The emotional counting Stroop: a task for assessing emotional interference during brain imaging

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The emotional counting Stroop (ecStroop) is an emotional variant of the counting Stroop. Both of these tasks require a motor response instead of a spoken response for the purpose of minimizing head movement during functional MRI (fMRI). During this task, subjects report, by button press, the number of words (1–4) that appear on a screen, regardless of word meaning. Neutral word-control trials contain common words (e.g., 'cabinet' written three times), while interference trials contain emotional words (e.g., 'murder' written three times). The degree to which this task represents a true 'Stroop' interference task, in the sense that emotional words will increase motor-response times compared with neutral words, depends upon the subjects of the study and the words that are presented. Much research on the emotional Stroop task demonstrates that interference effects are observed in psychopathological groups in response to words that are specific to their disorder, and in normal subjects when the words are related to current concerns endorsed by them. The ecStroop task described here will produce reaction time-interference effects that are comparable to the traditional color-naming emotional Stroop. This protocol can be completed in ~20 min per subject. The protocol described here employs neutral words and emotional words that include general-negative words, as well as words specific to combat-related trauma. However, this protocol is amenable to any emotional word lists.

INTRODUCTION

Staying on task requires the ability to balance competing information streams. Cognitive scientists have studied this ability within the context of interference paradigms. These studies demonstrate that primary task performance can be slowed by the presence of contradictory sensory information, as exemplified by the color-naming Stroop task[1]. However, the human condition is fraught with sources for primary task interference. For example, our emotional lives provide a wellspring of opportunities for intrusion on primary task performance. Indeed, modern cognitive scientists who are interested in whether emotional information is more likely to produce task interference in some individuals than others have modified many of these classic interference paradigms to incorporate emotional information of particular concern to their subjects of study[2]. To elaborate, competing information streams can reside within the cognitive realm, such as color naming versus prepotent reading responses during the color Stroop task. Yet one can also assess the ability of subjects to balance the presence of emotional information presented during cognitive-task performance. A delay in response when emotional versus non-emotional stimuli are present is interpreted as 'emotional interference.' Such is the logic of the emotional color Stroop variant[3] and, specifically, the emotional counting Stroop (ecStroop) variant[4] presented here.

Neuroimaging studies offer the opportunity to identify the neural substrates of behavioral phenomena, such as task interference. The majority of these studies have implicated the anterior cingulate cortex (ACC) as a critical component of a circuitry that functions to balance the processing of two competing information streams[5]. Of course, the measurement of subtle brain signals in neuroimaging technologies, such as functional MRI (fMRI), requires that subjects restrain their head movement during task performance. The ecStroop task described here was designed to allow for the assessment of the impact of emotional information on button-press performance (versus a spoken response), thereby minimizing the subjects' head movements. Subjects simply report via button press whether there are one, two, three or four repeated words on a screen in front of them (e.g., cushion, cushion, cushion; correct response is three). Half the words are neutral in nature (household items) and the other half are emotional in nature. Given that the emotional Stroop was designed to test psychopathological subject groups, the emotional words usually consist of items related to a particular diagnosed disorder (i.e., disorder-specific words), such as depression or an anxiety disorder, as well as more generally negative words (general negative) that are implemented as a comparison condition to reveal the disorder-specific nature of any observed Stroop effect. Indeed, the example detailed here involves stimuli designed to compare combat veterans with and without post-traumatic stress disorder (PTSD). Reaction times (RTs) to disorder-specific versus general-negative or neutral words would be expected to be increased in patient populations. Psychiatrically healthy subjects would not be expected to show such a Stroop effect in response to disorder-specific words, and thus serve as a control group. Note that one can observe an emotional Stroop effect in healthy controls if the emotional words used in the ecStroop are those the subject has endorsed as particularly concerning[6]. Thus, an emotional Stroop effect might not require a diagnosable disorder, but might only require that presented words tap into the current concerns of the subjects of study.

The present protocol differs from traditional color-naming emotional Stroop tasks[3,6] in both the source of interference (number versus color incongruence) and the response mode (finger press versus spoken response). As noted above, this modification was

implemented to minimize head movement during brain visualization. That said, Stroop-like tasks based on number incongruence have been used previously and these, as well as the ecStroop protocol described here, yield similar interference effects to the color-naming Stroop[6].

