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**“A Penny for Your Thoughts:” Developing an Adapted Stimulus Reward Association – Stroop Task to Assess the Impact of Individual Difference Factors on Cognitive Control**

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## Abstract

Limited studies have examined the effect of feedback sensitivity and intrinsic motivation on cognitive performance. The present study serves as a pilot project for a study at the University of Tennessee at Chattanooga that examines the modulating role of external, monetary reward incentives and cognitive intrinsic motivation on cognitive control. For the present study, the relationship among cognitive performance outcomes (reaction time and accuracy) on an adapted Stimulus Reward Association Stroop Task will be explored. Two main hypotheses were tested in the present study: $H_1$ Reaction time on congruent trials will be significantly faster than reaction time on incongruent trials. $H_2$ Accuracy on congruent trials will be significantly greater than accuracy on incongruent trials. Implications from the findings of this study will provide a foundation for future examinations of the motivational factors and feedback conditions that affect cognitive performance.

*Keywords: Cognitive Control, Cognitive Effort, Intrinsic Motivation, Feedback Sensitivity, Stroop Task*

**"A Penny for Your Thoughts:" Developing an Adapted Stimulus Reward Association – Stroop Task to Assess the Impact of Individual Difference Factors on Cognitive Control**

Cognitive control refers to the role of varying dimensions of executive function (EF) in regulation of attention, memory, and behavioral outputs oriented towards completion of a task (Botvinick & Braver 2015). In a contextualized scenario, a working professional intends to complete a written manuscript before the upcoming deadline. At times, this individual is able to implement effective strategies for directing their attention towards completion of the manuscript. However, they are intermittently distracted by emails, initiating conversations with co-workers, and surveying any updates on their Instagram feed. The person diverts their attention to these secondary activities, under the reasoning that a break is justified after long hours in the office setting. Later, the person re-directs their attention to completion of the manuscript, as the deadline is fast-approaching and proficient work could yield long term professional advancement. This brief vignette of a working professional demonstrates an application of cognitive control, where this individual needed to inhibit routine behavioral responses that directly conflicted with their goal-oriented behavior. When those circumstances occurred, there was opposition between automatic or impulsive behaviors and those that are goal-oriented. This opposition is referred to as cognitive conflict and presents a scenario where cognitive control is needed to attenuate task-irrelevant factors in favor of task-relevant ones (Abrahamse et al., 2013).

Underlying cognitive control are dual mechanisms of control: proactive control and reactive control (Braver & Burgess, 2008). Through goal-activation and maintenance, proactive cognitive control selects for task-relevant information prior to initiation of a cognitively-demanding task. Reactive control differs in that it utilizes conflict detection, response inhibition, and resolution after a cognitively-demanding task has occurred (Mäki-Marttunen et al., 2019). To demonstrate proactive and reactive control in a scenario, an undergraduate student needs to stop for gas on their drive home from campus. This individual establishes exiting the interstate to receive gas as prior selection for a goal-oriented behavior, where the execution of this plan is guided by proactive control. However, the student often drives to their house from campus without making any stops, which creates a conflict between the automatic, routine behavior of driving home and the goal-oriented behavior of making an additional stop. Based on this scenario, proactive control integrated the task-relevant selection of stopping for gas through preparatory attention, while reactive control characterized resolving the cognitive conflict between the routine drive and the goal of stopping (Braver & Burgess, 2008).

**Stroop Task**

Assessment of cognitive proactive and reactive control can be done within the well-documented conflict paradigm of the Stroop Color and Word Test (Stroop, 1935). Often referred to as the Stroop task, this task involves individuals stating the ink color of a presented word. The words in the Stroop task are color words, like blue, green, red, and yellow but they are also presented in colored text. The words can be presented in a congruent color ("GREEN") or an incongruent color ("GREEN"). For each word, individuals must exert cognitive control and disregard the semantic meaning of the written word. Therefore, a correct response to the trial ("GREEN") would be red, as that is the ink color of the word, and not green, the actual word that is written. The Stroop task induces a high level of cognitive conflict as it requires inhibition of information that is usually needed (the semantic meaning) and instead requires modulating attention towards the usually unneeded, but now task-relevant, information of the ink color.

