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Cardiac reactivity and preserved performance under stress: Two sides of the same coin?

Nathalie Pattyn [a,b,c,d,*], Olivier Mairesse [a,e], Aisha Cortoos [a,f], José Morais [c], Eric Soetens [b], Bart Roelands [d], Annick van den Nest [a], Régine Kolinsky [c]

[a] VIPER Research Unit, Royal Military Academy, Renaissancelaan, 30, 1000 Brussel, Belgium
[b] Dept of Biological Psychology, Vrije Universiteit Brussel, Pleinlaan, 2, 1050 Brussel, Belgium
[c] Unité de Recherches en Neurosciences Cognitives, Université Libre de Bruxelles, CP 191, avenue F.D. Roosevelt, 50, 1050 Bruxelles, Belgium
[d] Department of Human Physiology, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussel, Belgium
[e] CHU Brugmann, Sleep Unit, Belgium
[f] UZ Brussel, Sleep Unit, Belgium

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ABSTRACT

In the present experiment, cognitive control under stress was investigated using a real-life paradigm, namely an evaluation flight for military student pilots. The magnitude of cognitive interference on color–word, numerical and emotional Stroop paradigms was studied during a baseline recording and right before the test flight. Cardio-respiratory parameters were simultaneously assessed during rest and the performance of the Stroop tasks. Cognitive data suggested a different speed/accuracy trade-off under stress, and no modulation of the interference effect for color words or numerical stimuli. However, we observed a major increase in error rates for specific emotional stimuli related to the evaluation situation in the stress condition. The increase in cognitive interference from emotional stimuli, expressed as an increase in error rates, was correlated to the decreased cardiac reactivity to challenge in the stress situation. This relationship is discussed in the framework of Sanders' (1983) model of stress and performance. In terms of future research, this link warrants a fruitful lead to be followed for investigating the causal mechanism of performance decrements under the influence of stress.

1. Introduction

Ever since Yerkes and Dodson (1908), the effects of stress on cognitive performance have been investigated in both experimental and applied psychology. However, the concepts stress and performance have too often been stocked with idiosyncratic or unspecific connotations, hampering comparison of the available results. Operationalization of stress or arousal in research paradigms indeed is quite complex. While questionnaires rely on subjective evaluation, physiological measures like heart rate variability quantify a systemic outcome. Operational definitions based on response have been prominent in psychophysiological literature (Sanders, 1983), ever since Selye (1956) introduced the concept of stress as the response of the body to any demand made upon it. Intervening variable-definitions (Cox, 1978, in Sanders, 1983) on the other hand, have become very influential in clinical and coping literature, whereas this conceptualization has been surprisingly absent in psychophysiological research on stress and performance. The two most influential contemporary stress and performance models did nonetheless underscore an intervening variable concept, termed 'resource recruitment' in Hockey's (1997) compensatory control regulation and 'effort' in Sanders' (1983) cognitive-energetical model. In order to allow inferences about mechanisms at play, psychophysiological investigations of stress and performance should frame the design and data-analysis within such models, which happens surprisingly seldom in the most recent research.

With regard to performance, as mentioned by Kofman et al. (2006), very few studies examined the effects of stress on executive functions. Indeed, considering the importance of stress in applied research, for example on aviation or traffic safety (e.g. Matthews et al., 1998), and considering the involvement of higher order cognitive functions such as planning, monitoring and cognitive control for an adequate performance in the aforementioned settings, there is a remarkable lack of experimental results on the effects of stress on executive functions. According to Matthews et al. (1997), stress mainly affects performance in applied settings through cognitive interference. In experimental paradigms investigating executive functions, distinct variants of the Stroop task (Stroop, 1935) are known to trigger this type of cognitive interference.

* Corresponding author at: VIPER Research Unit, Royal Military Academy, Renaissancelaan, 30, 1000 Brussel, Belgium. Tel.: +32 2 629 15 94, +32 476 66 12 03 (mobile); fax: +32 2 629 24 89.
E-mail address: nathalie.pattyn@rma.ac.be (N. Pattyn).

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In the classical color–word Stroop task, subjects are instructed to name the color in which a word appears. Congruent stimuli display coherence between semantics and appearance (e.g. the word *red* in red), whereas incongruent stimuli do not (e.g. the word *red* in blue). The numerical Stroop variant (Pavese and Umiltà, 1998) requires participants to respond to the amount of characters presented onscreen; these can be either congruent (three times 3) or incongruent (four times 3). The response conflict elicited by incongruent stimuli materializes as longer reaction times (RTs) and lower accuracy (for a review, see MacLeod, 1991). The emotional Stroop variant includes (among the color words) negatively valenced emotional words, related to a particular individual's area of concern, causing interference as a result of attentional bias toward threat related expressions (McKenna and Sharma, 1995).