The ecStroop can be translated into most languages, and should be presented in the subject's primary language. The ecStroop was designed to be an fMRI protocol, and the following method details the block-formatted parameters that can be administered in 20 min per subject. However, the ecStroop can easily be converted to an event-related format for use with event-related fMRI, event-related potentials (ERPs), magnetoencephalography (MEG), intracranial recordings or simple offline behavioral performance (RT/accuracy). In this case, the timing between trials (intertrial interval) should be variable (i.e., 'jittered') so that unique estimates of the hemodynamic responses for each trial type can be computed[7,8]. A caveat is that some data suggest that a blocked format can produce greater interference effects within the color-naming emotional Stroop task[9]. Also, note that in blocked-design fMRI studies, block lengths of ~16–20 s are commonly used[10] versus the 30-s block lengths described here. Thus, the present protocol could be amended to use 18-s block lengths (12 trials per block). This is acceptable as long as the investigator feels that it will allow sufficient time to ensure that any changes in emotional state induced by emotional word blocks do not contaminate neutral word blocks. For the study of more severely affected psychopathological groups (e.g., those with PTSD), we recommend staying with the 30-s blocked format.

MATERIALS

REAGENTS

- Human subjects (see REAGENT SETUP)

EQUIPMENT

- Padded scanner couch
- Foam ear plugs
- Head stabilizer; for example, foam padding within a head coil, or a plastic bite bar molded to the subject's dentition
- MacStim 2.5–3.0, stimulus-presentation software for Macintosh computers (Dave Darby, WhiteAnt Occasional Publishing)
- Presentation, stimulus-presentation software for personal computers (Neurobehavioral Systems, Inc.)

REAGENT SETUP

Human subjects The ecStroop is appropriate for use with literate subjects of most ages (for young children or elderly adults who might not read and/or respond as quickly as typical adults, the rate of presentation (interstimulus interval) might be adjusted — in these specialized cases additional pilot testing might be needed to optimize the interstimulus interval). Handedness is not crucial, but should be assessed and documented by the Edinburgh Handedness Inventory[11] or an alternative. Subjects also need to have normal or corrected-to-normal vision. ! CAUTION The study protocol must first be approved for use by the appropriate Human Subjects Committee or Institutional Review Board.

EQUIPMENT SETUP

MRI equipment fMRI equipment and scanning techniques can vary appropriately — specifics are not crucial here as long as generally accepted practices are followed. Some general issues are highlighted below.

Stimulus generator Stimuli can be generated via any number of software/hardware configurations. Our stimuli have been created/displayed using MacStim 2.5–3.0 and Presentation, but any suitable stimulus-presentation software/hardware combination that can smoothly display stimuli and record responses (and RTs to ms accuracy) can be used. Whether displayed on a computer screen (for offline studies, positron-emission tomography (PET), MEG and ERPs) or projected for use during fMRI, individual words should be easily readable without strain, but should not take up a large proportion of the visual field. Generally accepted guidelines would be to display individual words that subtend ~1° of the visual angle vertically, and to space words such that a group of four subtends a visual angle of ~6° vertically.

During 'neutral' (control word) blocks, words depicting household items (e.g., cabinet and telephone) are used (**Fig. 1**). These words are matched for length and frequency of usage within the English language with emotional words, as differences between word categories along these two dimensions can produce Stroop effects[6].

During 'interference' blocks, the stimuli consist of emotional words. As noted in the introduction, the task is amenable to any psychopathological group or healthy control group. The example protocol offered here comes from a study of subjects who were exposed to combat and developed PTSD[12] compared with a control group who were also exposed to combat but did not develop PTSD. Two lists of emotional words were employed: one consisted of general-negative words not necessarily related to combat (e.g., danger and hazard), while the other comprised words that had specific relevance to combat-related PTSD previously rated by combat veterans to be stressful (e.g., bodybags and firefight)[13,14]. Comparison of response latencies between these two groups of words allows for the assessment of disorder-specific interference.

Figure 1 | Examples of single trials for the three types of stimulus. In all examples, the correct answer would be to press button number 3.

Investigators should carefully consider the number of words to be utilized within the neutral and interference categories. In the current example, we used 16 neutral words and 16 emotional words (**Fig. 2**). Of the emotional words, eight were general negative and eight were disorder specific for combat veterans with PTSD[12]. Another version of this task contains words specific to obsessive compulsive disorder (OCD)[4]. Across the experiment, subjects viewed each word 10 times. This was done by design. We wanted a stimulus-presentation profile that would potentially induce less interference with repeated trials. Thus, psychopathological groups could potentially differ from controls in the magnitude of their interference effect, but also in the slope of habituation over repeated trials. Investigators wishing to observe more sustained interference effects might increase the number of words within each category.

PTSD	Neutral	General Negative	Neutral
firefight	skylight	tragedy	tables
kill	drawer	deceit	closet
ambush	cellar	contempt	corridor
jungle	cabinet	hazard	porch
medevac	mirror	disaster	garage
incoming	renovate	danger	balcony
bodybags	colonial	poverty	doorway
Charlie	telephone	sadness	basement

Figure 2 | Words used in a study of combat veterans with and without PTSD[7]. The neutral columns are matched for average length and frequency of usage in the English language with the column of emotional words to their immediate left.

