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MIRRORING NEUROSTIMULATION OUTCOMES THROUGH BEHAVIORAL INTERVENTIONS TO IMPROVE CREATIVE PERFORMANCE

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ABSTRACT

Creativity, a key component of engineering design, is not a static trait, but a skill that can be strategically enhanced. Neurostimulation methods, e.g., using electrical current to stimulate brain areas, have been reliably shown to improve creative performance. However, safety and ethical concerns present obstacles to the direct implementation of such methods in the engineering-design process. Thus, the current work explores whether creative performance can be enhanced using behavioral tasks that recruit the same brain regions targeted in neurostimulation studies.

Study participants were 30 undergraduate students enrolled in an introductory psychology course. Two intervention tasks, a Stroop task and a finger-tapping pattern-matching task, each with easy and hard versions, were used in a 2 (task type) x 3 (task difficulty) within-subjects design. Relative to the pretest period, difficulty was manipulated by using versions of tasks with 1) predictable responses (easy) and 2) unpredictable responses (hard). Creativity in each experimental condition was assessed via the well-validated Alternative Uses Test (AUT).

A multilevel analysis revealed a significant increase in fluency (number of alternative uses) as task difficulty increased regardless of task type. Flexibility (number of alternative-uses categories) also increased with task difficulty, but the effect was stronger for the Stroop task. These results suggest that high-difficulty versions of the selected tasks may be more effective in increasing AUT performance. Between the two tasks studied, the Stroop task has greater potential as a candidate to adapt as a behavioral intervention to improve creativity. Beyond the Stroop task, other behaviors, which activate brain regions that respond favorably to neurostimulation, may also be explored as the bases of interventions to improve creative performance in engineering design.

NOMENCLATURE

Alternative Uses Test (AUT)	Task that measures divergent thinking; asks participants to come up with as many creative uses as possible for common objects within a given time.
Dorsolateral Prefrontal Cortex (dlPFC)	Frontal-lobe brain area that is responsible for decision making and resolving conflicting information.
Transcranial Direct Current Stimulation (tDCS)	Use of electrical current to stimulate specific brain regions; shown to improve creative performance.

1. INTRODUCTION

Engineering researchers have increasingly applied insights and methods from psychology to improve the design process. One aim has been to overcome design fixation, i.e., excessive focus on limited solutions while excluding other ideas without due consideration. A seminal study on design fixation by psychologists, Jansson and Smith (1991), has inspired much work by engineers, e.g., by Linsey et al. (2010) on fixation's effects in engineering-design faculty. Vasconcelos & Crilly's (2016) review paper summarized work-to-date on inspiration and fixation. More recently, Starkey et al. (2018) explored both advantages and disadvantages of fixation in design.

Beyond design fixation, engineers must also be concerned about the effectiveness of proposed solutions, irrespective of their novelty. Shah et al. developed metrics to measure ideation effectiveness (2003), and confirmed the relevance of divergent thinking for engineering design (2012). Dippo & Kudrowitz (2013) observed the progression of originality on the Alternative Uses Test (AUT), a standard tool used by psychologists to measure the divergent-thinking aspect of creativity. Toh & Miller (2016) developed a Preferences-for-

Creativity Scale towards predicting engineering students' ability to generate and select creative design concepts.

To better understand design outcomes, engineering researchers have increasingly adopted methods used by psychology researchers. For example, Reid et al. (2012) analyzed eye-gaze patterns to assess customer judgement of product design representations. Du & MacDonald (2014) used eye-tracking to predict the importance of product features.

