order of report in a multidimensional situation might be considered to be one type of S-R compatibility. Reporting the Part dimension first then the Shape dimension is more consistent with the "adjective then noun" habit of native speakers of American or Chinese. The order of report effect is a case of S-R compatibility; that is S-R compatibility is greater for Order Part/Shape than Order Shape/Part.

1.3 Task Switch

In task-switching paradigm, subjects are given two tasks. On some trials, subjects switch between the tasks while on others they repeat the previous task. A robust finding indicates that, when a task is performed on a switch trial (Task B then Task A), there is a sizable decrement in performance measured as increased reaction time or decreased accuracy compared with performance of a task which is repeated (Task A then Task A). This decrement is called switch cost and measured by reaction time [12] [13]. Gilbert and Shallice [14] suggested that the asymmetry of task switch cost is obtained when the two tasks demand larger differences in top-down control input, as in the classic Stroop tasks. It is easier to switch to the weaker task. The reverse pattern obtained when the tasks differ principally in the strength of their S-R mapping, as with typical S-R compatibility effects. If an experimental paradigm that amalgamates a task-switch design with two report orders as the two tasks is implemented. The appropriate order of report is the order in which long-standing habits based on a standard word order are not violated. The order of report effect is a case of S-R compatibility; that is S-R compatibility is greater for the appropriate order than the other. Based upon the results of the task-switching paradigm, it was assumed that switching from the report order of low S-R compatibility to the report order of high S-R compatibility is easier than switching in the opposite direction. In other words, if the report order of high S-R compatibility is indeed more appropriate, the effectiveness should be obtained by the asymmetry of task switch cost. Switch cost will be greater for the report order of low S-R compatibility than the report order of high S-R compatibility.

1.4 Color Dimension

Another important multidimensional stimulus code is color, which has been one of the most studied coding techniques. Color attracts attention, enhances contrast between objects, and even appeals to our esthetic senses [2] [15]. The effect of order of report in multidimensional situations involving color coding has been an ambiguous issue at best. Some studies [1] [16] [17] suggested that color is less vulnerable to order of report effects and that memory for color deteriorates less during a retention interval than does memory for other stimulus attributes, hence, reporting color later may have an advantage. Other researchers [18] [19] considered color to be a natural adjective and an attention attractor, which should be coded for important stimulus dimensions and those to be reported first. Shieh and Chen [7] suggested that the order in which the color attribute should be reported depended on the characteristics of the stimulus dimensions. If there was a natural language-appropriate order of reporting the dimensional attributes, the color attribute should be used as an adjective and reported first. Otherwise, reporting color attribute later seemed to have an advantage because color is less vulnerable to memory deterioration. To identify the efficiency gain involving color coding in processing multidimensional information deserves further empirical study.

1.5 Hypotheses

Both color and shape dimensions were used in the multidimensional stimulus in the present study. If the effects of natural language order effect can be consistent, the performance of Order Color/Shape will be better. We have two hypotheses: first, participants respond faster for Order Color/Shape than Order Shape/Color in between-subject and within-subject design studies. Secondly, response times would be longer for Order Shape/Color, switch trials, and switch cost would be greater from Order Color/Shape to Order Shape/Color than in the opposite direction.

2 Method

Two experiments are designed to provide information regarding the intention. In Exp. 1 one group report in color-shape order (Order Color/Shape) and the other group report in shape-color order (Order Shape/Color). The Order Color/Shape is a natural language order. Exp. 2 was designed to investigate performance using switch task paradigm; that is, order of reporting stimulus dimension was a within-subject factor. Experiment 1: Between-Subject Design.

2.1 Participants

Eighteen male college students between 19 and 26 years old (*M*=21.5 yr., *SD*=1.9) were tested. All had 18/20 corrected visual acuity or better and normal color vision. The participants were paid for their participation.