Proactive control, in context of the Stroop task, mediates the extent of cognitive conflict by applying the rules of the task instructions. In this way proactive control sets the goal-oriented behavior and selects, early on, the task-relevant information. Specifically, this means that when individuals use proactive control on the Stroop task, they focus their attention on preparing for incongruence in ink color and semantic meaning (Abrahamse et al., 2013). In comparison, reactive control is unrelated to early selection or preparatory attention for cognitive conflict. This mechanism mediates cognitive conflict just after being presented a stimulus (Braver, 2012). Therefore, reactive control happens between the presentation of a trial and the individual's response.

Previous findings from the Stroop task exhibit relatively consistent results across reaction time and accuracy in participant performance, enough to be termed the Stroop effect. A replication study of the Stroop Effect in Nepal examined 30 healthy male students for reaction time across congruent ("RED") and incongruent ("RED") conditions in the classical Stroop design (Ghimire et al., 2014). The reaction times for both conditions demonstrated a significant increase in reaction time for the incongruent condition, in comparison to the congruent condition. Further, accuracy was examined across both congruence conditions in this sample. The results exhibited 0 errors in the congruent condition, while 60% of participants made 1 or more errors in the incongruent condition. Therefore, the empirical study demonstrated a slower reaction time and a decreased accuracy for incongruent trials, in comparison to congruent trials (Ghimire et al., 2014). These findings are consistent with the overall predicted effect of the Stroop task, as first demonstrated by John Ridley Stroop in 1935, where it was noted that participants responded slower and less accurately to presentations of incongruence in word color and meaning (Stroop, 1935).

Further, the effects of both accuracy and reaction time can be examined by the presence of a speed-accuracy tradeoff (Wylie et al., 2009). This strategic method for completing a cognitively demanding task is examined through the level of accuracy on the speed of completion. For example, a corporate data analyst may favor an increase in precision and accuracy when inputting data points, at the expense of fast task completion. Therefore, this strategic approach to a task can inversely increase accuracy (fewer errors) at the cost of speed or increase speed at the cost of accuracy (greater errors). This speed-accuracy tradeoffs can be consciously chosen by the individual, or serve as an underlying mechanism affecting accuracy outcomes. In the Stroop effect, increased accuracy demonstrates a tradeoff for slower reaction time across both the congruent and incongruent conditions.

**Feedback Sensitivity**

Demanding tasks, like the Stroop task, require substantial and elongated attention modulation, working memory (WM), and cognitive control (Kool et al., 2012). This cost for initiating and maintaining goal-orientation through both proactive control and reactive control is in direct relationship with the associated benefit of the task goal (Westbrook & Braver, 2015). To elaborate, the interaction between cost and benefit serves as a cognitive tradeoff between the cost of maintaining proactive and reactive control mechanisms in cognitively demanding tasks in relation to the level of perceived benefit (Westbrook & Braver, 2015). This cognitive cost, higher with increasing levels of cognitive conflict, can be mitigated by the presentation of an extrinsic reward, like receiving positive feedback (Scott et al., 2015). Feedback sensitivity can thus be examined in relation to cognitive control, but it may not be the only important factor, as cognitive intrinsic motivation may also interact with the relationship. However, this relationship will not be explored in the analysis of the present study, but the conditions of feedback and no-feedback are present in the adapted Stroop task used in the experiment. The establishment of whether the present task first replicates the expected results of the Stroop task will allow for further exploration into this relationship.