Psychophysiological measures are also used in design research to observe factors that are not typically detected by conventional measures (Borgianni & Maccioni 2020). For example, Petkar et al. (2009) utilized eye-gaze and neuroimaging, i.e., electroencephalograms (EEG), to determine the levels of mental stress of designers. Specific to conceptual design, Goucher-Lambert et al. (2018, 2019) used neuroimaging, i.e., functional magnetic resonance imaging (fMRI), to better understand design ideation and the related patterns of brain activation. Most relevant to the current work, Shealy et al. (2018) used neuroimaging, i.e., functional near-infrared spectroscopy (fNIRS), to determine the brain regions activated during different design methods, e.g., brainstorming, morphological analysis and TRIZ. Thus, the application of neuroimaging methods to better understand creative processes and outcomes is well-established in design research.

Despite growing interest, few techniques have emerged as validated methods for improving creative productivity. An approach that has been reliably shown to improve creative performance involves neurostimulation, or the direct stimulation of brain areas using for example, electrical current. However, obstacles to their direct implementation in engineering design include safety and ethical concerns. Thus, the present work explores whether behaviors that activate the same brain areas as those stimulated in neurostimulation studies can also serve as effective interventions to increase creative performance.

1.1 Transcranial Direct Current Stimulation (tDCS)

Neurostimulation methods, intended to directly affect brain activity, differ from neuroimaging, e.g., EEG, fMRI, fNIRS, etc., intended to primarily observe brain activity. A specific neurostimulation method shown to improve creative performance is transcranial direct current stimulation (tDCS).

Several studies show that tDCS of brain areas in the dorsolateral prefrontal cortex (dlPFC) improves divergent-thinking performance (Cerruti & Schlaug 2009; Chi & Snyder 2011; Colombo et al. 2015; Zmigrod et al. 2015). Applying low levels of electrical current, tDCS is a non-invasive method that can stimulate specific brain areas. The use of an anode and cathode in tDCS can either excite or inhibit neuronal activation. The relationship between dlPFC activation through tDCS and improved divergent thinking is well established. However, the present work aims to study whether performing behaviors that activate the same brain areas effectively stimulated in tDCS studies also improves creative performance.

1.2 The Need for Behavioral Interventions

While tDCS is effective in directly increasing creative performance, its workplace use may be infeasible. Reports of adverse effects, e.g., headaches, occur with sufficient frequency that the ethics of subjecting designers to such risks is highly questionable (Poreisz et al. 2007). However, tDCS-related performance boosts may also be possible through more indirect methods that are safer and easier to implement. For example, since tDCS applied to the dorsolateral prefrontal cortex (dlPFC) improves divergent thinking, behaviors that activate the dlPFC may also improve divergent thinking. To be beneficial, such behavioral interventions must cause high levels of dlPFC activation, be relatively easy to implement, and remain effective after repeated use. Furthermore, the duration of the intervention tasks should be relatively short to maintain workplace productivity.

Using the above criteria, behavioral interventions chosen for the current work are the Stroop task and a finger-tapping pattern-matching task. Both tasks involve minimal instruction, cognitive conflict and responses that are difficult to anticipate.

1.2.1 Stroop task

A typical Stroop task requires participants to quickly and accurately name font color that is mismatched with word text, e.g., the word 'red' printed in green font. The participant must process conflicting information – the color named by the word may more strongly influence the participant, but the correct response is the color of the font used to display the word.

The Stroop task is challenging because the two sources of classification, language and hue, work against each other. Nguyen et al. (2013) administered the Stroop task to designers and measured its effect on mental stress. Previous work has shown that the Stroop task can significantly increase activation in the dlPFC, which is implicated as a brain region that manages conflicting information (Schroeter et al. 2002; León-Carrion et al. 2008). Thus, the dlPFC is expected to be activated by the Stroop task used in the present study.

Importantly, difficulty is easily manipulated within the Stroop task. Performance in the high-difficulty, mismatched condition is often compared to a low-difficulty, matched condition where the word matches its presentation color, e.g., the word ‘red’ printed in red font. In the present study, both the high- and low-difficulty versions of the Stroop task were used to examine its efficacy as a creativity induction.

