Investigating Predictive vs. Random Task-Switching Using the CVOE Task

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Abstract

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*Keywords:* Task-Switching; CVOE; Attentional Control; Working Memory

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Selectively attending to relevant information within one’s environment is a key element of goal-directed behavior. Attentional control allows individuals to ignore salient but unrelated information from the environment that would otherwise produce distractions. Traditionally, researchers have investigated attentional control using by contrasting task-related information (i.e., congruent trials) with information that is task-unrelated (i.e., incongruent trials). These studies consistently show that for incongruent trials, both response times (RTs) and error rates are increased relative to congruent trials. A classic example of this effect is Stroop’s (1935) seminal study investigating color naming, as both RTs and error rates were increased for color words presented in an incongruent ink (e.g., “Blue” presented in green ink) relative to when a congruent ink was used (e.g., “Blue” presented in blue ink). Often, these decreases in performance are exaggerated for incongruent trials immediately following congruent trials (congruency sequence effect, CSE; Aschenbrenner & Balota, 2018, [CITE])

Deficits in attentional control have been linked to decreased performance on the Stroop color naming task. For example, Spieler, Balota, & Faust (1996) showed that performance on the Stroop task decreased as a function of both healthy aging and Alzheimer’s Disease (AD) diagnosis. Specifically, compared to younger adults, healthy older adults showed increased RTs (but not error rates), while AD individuals exhibited large costs to RTs and error rates, even when matched to healthy individuals of the same age. More recently, Hutchison, Balota, & Ducheck (2010) found the Stroop task could be used to discriminate healthy aging from AD, suggesting that this task is sensitive to declines in attentional control inherent to AD. Thus, it is evident that attention plays a critical role in keeping internal goals active as breakdowns in attentional control cause participants to experience greater difficulty staying on task.

While the Stroop task has been commonly used to investigate attentional control processes [CITES], researchers have also made use of task-switching paradigms in which participants alternate between completing a set of contrasting tasks (Jersild, 1927; CITE, see XXX). In a standard task-switching experiment, participants are presented with at least two conditions. First, participants complete *pure blocks* which focus exclusively on one task (i.e., participants only complete addition problems). Participants then complete *switch blocks* in which they must quickly alternate between two contrasting tasks (i.e., addition on trial one but subtraction on trial two). Response times (RTs) and error rates are then compared between the two blocks. Typically, these studies show a switch cost, such that RTs are higher are participants commit more errors when switching between tasks.

Although a variety of paradigms have been used to investigate task-switching effects, the present study focuses specifically on paradigms in which a comparison can be made between local and globalswitch costs (e.g., EXAMPLE; CITE, CVOE task; Minear & Shah, 2008). These paradigms initially present participants with a set of pure blocks (one corresponding to each task). These pure blocks are immediately followed by a switch block in which switch and non-switch trials are interleaved (e.g., switch, non-switch, switch, non-switch, etc.). First, the *global switch cost* refers difference between switch trials and pure block trials and represents the cost of maintaining multiple task configurations in a switch block compared to a single task configuration within the pure block (Minear & Shah, 2008; Wylie & Allport, 2000). Alternatively, the *local switch cost* is found by computing the difference between switch and non-switch trials presented within the same switch block. Local costs represent task-set reconfiguration processes that occur due to participants changing tasks-sets within the same block of trials (Rogers & Monsell, 1995; see Huff, Balota, Minear, Aschenbreener, & Ducheck, 2015, for a review).

While several factors have been shown to affect the magnitude of switch costs (see XXX), previous research has shown that these costs are particularly magnified whenever the stimuli do not clearly signal to participants which of the two tasks is to be performed (Luwel, Schillemans, Ongehan, & Vershaffel; 2009). Termed *bivalent* stimuli, these items activate both task-sets used in a switch task (i.e., presenting participants with letter-number pairs and having them switch between classifying the letter or number), unlike *univalent* stimuli, which only correspond to one task-set (i.e., presenting participants with only letters or numbers). Because bivalent stimuli typically produce greater switch costs, researchers have often made use of them when investigating switching. For example, [BIVALENT SHAPE TASK]

[TRANSITION] the Color-Word Interference Task (CWIT; Delis, Kaplan, & Kramer, 2001) employs bivalent stimuli, as ALL EXAMPLES EXCEPT CVOE!] [BIVALENT SWITCH TASKS HERE -- CWIT AND OTHERS?]