**Cognitive Intrinsic Motivation**

The willingness to exude cognitive effort, and the associated personal value associated with this effort, is defined as cognitive intrinsic motivation (Inzlicht et al., 2018). Cognitive intrinsic motivation can be assessed by the Need for Cognition (NFC) scale, which examines this individual trait disposition across an 18-item questionnaire (Cacioppo, Petty, & Kao, 1984). On this scale, an individual who scores high is considered to have a significantly greater value associated with cognitive effort, in contrast to an individual who scores lower. In the presence of an external incentive, individuals who have lower NFC scores increase their cognitive effort (Sandra & Otto, 2018). However, the presence of external incentive led to a decrease in cognitive effort for individuals with higher NFC scores. These findings suggest that for those with lower NFC scores, or a lower amount of value attributed to cognitive effort, poor performance on cognitive tasks can be mitigated by the presence of an external incentive. Further, those with higher NFC scores are less impacted, if at all, by the presence of external incentive. This may be due to their perception of the ratio of task cost to benefit not being significantly altered with an additional, external source of motivation. With this finding in mind, it is possible that individual's cognitive intrinsic motivation can further inform the relationship between reactive control in cognitive performance on the Stroop task in the presence or absence of feedback. This relationship will not be explored in the analysis of the present study, but the findings from this research will allow for future analysis into the effect of cognitive intrinsic motivation on Stroop task performance.

## Purpose of the Present Study

The present study serves as a pilot project for a study at the University of Tennessee at Chattanooga that examines the modulating roles of external, monetary reward incentives and cognitive intrinsic motivation on cognitive control in a conflict paradigm, an adapted Stimulus-Reward Association (SRA) Stroop Task. For the present study, an adapted Stroop task was designed to integrate feedback, and eventually reward conditions, into the classic design of Stroop Color and Word Test (Krebs, Boehler, & Woldorff, 2010). This Stimulus-Reward Association (SRA) Stroop task retains all the same characteristics of the classic Stroop design, assessing the impact of congruency on cognitive performance across reaction time, accuracy, and a speed-accuracy tradeoff. The establishment that the Stroop effect is replicated in the adapted Stimulus-Reward Association Stroop task is necessary for later analysis into the effects of individual difference factors across feedback sensitivity and cognitive intrinsic motivation.

For the purpose of the present study, the following questions were explored: 1) What is the impact of word/color congruency on reaction time in an adapted SRA Stroop Task? and 2) What is the impact of word/color congruency on accuracy in an adapted SRA Stroop Task? Specifically, I hypothesized that the typical Stroop effects, where accuracy is greater and reaction time is faster on congruent trials than on incongruent trials, will be replicated with the adapted SRA-Stroop Task.

# Method

## Participants

Student participants (N = 10) were recruited from the University of Tennessee at Chattanooga by means of direct recruitment. For this pilot study, only a small sample size was assessed to determine whether the development of the adapted SRA-Stroop task replicates the typical effect in a classic Stroop task design. Participants were excluded from the study if they indicated any history of color deficiency or other condition(s) that would affect visual ability. Participants were also excluded if they had sustained a concussion within the last 90 days. No incentives were given for participation in this study.

**Measures**

***Need for Cognition Scale***

The Need for Cognition scale is an 18-item questionnaire that was used in this study as a measure of cognitive intrinsic motivation. The NFC scale measures a participants self-reported enjoyment of engaging with cognitively demanding activities (Caccioppo & Petty, 1982). For this questionnaire, the participant responds to statements like, "I prefer complex to simple problems" and "I prefer my life to be filled with puzzles I must solve" on a 7-point Likert scale. The Need for Cognition scale is integrated procedurally for the purpose of future study, but will not be examined in the statistical analyses for the present study.

***Stroop Color and Word Test (SCWT)***

The Stroop Color and Word Test (SCWT) is a neuropsychological experiment that measures the role of cognitive control in conflict situations (Krebs, Boehler, & Woldorff, 2010). The Stroop task requires naming the presented color of a word. On this task the presented color can be congruent with its semantic meaning ("BLUE") or incongruent with its semantic meaning ("BLUE"). For the present study, an adapted Stroop task was presented using SuperLab 5 on an iMac desktop computer in UTC's Assessing Cognition Lab. The adapted Stroop task was modeled after Krebs, Boehler, and Woldorff's (2010) Stimulus-Reward Association Stroop Task.