1.2.2 Finger-tapping task

Abiru et al. (2016) used a finger-tapping task which had participants tap or not tap in response to certain musical rhythms. Significant dlPFC activation occurred in response to a difficult and unpredictable musical rhythm, but not in response to a rhythm that was easy to follow and predict.

The current study used a modified finger-tapping task that responds to a repeating pattern of squares. The underlying premise of the task remains tapping in response to a pattern, but the stimulus type was changed for accessibility and ease of implementation. The dlPFC is believed to have a role in processing the information provided in the modified finger-tapping task.

The implemented finger-tapping task displays to participants a random sequence of dark and light squares on either the left or right side of the screen. Participants are instructed to respond with a keyboard key that corresponds to whether a light square appears on the left or right side, but to not respond to dark squares.

There are two dimensions to this task. The participant must determine whether or not to respond, according to whether the square is light or dark. The participant must also choose the key corresponding to which side of the screen the square appears.

1.3 Measuring Creativity: Alternative Uses Test (AUT)

Assessment of creative interventions requires validated instruments that test creative performance. The Alternative Uses Test (AUT) is a standard instrument that measures creative performance by quantifying divergent thinking (Guilford 1967). In the AUT, participants are asked to come up with alternative uses for common objects, and responses are typically assessed with respect to fluency and flexibility, as well as other measures. Fluency corresponds to the number of uses that participants state for each object, and flexibility corresponds to the number of categories of uses. Generally, high fluency and flexibility scores indicate a high level of divergent thinking. However, high fluency combined with low flexibility corresponds to many ideas, but the ideas are categorically similar to each other. The selected behavioral interventions, i.e., the Stroop and finger-tapping tasks, are hypothesized to increase the number of AUT uses and categories that participants generate.

2. MATERIALS AND METHODS

2.1 Participants

Study participants consisted of 32 (18 female, 14 male) undergraduate students enrolled in a first-year introductory psychology class at the University of Toronto. Two participants were excluded for not following instructions, i.e., by providing different descriptions of AUT items, and not different uses, leaving a final sample size of 30.

The sample size is justified using a power analysis conducted in G*Power (Faul et al. 2009), which estimates a required sample size of 28 to observe a medium (f=0.25) repeated-measures ANOVA effect. For the analysis, a minimum 80% power and 0.5 correlation were assumed between repeated measurements (pre-test, easy, and hard versions of tasks).

2.2 Methods

2.2.1 Study environment

Upon arrival to the engineering-design laboratory where the study was performed, participants were introduced to the study and provided a consent form to read and sign. The study was conducted using a laptop computer placed on a beige table, facing a plain beige wall with white foam-core dividers on both sides to minimize distraction. A PsychoPy (Peirce et al. 2019) program executed the study protocol, with scripted instruction from the experimenter.

2.2.2 Instructions to participants

A set of instructions (shown in Appendix A) were provided on a laptop screen before the start of each task. Additional instructions were provided by the experimenter before starting the initial AUT. These verbal instructions followed a script and were delivered identically to each participant. No other instructions were given unless the participant requested additional clarification.

At the start of each task, participants were provided written on-screen instructions. Next shown were possible combinations for the Stroop and finger-tapping tasks with corresponding correct responses. Finally, to familiarize themselves with the task, participants completed a practice run of the upcoming version of the Stroop or finger-tapping task.

2.2.3 Task and AUT-object order

The study used different task and AUT-object orders, where each participant performed both the Stroop and finger-tapping tasks. The order of the Stroop and finger-tapping task was switched every five participants, i.e., some participants completed the Stroop-task first, while others performed the finger-tapping task first. Task-order counterbalancing is shown in Appendix B.

A break of five minutes was inserted between the completion of the first task and the start of the second task. The entire study took between 30-40 minutes per participant.

2.2.4 Stroop-task details

The implemented Stroop task asked participants to identify the font color used to display, and not the text that spelled out the words *blue, green* and *red.*

Participant instructions. The current study instructed participants to press the keyboard key corresponding to the font color, i.e., the ‘g’ key for text in green font, ‘r’ for red font, and ‘b’ for blue font.