2.2 Stimuli

Nine symbols were used as the stimulus set (see Fig.2). Each of these nine symbols was encoded with two basic dimensions. The first dimension, "color," was yellow, green, or red. The second dimension, "shape," was circular, square, or angular. Nine stimuli were used, presented against a black background. The height and width of the stimuli were about 1 cm by 1 cm. The luminance of display symbols was about 35cd/m^2 on a black background.

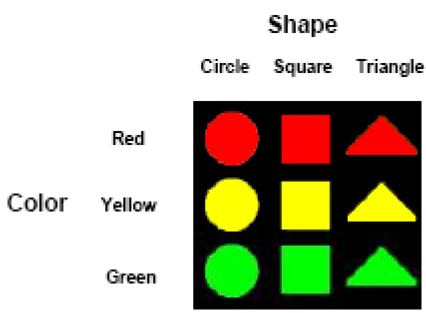

Fig. 2. One Nine symbols defined by color and shape dimensions. Each dimension had three values.

2.3 Design

A between-subject design was conducted with 18 male participants randomly assigned to the two order conditions. There were 9 participants in each treatment group. The study evaluated one independent variable, order of report, with two levels. In Order Color/Shape, participants were instructed to report the "color" dimension first and the "shape" dimension second. In Order Shape/Color, the order of report was reversed. A block consisted of 8 random presentations of the 9 symbols. There was one practice blocks prior to the experiment. Participants completed six blocks of 72 trials in experiment. There was a 2-min break between blocks.

2.4 Procedure

The symbols were presented one per trial at the center of the display during the identification task. Viewing distance between the participant and display was approximately 60 cm. The symbols were presented till the participants completed the response. Before each trial, a participant fixated on a small cross on the middle of the screen. The cross was presented for 0.9 sec prior to the onset of each stimulus. Each symbol could be identified on two dimensions according to the instructed order of report for the particular experimental conditions. The participants were instructed to identify the symbol presented during each trial by pressing the buttons that defined the symbols on a keypad. Two columns on the keyboard, three buttons in each column, were labeled with the descriptive names. The two columns represented the two stimulus dimension, and the three buttons in each column represented the three values of that dimension. Participants were instructed to enter the dimensional value of the left column first, and then enter the dimensional value of the right column. The order of report was manipulated by the dimension the left or right column represented. Each participant responded to the two stimulus dimensions by using the right index finger.

2.5 Performance Measures and Data Analysis

Behavioral data were averaged separately for each order of report condition. Four behavioral measures were collected. Response time for the first stimulus dimension (RT_1) was the time between the presentation of a symbol and the subjects' correct response to the first dimension. Response time for the second stimulus dimension (RT_2) was the time between subjects' identification of the first dimension and their correct response to the second dimension. Response time total (RT_T) was the sum of RT_1 and RT_2. Total percentage correct was 100 times the number of symbols correctly identified divided by the number of symbols presented under each experimental treatment.

2.6 Results

Table 1 shows mean response times for the first and second dimensions, total response time, and total percentage correct for each order of report. The over-all mean of response time for the first dimension (RT_1) was 826 msec.. Results of analysis of variance showed that order of report had significant effect on RT_1. Response time for RT_1 for Order Color/Shape (735 msec.) was significantly shorter ($F_{1, 16}$= 6.32, $p < .05$) than Order Shape/Part (916 msec.). The overall mean of response time for the second dimension (RT_2) was 343 msec., much shorter than for RT_1. RT_2 were 298 msec. and 388 msec. for Order Color/Shape and Order Shape/Color. However, these differences were not significant. The overall mean total response time (RT_T) was 1169 msec.. Results of analysis of variance showed that order of report had significant effect on RT_T. RT_T for Order Color/Shape (1034 msec.) was significantly shorter ($F_{1, 16}$= 5.90, p < .05) than Order Shape/Color (1304 msec.). Apparently, RT_1 was the more important component for RT_T than response time for RT_2. The overall percentage correct was 94.9, 95.8% for Order Part/Shape and 94.1% for Order Shape/Part. Analysis of variance performed on the percentage correct showed no significant effect.