In the adapted Stroop task used in this study, participants identified the task-relevant dimension of naming the presented color of a word in each trial, while ignoring the task-irrelevant information of the word's semantic meaning. The words used in this task were: "RED", "YELLOW", "BLUE", "GREEN", or "BROWN." The word "BROWN" served as the neutral condition. Each color word was presented in one of four colors ("RED", "YELLOW", "BLUE", or "GREEN") and each of those colors was assigned a key on the keyboard. Participants were instructed at the start of the task to respond as accurately and quickly as possible by pressing the key associated with the presented color of each word within the allotted time frame. Participant reaction times were recorded for each trial and accuracy was also calculated.

Each trial within this paradigm began with a fixation square in the center of a black screen. After a variable time of 500 to 1500 ms, the fixation square was replaced by a color word. Each word appeared on the screen for 300 ms and participants had up to 1800 - 2200 ms to respond (Krebs, Boehler, & Woldorff, 2010). Any response outside that window was not recorded. Two of the four presented colors (BLUE and GREEN) were associated with the potential for symbolic feedback in the form of a check mark symbol for correct responses or a hashtag symbol (#) for incorrect responses. The other two presented colors (RED and YELLOW) were not associated with any feedback. The feedback symbol appeared on the screen for 100ms. After the 100 ms, the next trial began.

The word "BROWN" served as a neutral stimulus. This word was presented in each of the colors but was not associated with feedback. The presentation of the neutral stimulus ("BROWN") was dispersed evenly throughout all trials in the task and served as a baseline for performance. In total, participants completed four experimental blocks, each consisting of 160 trials. Between each block, participants received four, 20 second, breaks. Over all four blocks, there were an evenly distributed 320 potential-feedback trials (BLUE and GREEN) and 320 no-feedback trials (RED and YELLOW). Further breakdown of the distribution of trials is as follows in Table 1:

Table 1: Proportion of Trials by Congruency and Feedback

| | |
|---|---|
| <u>FEEDBACK: Total = 320 trials</u> | |
| Congruent, Feedback-related (BLUE or GREEN): | 25% of trials |
| Incongruent, Feedback-related (BLUE or GREEN): | 25% of trials |
| Incongruent, Feedback-unrelated (RED YELLOW RED YELLOW): | 25% of trials |
| Neutral (BROWN or BROWN): | 25% of trials |
| <u>NO FEEDBACK: Total = 320 trials</u> | |
| Congruent (RED or YELLOW): | 25% of trials |
| Incongruent, Feedback-related (GREEN BLUE GREEN BLUE): | 25% of trials |
| Incongruent, Feedback-unrelated (YELLOW or RED): | 25% of trials |
| Neutral (BROWN or BROWN) | 25% of trials |

***Intrinsic Motivation Inventory***

The Intrinsic Motivation Inventory is a self-reported questionnaire that evaluates participants' subjective experience of an experimental task after it has been completed (Ryan, 1984). The participants in this study completed four subscales of the Intrinsic Motivation Inventory: Interest/Enjoyment, Effort/Importance, Competence, and Pressure/Tension. Participants respond on a 7-point Likert scale in terms of their level of agreement to statements such as, "While I was working on the task I was thinking about how much I enjoyed it" and "I would describe the task as very enjoyable." The Intrinsic Motivation Inventory is integrated procedurally for the purpose of future study, but will not be examined in the statistical analyses for the present study.