PROCEDURE

Subjects

1| Obtain informed consent following the established institutional guidelines.

Psychophysical procedures

2| Tell subjects that sets of one to four identical words will appear on the screen (**Fig. 1**), and instruct them to report, via button press, the number of words in each set, regardless of what the words are.

3| Instruct subjects that the keypad buttons represent responses one, two, three and four, from left to right, and that they should use the index and middle fingers of each hand to respond.

4| Explicitly instruct the subjects: (i) that the sets of words will change every 1,500 ms; (ii) to "Answer as quickly as possible, but since getting the correct answer is important, do not sacrifice accuracy for speed"; and (iii) "Do not 'blur your vision' in an attempt to make the task easier — keep the words in sharp focus."

5| After instructions are reviewed, and just prior to entering the scanner (or being formally tested), have subjects complete a 1-min computerized practice version of the task (20 neutral trials followed by 20 interference trials). Reviewing the responses here ensures that the subject understands the task and can perform correctly without requiring excessive practice.

Formal testing: fMRI scanning techniques and data analysis

6| Lie subjects on a padded scanner couch in a dimly illuminated room, and ensure they are wearing foam ear plugs that attenuate high-intensity scanner sounds, but allow spoken instructions to be heard clearly.

7| Ensure head stabilization via one of the generally used techniques (i.e., foam padding within a head coil or using a plastic bite bar molded to the subject's dentition).

8| Start the block-formatted fMRI scan with 30 s of fixation on a small dot (to assist in drift correction and between-run assessment by providing a less-biased baseline unrelated to task). In addition, this baseline condition can allow for the assessment of brain regions responsive to the task itself (e.g., neutral word condition versus fixation).

9| Perform two scans of the ecStroop per subject, in which four 30-s blocks of the neutral words alternate with four interference blocks (two general negative and two disorder specific). Given a fixed intertrial interval of 1,500 ms, subjects will complete 20 trials during each (neutral/interference) block, 80 trials of each type during a single scan and 160 total trials of each type during the two-scan session.

▲ **CRITICAL STEP** The order of presentation, regarding the neutral and interference blocks, should be counterbalanced across runs and subjects.

10| End the block-formatted fMRI scan with 30 s of fixation on a small dot.

ANTICIPATED RESULTS

Performance

In the patient group of interest, RTs should be greater for interference trials than for neutral trials ($RT_{interference} - RT_{neutral}$). RTs should not be greater for interference trials than for neutral trials for healthy control subjects. For example, PTSD subjects[7] take, on average, 60 ms longer to respond to disorder-specific words compared with neutral words (1,059 ms versus 995 ms). This effect was more pronounced during the first stimulus-presentation block per scan (~100 ms slower for PTSD versus neutral words). In comparison to trauma-exposed control subjects, responses to disorder-specific words in PTSD subjects were, on average, ~300 ms slower (1,059 ms versus 774 ms). Trauma-exposed control subjects without PTSD showed similar RTs for general-negative or disorder-specific and neutral words.

Accuracy in healthy adult volunteers serving as a control group for patient populations is expected to be high (generally above ~95% for both neutral and interference trials). Accuracy for patient groups can be lower. In a recent test of PTSD subjects[12], they were ~85% correct for neutral and general-negative words, and ~80% correct for disorder-specific words. Importantly, within each group, error rates did not differ between word categories.

Brain responses

Anatomic-tracing studies suggest that the pregenual and subgenual portions of the ACC have reciprocal connectivity with classic limbic areas of the brain, such as the amygdala[15,16]. Based upon this anatomy, we hypothesized that these portions of

the ACC in particular would be sensitive to the presence of emotional information in the environment. Indeed, in two separate studies, psychiatrically healthy subjects showed greater activation of the rostral portion of the AC when emotional words were presented within the ecStroop paradigm[4,12]. This effect should not be interpreted as being related to task interference, because healthy subjects showed no interference effect in these studies. Indeed, we speculated that these effects might be evidence that the ACC was involved in 'balancing' task performance in the presence of potentially interfering emotional information, and that this activation was necessary to avoid interference. Based upon this speculation, as well as other available data, we predicted that PTSD subjects would fail to recruit the pregenual ACC when disorder-specific words were present during the ecStroop. We published this effect, showing that the lack of activation coincided with greater response latencies[12]. Finally, psychiatrically healthy subjects performing the ecStroop show the typical 'deactivation' effects in affective regions, such as the pregenual/subgenual ventral ACC, posterior cingulate cortex and hippocampus[4]. Interestingly, they do not show robust deactivation of the amygdala, as is observed during the counting Stroop[17], perhaps owing to the presence of the emotional words in this experimental paradigm.

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