Timing of stimuli. The implemented Stroop task revealed a word that disappeared when the participant responded by pressing a key, and the next word was revealed after a 500 ms delay. In the absence of a response, the word remained on the screen for 4 s, after which the word disappeared until a response, at which point the next word appeared after a 500 ms delay.

Easy (color-matched) and hard (color-unmatched) versions. The easy and hard versions of the Stroop task each showed 60 words. The easy version showed 60 color-matched words, e.g., the word ‘red’ in red font, 'blue' in blue font, etc. After 60 participant responses, the program continued to the next condition or task. The hard version showed 60 words that randomly combined text and font color. That is, the word may match its font color, e.g., ‘red’ in red font, or the word may mismatch its font color, e.g., ‘red’ in blue font, with no predictable order of text-font-color combinations.

Unintended effects may be caused by the Stroop task when participants simply press keys in response to quickly appearing words. Therefore, the easy, color-matched version of the Stroop task, where words always match their font color, was intended to isolate the conflicting nature of the hard, randomly matched version of the Stroop task.

2.2.5 Finger-tapping-task details

The finger-tapping task revealed a sequence of dark and light squares on either the left or right side of the laptop screen, and participants were instructed to respond as follows.

Participant instructions. Three instructed responses for four combinations of square shade and side of screen are shown in Table 1. For a light square appearing on the left side of the screen, the instructed response was the ‘s’ key. If the light square was on the right side, the instructed response was the ‘k’ key. For dark squares on either side of the screen, the participant was instructed to not press any key until the next square appeared.

Table 1: Instructed responses for finger-tapping stimuli

Shade of Square	Side of Screen	Instructed Response
light	left	‘s’
light	right	‘k’
dark	left	no response
dark	right	no response

Timing of stimuli. Each square was shown on screen until the participant responded, up to a maximum of 500 ms, with a constant gap of 250 ms between one square disappearing and the next square appearing. To maintain consistent levels of difficulty despite variable reaction times, faster-responding participants had a correspondingly faster sequence of squares. However, participant reaction time did not affect the gap between when one square disappeared and the next square appeared.

Response aspects. This task had two response aspects. First, a response was required when a light square appeared but not when a dark square appeared. The second response aspect corresponded to whether the light square appeared on the left or right side of the screen. This task was intended to be challenging in order to activate the dlPFC.

Hard (random-pattern) vs. easy (repeating-pattern) versions. The two versions of the finger-tapping task each showed 84 squares. In the hard version, the light and dark squares appeared randomly on either side of the screen until the end of the task. In the easy version, squares appeared in the following repeating pattern until the end of the task: light square left side, light square right side, light square left side, dark square right side.

2.2.6 Alternative Uses Test (AUT)

All participants completed six AUTs, three each for the Stroop and finger-tapping task, with the first and fourth being the pre-test AUT before each task. Each AUT lasted two minutes, and the subsequent task began as soon as the two minutes passed. The order of AUT objects (brick, bottle, belt, ring, sponge and newspaper) was counterbalanced, as shown in Appendix B. The name of the object appeared and remained in the top right corner of the screen throughout each AUT. Participants were instructed to type in creative uses for the assigned AUT object, and to press the ‘enter’ key between different uses.

2.2.7 Study completion and debriefing

Upon study completion, participants were given debriefing forms and informed of the nature of the experiment.

2.3 Evaluation of AUT responses

2.3.1 Fluency

Fluency was determined by counting the total number of distinct responses for each AUT object. A response was considered distinct if it was separated by the ‘enter’ key. Incomplete responses (e.g., "the object can be used for" with nothing after 'for') were not counted as distinct responses.

Two raters blindly scored fluency, with high inter-rater reliability (average intra-class correlation (ICC) above 0.97).