**Procedure**

Participants met in-person at the UTC Assessing Cognition Lab to complete this study. They first read and completed the IRB-approved informed consent. Demographic questions and the Need For Cognition scale were then completed via a QuestionPro administered survey on an iMac desktop computer within the lab. Upon completion of the Need For Cognition scale, the adapted SRA-Stroop Task was presented using SuperLab 5. Following that experimental section, the Intrinsic Motivation Inventory was administered to assess subjective experience. A debrief on the nature of the experiment was provided to all participants at the conclusion of the study.

## Results

To test my hypothesis that accuracy would be greater and reaction time would be faster on congruent trials than on incongruent trials, I first calculated reaction time and accuracy for neutral, congruent, and incongruent trials on the adapted SRA Stroop task. Performance on each trial was categorized as either a hit, miss, or omission. Responses were considered a “hit” when the participant response was correct and recorded within the allotted time frame. A “miss” was categorized as a participant incorrectly responding to the presented color of a trial. An “omission” was categorized when no response was recorded within the allotted time frame.

The reaction time data was examined in terms of color/word congruence (congruent, incongruent, neutral) and averaged across all ten participants. Means and standard errors for reaction time on congruent, incongruent, and neutral trials are presented, and the analysis for average correct RT and average incorrect RT, are included in Table 2.

*Table 2: Mean Reaction Time by Trial Congruence*

| | Mean (Standard Error) | | |
|---|---|---|---|
| | RT Overall | Correct RT | Incorrect RT |
| Congruent | 469.9 (14.2) | 482.0 (13.7) | 439.1 (16.1) |
| Incongruent | 505.2 (15.5) | 518.9 (14.0) | 479.9 (20.5) |
| Neutral | 489.1 (20.5) | 496.7 (14.8) | 469.0 (20.8) |

As presented above in Table 2 and below in Figure 1, average RTs overall were significantly faster for congruent trials ("BLUE") than incongruent trials ("GREEN"), $t(9) = -3.81$, $p = .004$. This pattern of results replicates the typical Stroop effect.

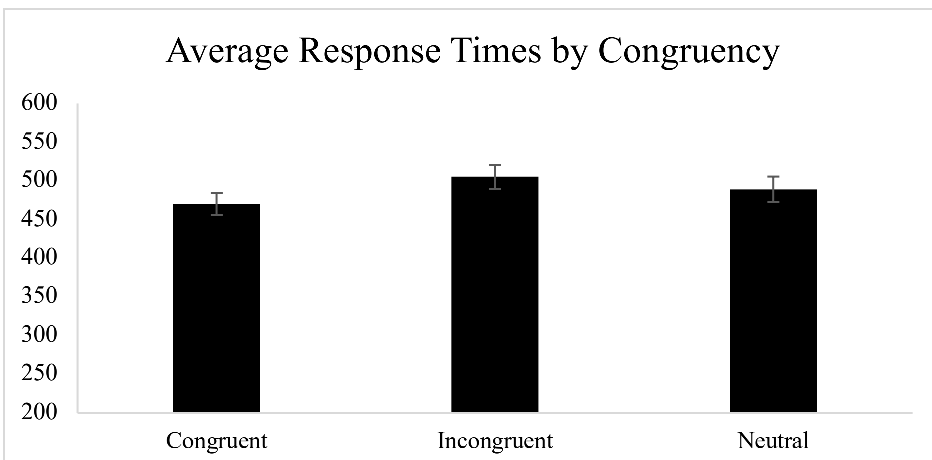


**Figure 1:** Mean reaction time (ms) and standard error for congruent, incongruent, and neutral conditions in the adapted SRA-Stroop task.

Moreover, a repeated measures analysis of variance (ANOVA) demonstrates a main effect of accuracy such that when participants responded correctly, reaction times were consistently slower than when participants responded incorrectly, $F(1,9) = 21.83$, $p = .001$. However, this did not interact with the trial congruency type as no significant interaction was found between accuracy and congruency, $F(1,9) = 15.84$, $p = .003$. This pattern of results replicates a typical speed-accuracy trade-off. Of note is that the difference between correct and incorrect reactions times is slightly less for neutral trials than for congruent or incongruent trials but neutral trial RTs were not examined statistically. These differences can be seen below in Figure 2. Therefore, the presented data analysis of RT in the 10 participants from this pilot project suggest support for my hypothesis: reaction time (RT) on congruent trials will be faster than reaction time (RT) on incongruent trials.