[TRANSITION] A commonly used bivalent switch task is the Consonant-Vowel Odd-Even task (CVOE; Minear & Shah, 2008). [TRANSITION] is a simple task-switching paradigm that allows the measurement of both local and global task switching costs. [OVERVIEW OF THE CVOE/HOW DOES IT COMPARE TO OTHER SWITCH TASKS?

[TRANSITION TO GET US TO AGING] Regarding task-switching paradigms like CVOE, older adults with mild cognitive impairments (MCI) like as Alzheimer’s Disease often commit more errors and have slower RTs relative to younger adults and non-impaired older adults. Additionally, task performance for MCI older adults is particularly affected for switch trials compared to trials in which the task set does not change. Additionally, work by Huff et al. (2015) has shown that global switch costs (switch trials compared to pure trials) increase as a function of both age and MCI status, suggesting that…[EXPAND]. [ADD A SENTENCE OR TWO HERE ON WHY THE CVOE SPECIFICALLY IS USEFUL] Regarding younger adults…. [EXPAND]

Although researchers have used the CVOE to investigate a variety of questions regarding task-switching, previous work using this paradigm has routinely used switch blocks in which switches occur in a predictable sequence. [INTRODUCE ALTERNATING RUNS HERE] In this presentation pattern, trials within switch blocks are arranged such that participants complete the same type of trial twice before the instructions switch participants to the second. Thus, participants complete two CV trials before completing two OE trials. As a result of this pattern, every other trial (following the initial trial) is a switch trial, with non-switch trials interleaved. Although this pattern [UPSIDE TO IT], [POTENTIAL PROBLEMS WITH THIS – PREDICTABILITY!] [INTRODUCE RANDOM SWITCHING HERE]

**Distributional Analyses of RTs**

Across task-switching studies, [EXPAND – SOMETHING ABOUT RTS BEING FUNDAMENTAL] Researchers studying attentional systems have commonly relied upon mean response scores (i.e., error rates and RTs) as a method to gain insight into these processes. However, because RT distributions are almost always positively skewed, with most RTs generally occurring at the faster end of the scale, an analysis of only mean RTs may produce results that are misleading (see Balota & Yap, 2011, for a review). To account for this, researchers have increasing moved away from the use of traditional measures of central tendency when assessing RTs, and instead, have elected to focus on RT distributions [SEE XXX FOR A REVIEW]. RT distributions have been shown to capture aspects of human cognition, including semantic priming (Balota, Yap, Cortese, & Watson, 2008), word recognition [CITE], and, importantly, attentional control within the context of task switching [CITE HUFF PAPER AND TRY TO FIND ONE MORE].

In the present study, we further analyze RTs using two types of distributional analyses: 1) Averaging RTs across participants and binning them via a Vincentile analysis and 2) fitting individual RTs to an ex-Gaussian distribution. First, the Vincentile analysis rank orders all RTs for each trial type at the participant level and then bins the ordered data into groups of equal size. For example, a Vincentile analyses using four bins would first each participant’s RTs from fastest to slowest. Next, for each participant, RTs within the first 25% of the data would be averaged, followed by the second 25%, third the 25%, and the final 25%. This process is then repeated for each participant, and Vincentiles are computed by taking the average of each bin across participants. [TALK ABOUT THE SHAPE OF THE DISTRIBUTION?] [NEED TO EXPAND SOMEHOW]

The ex-Gaussian analysis [EX-GAUSS HERE]

**The Present Study**

[TRANSITION – SET UP HYPOTHESES SEGUE INTO METHODS] The present study expands upon previous research investigating CVOE task-switching (e.g., [XXX AND XXX]) by incorporating both an alternating runs switch task and a randomized switch task (i.e., CV, OE, OE, OE, CV, OE) in which no discernable pattern of task switching can be detected. [DISTRIBUTIONAL STUFF]

**Comparing Error Rates and RTs for Alternating Runs vs. Random Switching**

[WORDS HERE] Overall, we expected that mean error rates and RTs would be higher on Switch Blocks relative to Pure Blocks. Furthermore, we expected that participants would particularly struggle with the switch task when switching occurred at non-predictive intervals due to the lack of pattern. We anticipated that these difficulties would result in higher error rates and greater RTs for random switch trials relative to alternating runs switch trials.