2.3.2 Flexibility

Flexibility was determined by grouping AUT responses into distinct categories for each object. For example, for the object 'brick', the responses "building a house" and "building a wall" would be scored as a single category. In contrast, the response "bricks can be thrown to break windows" would be scored as a separate category from the previous two uses. The number of distinct categories corresponded to the flexibility score of that object for that participant.

Two raters blindly scored flexibility, with average intra-class correlation (ICC) above 0.85.

3. RESULTS

3.1 Fluency

Fluency was modelled as a 2x3 repeated-measures design, with task type (Stroop, finger tapping) and task difficulty (pre-test, easy, hard) as the factors. The model suggested an overall main effect of task difficulty, F(1,145)=1.81, $p<0.001$, with no evidence for a main effect of task type ($p=0.93$), nor any interaction between task type and task difficulty ($p=0.48$).

Follow-up pairwise comparison tests suggested that the main effect of task difficulty was driven primarily by significant differences between the pre-test and hard versions of the Stroop task (Table 2, Figure 1), with weaker effects in the same direction for the finger-tapping task.

Table 2: Fluency vs. Task Type and Task Difficulty

	Pre-test (SD)	Easy (SD)	Hard (SD)
Stroop Task	6.9 (2.9)	7.2 (3.4)	8.5 (4.1)
Finger Tapping Task	7.2 (3.6)	7.3 (3.5)	8.0 (3.4)

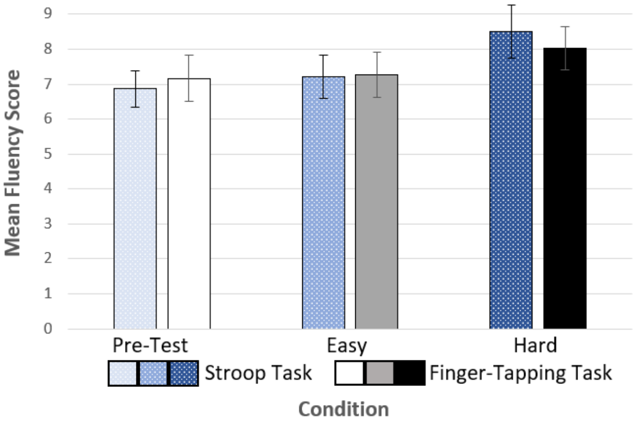

Figure 1: Mean fluency by Task Type and Task Difficulty

3.2 Flexibility

Flexibility was similarly modelled as a 2x3 repeated-measures design, with task type (Stroop, finger tapping) and task difficulty (pre-test, easy, hard) as the factors. The model suggested an overall main effect of task difficulty, F(1,145)=18.9, p<0.0001, with no evidence for a main effect of task type (p=0.65). However, an interaction between task type and task difficulty was observed, F(2,145)=3.7, p=0.027.

Follow-up pairwise comparisons and visualization suggested that the main effect of task difficulty was similar to that observed for fluency, with greater difficulty yielding higher flexibility scores (Table 3, Figure 2). For the interaction between task type and task difficulty, increasing difficulty in the Stroop task produced a greater increase in flexibility scores than the finger-tapping task.

Table 3: Flexibility vs. Task Type and Task Difficulty

	Pre-test (SD)	Easy (SD)	Hard (SD)
Stroop Task	5.2 (1.9)	5.9 (2.4)	7.3 (3.1)
Finger-Tapping task	5.8 (2.3)	5.8 (2.3)	6.6 (2.5)