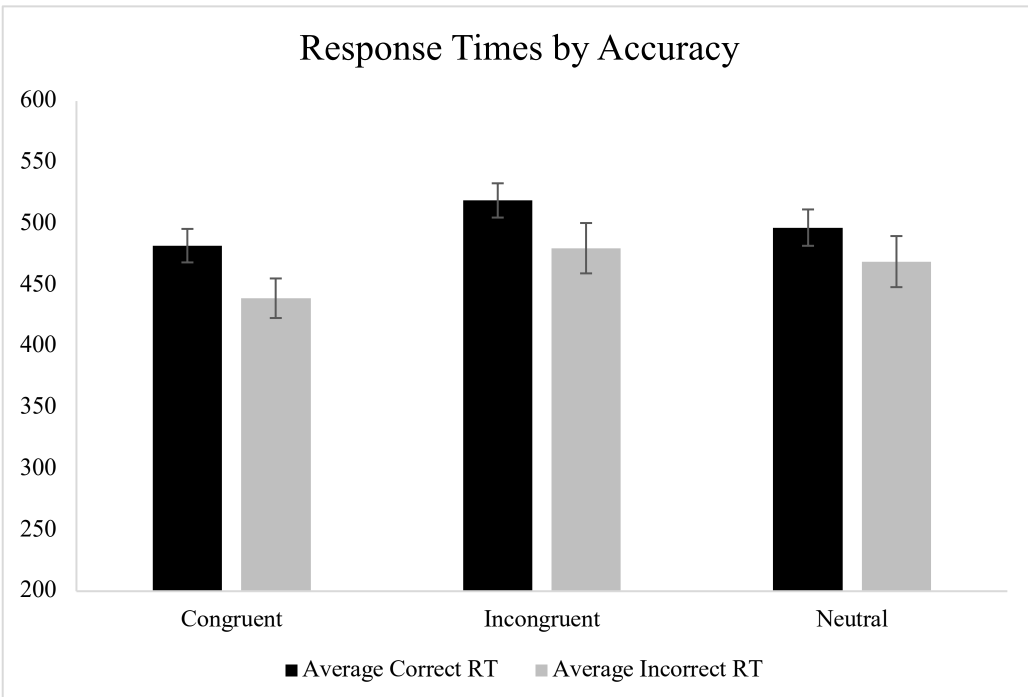


**Figure 2:** Mean correct and incorrect reaction times (ms) and standard error for congruent, incongruent, and neutral conditions in the adapted SRA-Stroop task.

In addition to examining reaction times, I also explored how accuracy (hit, miss, or omission) differed across congruent, incongruent, and neutral conditions. That data is included below in Table 3.

***Table 3: Mean Accuracy by Trial Congruence***

| | Mean Accuracy (Standard Error) | | |
|---|---|---|---|
| | Hit | Miss | Omission |
| Congruent | 55% (3%) | 18% (3%) | 26% (2%) |
| Incongruent | 45% (1%) | 20% (2%) | 35% (3%) |
| Neutral | 52% (2%) | 18% (3%) | 30% (3%) |

As presented above in Table 3 and below in Figure 3, participants responded correctly on congruent trials ("BLUE") significantly more often than on incongruent trials. ("GREEN"), $t(9) = 3.89$, $p = .004$. Participants also responded correctly on neutral trials more often than on incongruent trials, but that difference was not examined statistically. Misses were equally as likely between congruency types. Omissions, trials where a response was not recorded in the allotted time, were more common for incongruent trials, and least common for congruent trials. This pattern of results replicates the typical Stroop effect and suggests support for my hypothesis: accuracy on congruent trials will be significantly greater than accuracy on incongruent trials.

