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Introduction

Methods

For the category-learning task, we used the procedure in Ashby et al. (2003), which distinguished indicators in performance between rule-based versus information-integration category learning. To generate our verbal and non-verbal interference tasks, we referenced the method used in Gilbert et al. (2006), which interleaved the interference and the main task to allow us to develop our 2-back matching interference paradigm.

Participants

122 participants were recruited from the University of California, Berkeley and received course credit for participation. All the participants (mean age = 20.5 years) reported 20/20 vision or vision corrected to 20/20. Each individual participated in only one of the six experiment conditions, resulting in the following breakdown: rule-based/control (no interference), rule-based/verbal, rule-based/spatial, information-integration/control (no interference), information-integration/verbal, and information-integration/spatial. (From this point forward, they will be referred to as RB-C, RB-V, RB-S, II-C, II-V, and II-S, respectively).

Stimuli Generation

Category-learning stimuli: Every stimulus was a line that varied across two dimensions âĂŞ length and orientation. Two sets of 600 unique lines were generated for each type of category structure using the procedure described in Ashby et al. (2003). Each point in Figure 1 indicates the length and orientation of each unique line. The rule-based category structure was unidimensional âĂŞ it only required the participant to attend to line length and ignore orientation completely. Participants often described the categories as âĂIJone category was for short lines and the other was for long lines.âĂİ On the other hand, the information-integration category structure required participants to perceive both dimensions. If a rule-based rule were used, it would only result in 70% accuracy at best. Unlike the rule-based structure, the information-integration condition is difficult to describe verbally.

Interference stimuli

For the verbal interference task, the display presented a single word randomly selected from this set: âĂIJthin,âĂİ âĂIJthick,âĂİ âĂIJstraight,âĂİ âĂIJcurved,âĂİ âĂIJsolid,âĂİ âĂIJnarrow,âĂİ âĂIJslim,âĂİ âĂIJbent,âĂİ âĂIJwide,âĂİ âĂIJangled,âĂİ and âĂIJcrooked.âĂİ These words were specifically selected due to their association in typically being used to describe types of lines. For the spatial (non-verbal) interference task, the display showed a 5cm x 5cm grid in which 12 of the squares were black and 13 were white. A set of 15 unique displays were generated and randomly selected to display.

Procedure

The experiment was run in a designated room on a computer. Participants were given brief verbal instruction prior to the beginning of the experiment in which the general format of the experiment was explained.

The experiment duration was about 60 minutes, with 12 blocks total, each block consisting of 50 trials for a total of 600 trials. The participant would be notified of each new block with a display that stated the Block number. The category-learning stimuli and interference displays were interleaved (Figure 2). A fixation marker was shown for 1.25 s. It was then followed by either a word (verbal interference) or a grid (spatial interference) for 1.5 s. The participant would then try to recall if the interference display was the same as the interference display from two trials prior (two-back match). If it was the same, the participant would press the space bar. No key press was required for a non-matching interference.

For the interference task, the participants were urged to respond as quickly as possible. No feedback was given to the participant regarding the accuracy of their performance on the interference task. The fixation screen then reappeared for another 1.25 s, followed by one of 600 randomly selected category-learning lines. The line would be displayed until the participant pressed one of the two category-learning keys. The category-learning keys were âĂIJDâĂİ and âĂIJKâĂİ on a standard QWERTY keyboard. The keys were indicated with two different-colored squares that covered the letter. Feedback was immediately displayed, with the screen displaying either the word âĂIJCorrectâĂİ or âĂIJWrongâĂİ for 1 s. If they exceeded the 5-second response requirement, âĂIJPlease respond within 5 secondsâĂİ was displayed on the screen for 1 s and the trial was discarded. Performance in the interference task was emphasized over that in the categorization task.

Participants were also instructed that the response keys for the category-learning task would switch for the last two blocks (Blocks 11 and 12). Additionally, the response requirement for the category-learning task would decrease from 5 sec to 1.5 sec to prevent participants from inhibiting their initial response. If they exceeded the 1.5 sec response requirement, âĂIJPlease respond within 1.5 secondsâĂİ was displayed on the screen for 1 s and the trial was discarded. Participants were assured that they would be informed of these changes immediately before they occurred. âĂIJRespond quickly and the response buttons will now be switchedâĂİ was displayed on the monitor immediately prior to the change. The interference task remained constant throughout the entire experiment.

Results

Dual-Task Performance

Overall performance on the secondary task was good, with mean accuracies of 0.74 in the V-RB condition, 0.72 in the S-RB condition, 0.72 in the S-II condition, and 0.80 in the V-II condition (see Fig. 1). A one-way ANOVA with condition as a factor revealed that these differences were not significant [$F(3, 106) = 2.03, p = 0.11$].

Category Learning Performance

Performance during the training phase (i.e., every block up until the button switch) of the expierment is shown in Fig. **??**. Within the II conditions, there were no significant differences according to a one-way ANOVA [$F(2, 69) = 2.97, p = 0.06, Omega = 0.08$]. This ANOVA used condition as a factor and the mean accuracy across the entire experiment for each participant as the observations. However, independent samples t-tests revealed a significant difference between the II-S and the II-V conditions [$t(29) = -2.56, p = 0.02, d = 1.22$], but not between the other pairwise comparisons [II-S vs II-N: $t(31) = -1.43, p = 0.16, d = 0.37$; II-V vs II-N: $t(45) = 1.29, p = 0.20, d = 0.25$].