Table 1. Means and Standard Deviation (msec.) for the Four Behavior Measures for Each Report Order

Experimental Condition	*n*	RT_1		RT_2		RT_T		% Correct	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Color/Shape	9	735	151	298	94	1034	237	92.6	4.8
Shape/Color	9	916	153	388	118	1304	234	95.8	3.1
Grand mean	18	826	174	343	113	1169	267	94.2	4.2

3 Experiment 2: Within-Subject Design

3.1 Participants

Eleven male college students, another group different from experiment 1, between 19 and 24 years old (*M*=20.8 yr., *SD*=1.6) were tested. All had 18/20 corrected visual acuity or better and normal color vision. The participants were paid for their participation.

3.2 Design and Procedure

The experimental stimulus sets and performance measures were the same as those used in Exp. 1, except as noted below. There was a task cue prior to each presentation of a symbol indicating which task the participant was to perform. For example, if the task cue was 'color/shape', then the participant had to report the 'color' dimension first and the 'shape' dimension second by pressing the appropriate buttons on the keypad. If the task cue was 'shape/color,' then the order of report was the reverse. The task cue changed randomly. On a non-switch trial, the task cue was preceded by the same task cue; on a switch trial, the task cue was preceded by a different task cue. The task cue was presented for 0.9 sec prior to the onset of each stimulus. Each participant completed five blocks; each block consisted of eight random presentations of the nine symbols (a total of 72 trials). The task cue was randomly selected and balanced for each stimulus. There was one practice blocks prior to the experiment. The independent variables in the analysis were 2×2 within-subjects factors and included order of report (Order Color/Shape or Order Shape/Color) and trial type (switch trial or non-switch trial).

3.3 Results

Tables 2 to 5 summarize the means and standard deviations for the four dependent measures for the two orders of report and the two trial types of switch and non-switch trial separately. The switch cost was calculated by subtracting the mean reaction time on non-switch trials from the corresponding values on switch trials. The over-all mean of response time for the first dimension (RT_1) was 1097 msec. Analysis of variance showed that order of report had significant effect on RT_1. RT_1 for Order Color/Shape (1144 msec.) was significantly longer ($F_{1, 10}$= 14.49, p <.01) than Order Shape/Color (1050 msec.). The effect of trial type was statistically significant ($F_{1, 10}$=12.58, p < .01). RT_1 was greater for switch trial (1132 msec.) than for non-switch trial (1063 msec.). Interaction between order of report and trial type was not significant. The overall mean of response time for the second dimension (RT_2) was 388 msec., much shorter than for RT_1. RT_2 were 372 msec. and 403 msec. for Order Color/Shape and Order Shape/Color. The difference was statistically significant ($F_{1, 10}$= 5.58, p < .05). The effects of trial type and interaction between order of report and trial type were not significant. The overall mean total response time (RT_T) was 1485 msec.. Results of analysis of variance showed that order of report had significant effect on RT_T. RT_T for Order Color/Shape (1517 msec.) was significantly longer ($F_{1, 10}$= 12.09, p < .01) than Order Shape/Color (1454 msec.).The effect of trial type was statistically significant (switch trial: 1516 msec.; non-switch trial: 1455 msec.; $F_{1, 10}$= 11.21, p < .01). Interaction between the two factors was not significant. Analysis of variance performed on the correct rate showed no significant effect for order of report (Order Color/Shape: 80.2.6%; Order Shape/Color: 80.8%). However, the effect of trial type was statistically significant (switch trial: 77.7%; non-switch trial: 83.2%; $F_{1, 10}$= 6.32, p < .05). Interaction between the two factors was not significant.