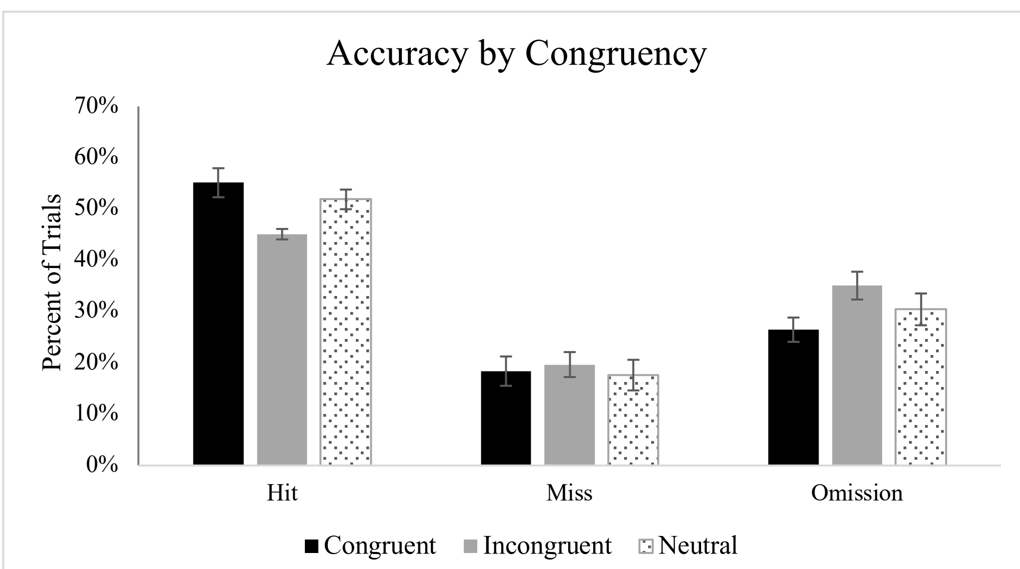

**Figure 3:** Accuracy by percentage of hits, misses, or omissions on the congruent, incongruent, and neutral conditions in the adapted SRA-Stroop task.

## Discussion

The results of the present study using an adapted SRA-Stroop task indicate support for the expected results of a typical Stroop task. The findings supported the two hypotheses of this study by demonstrating a decrease in reaction time and accuracy for the incongruent condition, in comparison to the neutral and congruent conditions. Further, a speed-accuracy tradeoff was exhibited by the slower reaction time for correct responses across all conditions. Therefore, the expected Stroop effect was replicated in the data analysis of this phase of the study. These findings suggest that the adapted SRA-Stroop task can be used in future studies to examine the impacts of feedback sensitivity, extrinsic reward, and cognitive intrinsic motivation on cognitive control.

### Limitations

The primary limitation of the present study is the relatively small sample (n=10) completing the experiment, which exhibits an inability to sufficiently assess for applicable statistical significance in data analysis. For the 10 participants in this pilot project, the demographic questions were not recorded, which serves as a limitation for analyzing the data in terms of demographics. Further, this phase of the study is limited by the non-representative sampling method for obtaining participants, through the direct means of recruitment. Moreover, the sample population of undergraduate students serves as a limitation, where an academic setting may not demonstrate a representative distribution of cognitive intrinsic motivation or cognitive performance. Alongside this, undergraduate students fall primarily in the range of 18 to 22 years old, which exhibits a lack of generalizability for the present findings.