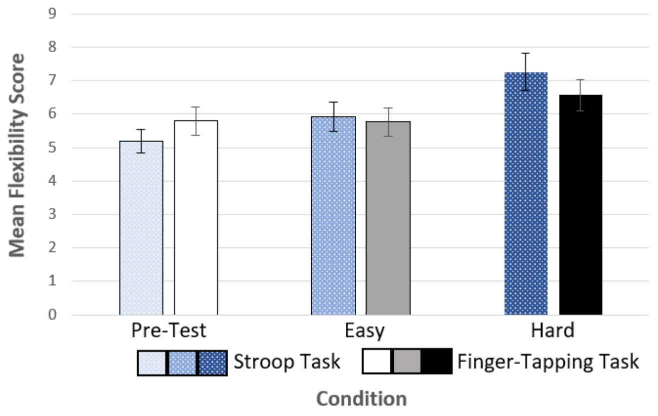

Figure 2: Mean Flexibility by Task Type and Difficulty

3.3. AUT-object effects

Characteristics of AUT objects may lead to different fluency and flexibility scores. To check for differences between AUT objects, fluency and flexibility scores were organized by object as shown in Table 4. There were no significant differences between mean scores for AUT objects. Average fluency scores between objects did not differ significantly, using a one-way ANOVA [F(5,174)=0.31, p=0.906]. Average flexibility scores between objects also did not differ significantly, using a one-way ANOVA [F(5,174)=0.43), p=0.824].

Table 4: AUT objects average fluency and flexibility

AUT Object	Fluency (SD)	Flexibility (SD)
Bottle	7.3 (3.5)	5.8 (2.6)
Belt	7.3 (3.6)	6.1 (2.4)
Newspaper	8.0 (4.3)	6.6 (3.2)
Ring	7.1 (3.1)	6.0 (2.4)
Sponge	7.4 (2.7)	5.9 (1.8)
Brick	7.9 (3.7)	6.3 (2.6)

3.4. Task-order effects

While the order of the Stroop and finger-tapping sets were counterbalanced between participants, within each set, the AUTs after the intervention tasks always followed the pre-test AUT. Thus, the pre-test AUTs were compared to check for task-order effects, e.g., improved performance due to learning or decreased performance due to fatigue.

Fluency and flexibility scores for the Stroop task pre-test and the finger-tapping task (FTT) pre-test were organized by task order. Neither fluency (Table 5) nor flexibility (Table 6) differed significantly between the two pre-test AUTs regardless of task order.

Table 5: Pre-test Fluency vs. Task Order

	Stroop(SD)	FTT (SD)	T-test results
Stroop First	7.7 (3.1)	8.1 (4.0)	t(30)=0.33, p=0.740
FTT First	6.0 (2.2)	5.9 (2.8)	t(23)=0.16, p=0.877

FTT = Finger-Tapping Task

Table 6: Pre-test Flexibility vs. Task Order

	Stroop (SD)	FTT (SD)	T-test results
Stroop First	5.4 (2.2)	6.3 (2.4)	t(32)=1.19, p=0.242
FTT First	5.0 (1.6)	5.2 (2.1)	t(22)=0.21, p=0.834

FTT = Finger-Tapping Task

4. DISCUSSION

4.1 Analysis of Results

The current study investigated whether tasks that require mental effort would improve divergent thinking as measured by the AUT. The study also explored whether increasing the difficulty of the task would further improve AUT task performance. For fluency (number of uses), scores increased as task difficulty increased, an effect that was common to both the Stroop and finger-tapping tasks. Furthermore, flexibility (number of categories of uses) increased with task difficulty for both tasks, although the Stroop task was more effective than the finger-tapping task at improving scores.

To check for differences between AUT objects, scores were organized by object and analyzed. Significant differences were found between neither mean fluency nor flexibility scores of objects. In addition, the effects of task order, i.e., whether participants completed the Stroop task or finger-tapping task first, were checked by comparing pre-test AUT fluency and flexibility scores. Neither learning nor fatigue effects were significant.

4.2 Potential Role of Cognitive Control

The efficacy of the Stroop task may be related to its effect on cognitive control. Cognitive control refers to a preference for target information that is goal dependent when attending to a task with conflicting information. The processing of conflicting information (as required for the Stroop task) could carry over to and better inform processing on subsequent tasks, i.e., the AUT that immediately follows.