Regarding switch costs, we expected that local costs would be higher on the random switch task relative to the alternating runs. [WHY?] Global costs [GLOBAL COSTS PREDICTION]

**Method**

**Participants**

A total of 100 undergraduate students were recruited from the University of Southern Mississippi’s undergraduate research pool and completed the study in exchange for partial course credit. Data from 9 participants were removed due to excessive error rates in either the pure or switch blocks (i.e., mean error rates within a block that were > 3 standard deviations above the mean), which indicated that participants did not correctly follow task instructions. Additionally, data for two participants were removed due to a coding error. A sensitivity analysis conducted with *G\*Power* [CITE] indicated that our final sample of 89 participants was sufficient to detect XX effects [STATS]. All participants were native English speakers who reported normal or corrected to normal vision.

**Materials**

To create the stimuli, we generated a series of letter-number stimulus pairs (e.g., A 15) using the following process. First, an even number of consonants and vowels were created. These letters were always selected from A, D, E, H, I, J, O, P, S, or U. Next, a series of numbers were randomly selected between 1 and 99, with the constraint that half of the numbers selected were always even. To create the pairs, half of the consonants were paired with an odd number, while the remaining half were paired with even numbers. This process was then repeated for vowels. This resulted in an equal number of each of the four possible stimulus pair types (Consonant-Odd, Consonant-Even, Vowel-Odd, Vowel-Even) within each block. Letters and numbers repeated within blocks, however, pairs were arranged within each block such that repeats did not occur on consecutive trials.

**Procedure**

The CVOE task presented participants with two sets of instructions, which either differed between blocks (pure blocks) or as a function of trial (switch blocks). For each trial, a letter-number pair was presented in the center of the computer screen, and participants were tasked with classifying whether the letter was a consonant/vowel (CV trials) or an odd/even number (OE trials). Depending on the type of trial, the words consonant/vowel or odd/even were presented at the top of the screen in the left and right corners to serve as a reminder. Participants were instructed to press the *q* key for consonants/odd numbers or the *p* key for vowels/even numbers. These keys were selected given that they are on opposites sides of a standard QWERTY keyboard. Stimuli were presented in 30-point Courier New font, and trials were presented with an xx ms intertrial delay.

Trials were arranged into four blocks, with each block containing an equal distribution of *q* and *p* responses. Following the design of Huff et al. (2015), participants first completed two pure blocks (CV and OE) before completing two switch blocks (alternating runs and random presentation). Participants initially completed a set of 10 practice trials which corresponded to the first pure block’s task (CV or OE) and received verbal feedback on their performance. Following completion of the practice phase, participants immediately began the first pure block. Pure blocks each contained 96 trials and focused exclusively on one of the two tasks, with one block containing the CV task and the other the OE task. Following completion of the first pure block, participants completed a second set of practice trials (corresponding to the task in the second pure block) before completing the second pure block.

Immediately following completion of the two pure blocks, participants began the two switch blocks. In the switch blocks, the task change occurred at the trial level rather than the block level. For each trial, participants were prompted with the word “letter” or “number”, which corresponded to the CV or OE task, respectively. This prompt was located above the stimulus pair, and participants were informed that the prompt could potentially change following each key press. To practice the switching task and become familiar with the prompts, participants first completed a set of ten practice switch trials. Following this practice session, participants immediately began the first switch block. Trials within the switch blocks were arranged such that they were presented either with an alternating runs pattern (e.g., CV, CV, OE, OE, CV, CV, etc.; see Huff et al., 2015) or presented using a random presentation sequence (e.g., CV, OE, OE, OE, CV, OE, etc.). Each switch block consisted of 120 trials, which consisted of 59 switch trials (i.e., a CV trial followed by an OE trial) and 61 nonswitch trials (i.e., two consecutive OE trials). Like the pure blocks, each switch block corresponded to one of these two presentation modes (alternating runs or random). Thus, participants completed one pure CV block, one pure OE block, one alternating run switch block, and one random presentation switch block. Block presentation was randomized across participants; however, blocks were always ordered such that participants completed the two pure blocks before completing the two switch blocks (Huff et al., 2015; Minear & Shah, 2008).

Across blocks, participants were instructed to respond to each trial as quickly as possible without compromising accuracy. The task was presented to participants on a laptop running E-Prime 3.0 software [CITE], and all participants were tested individually in a laboratory setting. The total experiment lasted approximately 20 minutes.