In terms of the Stroop Task, extraneous and uncontrolled factors could potentially influence cognitive control, such as loud noise obstructions from construction outside the laboratory impeding on the ability to implement effective modulation of attention. Additionally, the presence of the experimenter in the lab setting could have integrated an additional social-perceived pressure while completing the study. This component has been altered in the protocol for experiments following this preliminary phase of testing to remove the possibility of socially induced effects on task performance. Also, the experimental design of the adapted Stroop task on Superlab 5 was constructed with key-color associations on the right side of the keyboard, which provides a right-hand dominant advantage for participants. In the following experiments, participants with left-hand dominance are not included in the study, as there is a preferential design within the present study for right hand participants. Lastly, comments from participants following completion of the study suggest a limitation in the Stroop design itself, as a small number of participants suggested that the primarily effective method for completion of the task was unfocusing their attention to the word by directing attention elsewhere on the screen and observing only the color. This strategic response method of not reading the semantic meaning of the presented word serves as a reduction in cognitive conflict, which alters the interaction of proactive and reactive control in response time and accuracy, and consequently, skews the data of participants who implement this method for response.

**Implications and Future Directions**

The present study suggests support for the development of this adapted SRA-Stroop task as an assessment of cognitive control, as participant performance outcomes were consistent with the expected results of the Stroop task. The findings of the present study suggest that the adapted SRA-Stroop task can be used to assess cognitive control in relation to extrinsic incentives, such as feedback, and cognitive intrinsic motivation. In future directions, the study needs to include a larger sample size, including participants from a more comprehensive background. An increase in demographic diversity of participants is needed for an increased level of ecological validity in assessing the relationships of feedback sensitivity, cognitive intrinsic motivation, and cognitive control performance.

To further contextualize these results for clinical use, sample populations of individuals with diagnosed schizophrenia, and other mental health conditions relating to cognitive control, should be assessed. As a paradigm concerning the assessment of selective attention, the Stroop task has often been employed to investigate attention deficits in clinical populations, such as individuals with the diagnosis of schizophrenia (Perlstein et al., 1998, Fervaha et al., 2014). In empirical assessments of cognitive control, decreased proactive control and increased reactive control has been associated with individuals with schizophrenia (Barch & Ceaser, 2012; Edwards, Barch, & Braver, 2010). Pragmatically, results from SCWT assessments of proactive and reactive control in this clinical population advance our current understanding of the cognitive behavioral mechanisms underlying schizophrenia. Further, these findings are applicable for the exploration of potential assessments, interventions, and treatment strategies related to preparatory attention and inference, conflict resolution.

Further, the findings exhibit the importance of additional study in assessing cognitive control, as there is a significant amount of remaining unknowns related to the factors influencing cognitive performance. Future studies could explore other motivation factors, such as the impact from baseline measurements of other intrinsic motivation dimensions like creative or physiological motivation. Further, assessment of additional extrinsic motivational factors, such as the role of fear, power, or affiliation-related motivations, could yield greater insight into the relationship of motivation and cognitive control. The examination of cognitive control, measured by an experimental condition other than the presently adapted Stroop task, can also provide an examination of this relationship by comparing results across a differing conflict paradigm. For example, the implementation of an A-X continuous performance task would provide further findings that elaborate on the focus on this study.

The present study serves as a pilot project for a study examining external, monetary reward incentives and cognitive intrinsic motivation on performance in an adapted Stimulus-Reward Association Stroop Task. With the establishment that this adapted Stroop task replicates the expected Stroop Effect, further study on individual differences on cognitive performance can be examined. The implications of these findings, with the future studies conducted with this adapted SRA-Stroop task, are applicable to expanding our current framework of cognitive outcomes. Assessments of cognitive control, both within and outside the clinical setting, could approach effective intervention and compensatory strategies for individuals with deficits in attention modulation. Further, findings that examine the addition of external motivation could be applied within these interventions, as individuals with decreased cognitive intrinsic motivation for goal completion could experience substantial increases with the introduction of extrinsic factors to compensate for low motivation. These findings illuminate an understudied dynamic in our current model and approach to cognition, alongside establishing the potential for remediation of deficits in cognitive control that can significantly alter quality of life.

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