Specific to the Stroop task, MacDonald et al. (2000) found that the dlPFC is responsible for processing color hue rather than word reading. The goal of a typical Stroop task is to respond with the font color hue, rather than read the word that names a color. By prioritizing font color over text content, the resulting selective focus reduces the conflict between incongruent cues. Cognitive control can reduce conflict compared to processing both font color and named color equally. As such, the color-incongruent Stroop task requires more discerning focus than its easy color-congruent version, which in turn increases the level of dlPFC activation in comparison.

The AUT may have conflicting elements due to its emphasis on producing creative (and not only typical, default uses) for each object. That is, coming up with novel uses in the AUT could require overcoming a tendency to name common uses. Thus, cognitive control may modulate the production of new uses by focusing on creative and novel uses over typical uses.

Resolving conflict, as required for the Stroop task, may ‘warm-up’ the ability to focus on task-relevant processing in the AUT, allowing for a focus on a greater diversity and number of creative uses. AUT performance could then improve with increased intervention difficulty. That is, the hard version of the Stroop task demanded increased cognitive control, which may then be carried over to the subsequent AUT trial.

4.3 Limitations of Finger-tapping Task

The finger-tapping task did not improve AUT performance as effectively as the Stroop task. While the finger-tapping task was considerably challenging in its rapidity, it may not have had sufficient conflicting content to elicit the desired response. Since the side of the laptop screen where squares appeared was consistent with the side of the keyword where keys were to be pressed, participants may have been able to respond reflexively. In future studies, this task can be modified by requiring participants to press keys on the side opposite to where stimuli appear for one square shade but not the other. For example, instructed responses for light squares could be 'k' for a square on the left side of the screen and 's' for the right side, and the reverse for dark squares, i.e., 's' for left and 'k' for right sides.

The current study's finger-tapping task may have otherwise differed too much from that used by Abiru et al. (2016), which increased dlPFC activation in response to a difficult musical rhythm. For practicality and accessibility reasons, the present finger-tapping task replaced the musical rhythm with a pattern of squares, but this change may have also affected the task qualities responsible for dlPFC activation. In contrast, the current study's hard version of the Stroop task was similar to that used in studies which found significant dlPFC activation (Schroeter et al. 2002). Again, neuroimaging is required to determine the effect of the finger-tapping task in this study on dlPFC activation despite its lower effect on AUT performance compared to the Stroop task.

4.4 Limited AUT Response Time

The overall AUT scores may have been capped by the limited response time allotted for the task. While past AUT studies in the same laboratory (e.g., by Kwon et al. 2020) also provided two minutes per object, participants spoke aloud responses. Verbally expressing AUT responses in past work may have required less time per use than writing or typing them. Therefore, a two-minute limit may not have capped as strongly the number of uses participants were able to express. In contrast, the current study's participants had two minutes to type in their responses for each AUT object. It is thus possible that this same time constraint capped the number of responses that could be expressed. Given more time, participants may have been able to produce more uses. Not artificially capping the number of uses could thus enable the expression of individual differences (i.e., some participants are simply more fluent then others). Inadvertently capping responses due to a time limit also reduces the possibility of different AUT scores following the interventions studied. Thus, the time limit on the AUT may have obscured higher-level trends in the present study.

By definition, flexibility (number of categories of uses) cannot be higher in value than fluency (number of uses). Therefore, flexibility may not have been as strongly capped by the time limit. Future studies should incorporate more AUT response time, as to not cap performance, a possible limitation of the current study.

4.5 Other Limitations and Future Work

The current study examined two difficulty levels of the two intervention-behavior tasks, i.e., easy and hard versions. Future studies can establish and test different variations of the Stroop and finger-tapping task that account for several distinct levels of difficulty and effort. Such studies can better distinguish the effect of intervention difficulty on divergent thinking. Concurrent use of neuroimaging can highlight differences in dlPFC activation due to these tasks and variations in their difficulty, as well as how they mediate improved AUT performance.