Table 2. Means and Standard Deviations (msec.) of RT1 for Each Experimental Condition

	Switch		**Non-Switch**		**Switch Cost**		
	M	*SD*	*M*	*SD*		*M*	*SD*
Color/Shape	1193	344	1096	310	[97]	1144	323
Shape/Color	1071	306	1030	280	[41]	1050	287
	1132	324	1063	290	[69]	1097	306

Table 3. Means and Standard Deviations (msec.) of RT2 for Each Experimental Condition

	Switch		**Non-Switch**		**Switch Cost**		
	M	*SD*	*M*	*SD*		*M*	*SD*
Color/Shape	372	88	374	81	[-2]	372	83
Shape/Color	398	100	410	113	[-12]	403	105
	385	93	392	98	[-7]	388	94

Table 4. Means and Standard Deviations (msec.) of RTT for Each Experimental Condition

	Switch		**Non-Switch**		**Switch Cost**		
	M	*SD*	*M*	*SD*		*M*	*SD*
Color/Shape	1565	403	1470	366	[95]	1517	379
Shape/Color	1468	377	1440	370	[28]	1454	365
	1516	384	1455	359	[61]	1485	369

Table 5. Means and Standard Deviations of Correct Rate for Each Experimental Condition

	Switch		Non-Switch		Switch Cost		
	M	*SD*	*M*	*SD*		*M*	*SD*
Color/Shape	76.3	8.6	84.1	7.6	[-7.8]	80.2	8.8
Shape/Color	79.1	11.2	82.4	6.1	[-3.3]	80.8	8.9
	77.7	9.8	83.2	6.8	[-5.5]	80.5	8.8

5 Discussion and Conclusions

Shieh, *et al.* [6] suggested that subjects responded faster and more accurately if the order of reporting stimulus dimension was natural language-appropriate. In Exp.1, results showed that response time for the first stimulus dimension (RT_1) and response time total (RT_T) for Order Color/Shape was significantly shorter than Order Shape/Color. Results suggest that Order Color/Shape, fit the Chinese "adjective then noun" grammar, is more appropriate if people report stimulus attributes in ways consistent with their long-standing language habits. Results in Exp.1 support findings by Shieh, *et al.* [6] and Shieh and Lai [20] [21]. However, results in Exp.2 didn't support natural language order effect.

Comparison of the results of Exp. 1 and 2 showed that the participants' responses in Exp. 2 were significantly slower than those in Exp. 1. Participants responded according to the instructed report order and had no need to switch the other report order in Exp.1. However, as contextual requirements changed randomly in Exp. 2, previously information became irrelevant and cognitive processes need to be reconfigured to deal with changing contextual demands, suppressing previously relevant report order and implementing the currently report order. In Exp.2 with respect to the effect of task switch, the results showed that RT_1, RT_T and error rate were significant greater for switch trial than for non-switch trial. Exp.2 has revealed that even a simple switch between one of two response rules will take normal individuals extra time to complete.

Performance on a more demanding task (within-subject study) may differ unexpectedly from performance on a simple task (between-subject study). Order Color/Shape is more appropriate and supports that if people report stimulus attributes in ways consistent with their long-standing language habits in Exp.1. However, that report order effect was not consistent in Exp.2. RT_1 and RT_T for Order Color/Shape were significantly longer than Order Shape/Color. Moreover, switch cost for RT_1 and RT_T was greater from Order Shape/Color to Order Color/Shape than in the opposite direction. These results are contrary to the findings by Shieh and Shen [10]. Different stimulus sets might be responsible for the different results. Color dimension is an attention attractor and not a spatial attribute like shape or part. Attention research by Treisman [22] clearly showed that some dimensions are preattentively discriminated and have a special status (like color or orientation) whereas others are not. With respect to the effect of task switch, switch cost for RT_1 and RT_T was greater from Order Shape/Color to Order Color/Shape than in the opposite direction. Our second hypothesis that the switch cost would be greater for Order Color/Shape than for Order

Shape/Color were not supported by these data. Further empirical study deserves to identify the effects involving color coding in processing multidimensional information.

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