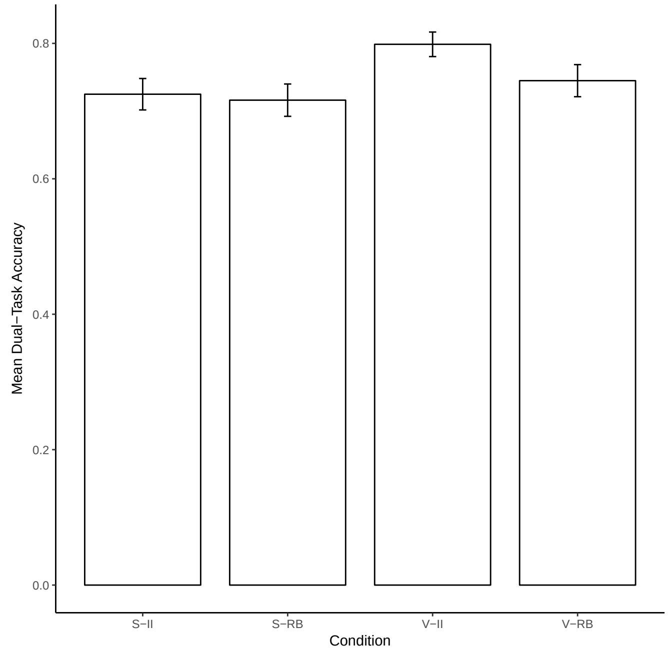

Figure 1. Mean dual-task accuracy across the entire experiment plotted separately for each condition. Error bars are SEM.

Within the RB condtions, there were large significant differences according to the same one-way ANOVA just described for the II condtions [$F(2, 83) = 17.11, p = 0.00, Omega = 0.29$]. Pairwise comparisons using independent samples t-tests revealed that each RB condition is significantly different from every other RB condition [RB-N vs RB-S: $t(39) = 3.16, p = 0.00, d = 1.59$; RB-N vs RB-V: $t(58) = 7.05, p = 0.00, d = 6.54$; RB-S vs RB-V: $t(52) = 2.54, p = 0.01, d = 0.90$]. Visual inspection of Fig. 2 clearly shows that these differences show that both dual-tasks dignificantly impaired category learning performance relative to the no dual-task control, and further shows that verbal dual task caused much more interference than the spatial dual task.

Button Switch Performance

Fig. 3 shows the button-switch cost – defined as mean block 10 accuracy minus the mean block 11 accuracy – plotted separately for each condition.

The button-switch cost was significant in the II-N [$t(24) = 2.60, p = 0.02, d = 1.38$] and II-V [$t(20) = -0.06, p = 0.95, d = 0.00$] conditions, but was not significant in any other condition [II-S: $t(25) = 0.62, p = 0.54, d = 0.08$; RB-N: $t(22) = 0.43, p = 0.67, d = 0.04$; RB-V: $t(36) = 1.66, p = 0.11, d = 0.46$; RB-S: $t(25) = 3.44, p = 0.00, d = 2.37$;].

The difference in button-switch cost was not significantly different betweeen any pair of RB conditions [RB-S vs RB-

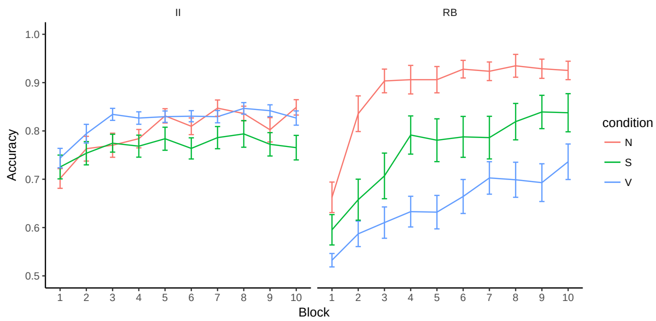

Figure 2. Mean classification accuracy across participants computed sepatately for each condition and block of the experiment. Error bars are SEM.

V: $t(55) = -1.87, p = 0.07, d = 0.47$; RB-N vs RB-S: $t(47) = -0.22, p = 0.82, d = 0.01$; RB-N vs RBV: $t(50) = -1.64, p = 0.11, d = 0.38$].

The difference in button-switch cost in the II-S condition was significantly different from the cost in the II-N condition [II-N vs II-S: $t(47) = 2.96, p = 0.00, d = 1.28$], but not significantly different than the cost in the II-V condition, [II-V vs II-S: $t(42) = 1.98, p = 0.05, d = 0.61$] although this latter difference was nearly significant. The difference in button-switch cost between the II-V and the II-N condition was not signifiant [II-V vs ii-N: $t(44) = -0.93, p = 0.36, d = 0.13$].

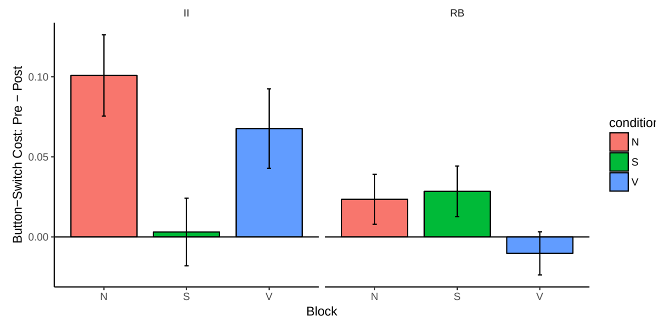

Figure 3. Mean Accuracy difference between the last block of training and the first block of the button-switch (block 10 - block 11) plotted separately for each condition. Error bars are SEM.

Discussion