**Results**

For all analyses, significance was set at the *p* < .05 level. Generalized-eta squared (*η*2G) and Cohen’s *d* effect size estimates were computed for all significant analyses of variance (ANOVAs) and *t*-tests, respectively. In addition to reporting effect size indices, we supplemented all standard null-hypothesis testing with a Bayesian estimation of the strength of evidence in favor of the null hypothesis, which compares a model that assumes a significant effect to one that assumes a null effect (Masson, 2011; Wagenmakers, 2007). This analysis returns a probability estimate termed *p*BIC (Bayesian Information Criterion) which represents the likelihood that the null hypothesis is retained. Therefore, all null effects include a *p*BIC estimate.

In the following analyses, we first examine mean error rates across trial types (pure, alternating switch, alternating nonswitch, random switch, and random nonswitch) and switch cost (local vs global). We then assess changes in mean RTs across trial types and switch costs. For completeness, error rate and RT comparisons are reported in the Appendix (Tables AX and AX, respectively).

Following the design of Huff et al. (2015), RT analyses only utilized correct trials. Additionally, we employed a trimming procedure to reduce the likelihood of RT analyses being disproportionately influenced by extreme scores. RT outliers were defined as any responses three standard deviations above or below of each participant’s respective mean. Overall, this trimming procedure eliminated xx% of pure block trials, xx% of nonswitch trials, and xx% of switch trials. Finally, [DISTRIBUTIONAL STUFF HERE]

**Mean Error Rates**

Mean error rates as a function of trial type are displayed in Figure 1 (top panel). Overall, participants committed the most errors on alternating runs switch trials (6.12%), followed by random switch trials (5.17%), alternating runs nonswitch trials (3.49%), pure trials (3.25%), and random nonswitch trials (3.01%). A one-way repeated measures ANOVA confirmed that error rates differed as a function of trial type, *F*(4, 352) = 20.29, *MSE* = 8.16, *η*2G = .09. Post-hoc *t*-tests revealed that this effect was driven primarily by increased errors for switch trials relative to nonswitch and pure trials, *t*s ≥ 3.63, *d*s ≥ 0.43. For switch trials, mean error rates were marginally greater when trials were presented using alternating runs compared to random presentation, *t*(88) = 1.92, *SEM* = 0.50, *p* = .06, *d* = 0.21, *p*BIC = .60. However, no differences were detected between pure and nonswitch trials, regardless of switch block presentation, *t*s < 1, *p*s ≥ .48, *p*BICs ≥ .88.

Next, we compared differences in switch costs for errors as a function of presentation and cost type (Figure 1, bottom panel). A 2 (Switch Cost: Local vs Global) × 2 (Presentation: Alternating Runs vs Random) yielded a significant main effect of Switch Cost, *F*(1, 88) = 26.83, *MSE* = 19.03, *η*2G = .10, such that collapsed across presentation modes, local switch costs exceeded global costs (2.39 vs. -0.01). Additionally, this analyses revealed a marginal effect Presentation, *F*(1, 88) = 3.68, *MSE* = 5.43, *p* = .06, *p*BIC = .60, *η*2G = .01. The interaction between Switch Cost and Presentation, however, was not significant, *F*(1, 88) < 1, *MSE* = 17.35, *p* = .99, *p*BIC = .90.

**Mean RTs**

As displayed in Figure 2 (top panel), participants were quickest when responding to trials presented in pure blocks compared to switch and non-switch trials. A one-way repeated measures ANOVA confirmed the presence of trial type differences, *F*(4, 352) = 357.72, *MSE* = 19.03, *η*2G = .10. Post-hoc testing indicated that this effect was largely driven by differences in RTs between trials presented in the pure and switch blocks

**Vincentile Plots**

[VINCENTILES] [WILL NEED TO RUN ANOVAS]

**Ex-Gaussian Distribution of RTs**

[EX-GAUSS]

**General Discussion**

The goal of the present study was to [SUMMARY PARAGRAPH – MAIN ANALYSES] Overall… [EXPAND]

[SUMMARY PARAGRAPH – DISTRIBUTIONAL ANALYSES]

[SOMETHING HERE – I’LL FIGURE IT OUT LATER]

[AGING IMPLICATIONS]

[FUTURE DIRECTIONS]

**Summary and Conclusion**

[WORDS HERE]

References