The present study's participants consisted exclusively of undergraduate students performing a laboratory task. Future work would examine the relationship between improved AUT performance and more complex cases of design. Many other researchers, e.g., Viswanathan & Linsey (2013), found that expertise plays a role in the effectiveness of design-fixation interventions. Thus, the effects of interventions tested on novices may not translate to design professionals. As such, future participants that include professional designers would help to establish the external validity of using interventions, e.g., the Stroop task, in the workplace. Longitudinal studies can reveal changes over time in the effectiveness of intervention tasks on divergent thinking.

Further research with neuroimaging is required to confirm the effects of interventions on dlPFC activation in a subsequent divergent-thinking task. High levels of activation in the dlPFC would confirm the link between task-difficulty-induced creativity benefits and the dlPFC. Nonetheless, the current study supports the Stroop task's efficacy in increasing divergent-thinking abilities, and thus its potential as the basis of a useful intervention for the conceptual-design process. Furthermore, the study supports the overall effect of increased difficulty in improving AUT fluency and flexibility scores.

5. CONCLUSION

The current study highlights the potential of the Stroop task as the basis of an effective intervention to increase idea flexibility and fluency in divergent-thinking tasks. For maximum benefit, a person should be given the hard, color-mismatched Stroop task over any other combination of task type and difficulty. Ease of implementation, resilience to practice effects and appropriateness for the workplace further support the Stroop task's potential as an effective precursor to design processes, e.g., concept generation, that benefit from added idea fluency and flexibility.

Beyond the Stroop task, other candidates for behavioral intervention can be explored on the basis of increased task difficulty on dlPFC activation. Additional behaviors that activate other brain regions effectively stimulated using tDCS also have high potential for improving creative performance in design.

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APPENDIX A - TASK INSTRUCTIONS

Alternative Uses Test (AUT) Instructions

A word will appear in the top right corner of the following screen.
Please come up with as many creative uses as you can for that object within two minutes.
Separate each creative use by pressing the 'enter' key before writing down the next use.

Stroop Task Instructions

In this task, you will be briefly shown the name of a color which will have a colored font.
You only want to respond with the color of the letters, not the word itself.
If the color of the word is red, press 'r'
If the color of the word is green, press 'g'
If the color of the word is blue, press 'b'

Finger-Tapping Task Instructions

In the following task, you will be shown a sequence of squares in changing shades.
If the square is light and on the right side - press 'k'
If the square is light and on the left side - press 's'
If the square is dark - do NOT press any key.
Tip: The squares will change very quickly.

APPENDIX B: TASK-ORDER AND AUT-OBJECT ORDER COUNTERBALANCING

Table B1: Task-Order Combinations

Task Order	1st	2nd	3rd	4th	5th	6th
1	Stroop Pre-test	Stroop - Easy	Stroop - Hard	Finger-Tapping Pre-test	Finger-Tapping Easy	Finger-Tapping Hard
2	Finger-Tapping Pre-test	Finger-Tapping Easy	Finger-Tapping Hard	Stroop Pre-test	Stroop - Easy	Stroop - Hard

Table B2: Object-Order Counterbalancing Combinations

Combination	1st AUT	2nd AUT	3rd AUT	4th AUT	5th AUT	6th AUT
C1	Bottle	Belt	Newspaper	Ring	Sponge	Brick
C2	Brick	Bottle	Belt	Newspaper	Ring	Sponge
C3	Sponge	Brick	Bottle	Belt	Newspaper	Ring
C4	Ring	Sponge	Brick	Bottle	Belt	Newspaper
C5	Newspaper	Ring	Sponge	Brick	Bottle	Belt
C6	Belt	Newspaper	Ring	Sponge	Brick	Bottle

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