The emotional Stroop version therefore allows inferences about attentional biases, reflected as longer response latencies to name the ink color of emotional words as compared to neutral words. As Williams et al. (1997) summed up, emotional Stroop interference could be attributed to variance in state or trait emotion, to variance in the particular situation in which the task is performed, or to the specific nature of the negatively valenced words used. Impact of negative valence requires the presented material to be accustomed to both the subject's current concerns, and the situation, as in Ray's (1979) pioneering emotional Stroop challenge.

In addition to aforementioned Stroop interferences, effects from negative priming and inverse negative priming have been investigated as well. Negative priming refers to a slowed response time to a target stimulus that has been previously ignored (correct response for stimulus S is the inhibited response for item S-1, e.g. *yellow* presented in blue after *blue* presented in red), and involves inhibition of a mechanism of selective attention (Tipper, 1985). Inverse negative priming further adds the reciprocal variation of relevant and irrelevant dimension (*yellow* presented in blue after *blue* presented in yellow). Examining negative priming effects thus provides more insight in the quality of cognitive control for selecting relevant information.

Moreover, the Stroop tasks are among the most widely applied paradigms to elicit stress in laboratory conditions, for the purpose of investigating autonomic reactivity to mental stress (e.g. Akerstedt et al., 1983; Kamarck et al., 1994; Heims et al., 2006; Wright et al., 2007). In this line of research, reactivity is conceptualized as "an acute and relatively rapid change in a cardiovascular parameter as a function of the presentation of a stressor" (Hughdahl, 1995). This concept of reactivity could be applied to quantify the "recruitment of resources" from Hockey's model, or the "effort" from Sander's model. Kofman et al. (2006) emphasized that, since both the regulation of the autonomic stress response and the inhibition of prepotent responses activate common prefrontal cortical regions, particularly the anterior cingulate cortex (ACC), an interaction between these processes could indeed be expected on this neural basis.

In order to further explore the interplay between real-life stress and cognitive interference, within a psychophysiological frame linking reactivity and the quality of performance, student pilots were subjected to color–word, numerical and emotional Stroop tasks, once in a baseline recording and once right before their Progress Test General Flying (PTGF). PTGF is the most feared examination flight in the basic flight training, as failure to pass might force the student pilot out of the training. To assess stress induction efficiency, prior to experimental measurements, subjects were administered the State Trait Anxiety Inventory (STAI) (Spielberger, 1983). Cardio-respiratory parameters were recorded both during rest and execution of the cognitive tests. We expected faster responses on both the color–word and the numerical Stroop task under stress, but increased interference effects as a result of a decline in cognitive control. Furthermore, we expected these effects to be related to the magnitude of stress reactivity, as quantified by the cardio-respiratory parameters, fitting within the resource recruitment or effort notion.

2. Method

2.1. Subjects

Student pilots (N = 12) from the Belgian Air Force in their basic flight training, aged 19 to 25 years (mean = 22.5), all medically fit to fly and free of significant medical antecedents, with normal vision, participated.

2.2. Procedure

The total duration of the procedure approximated 40 min. Prior to cognitive testing, participants were equipped with the LifeShirt system (VivoMetrics, Inc.). After a rest recording period of 5 min, participants completed the STAI questionnaire. The cognitive battery was computer driven and lasted for approximately 20 min. Onscreen instructions were followed by a series of 7 cognitive tasks in the following sequence: a Stroop color–word task with neutral words (S1-N) among the color words on a white background, a Stroop task including emotional words among the color words (S1-E) on a white background, a similar Stroop task with neutral words (S2-N) on a black background and a Stroop task with emotional words (S2-E) on a black background. Subsequently, two recognition tasks (Rec1 and Rec2) were presented, each including neutral and emotional words from the lists presented in the four previous tasks, as well as new words. The last Stroop paradigm was a numerical Stroop task (Num). Task presentation (lists and stimuli) was counterbalanced, to control for potential order effects. The procedure was applied in a repeated measure design: the baseline recording took place after approximately one third of the flight training, the stress-condition recording was planned just before the PTGF, a major stress-inducing flight evaluation. This evaluation flight would always take place as the first flight of the day, therefore, all recordings started around 09.00 AM (thus avoiding circadian interference), ended around 09.40 AM, after which the student pilot started with the briefing for his PTGF. Recording sessions were separated by minimum 2 and maximum 5 months. The memory tasks will not be discussed in the present paper. In the description and discussion of results, task will refer to the cognitive tasks, and test will be used to qualify the pre-test condition (i.e. before the evaluation flight).

2.3. Task description

In the color–word Stroop task, words were presented in the middle of the screen, in bold Courier New font, 14 points, under a vertical visual angle of 2° 03′. The response–stimulus interval (RSI) was 32 ms; response times and error rates were recorded. After detailed and standardized onscreen instructions, a 60 trial practice block was inserted, providing subjects with performance feedback. Subjects were instructed to respond to the color in which a word appeared as quickly and accurately as possible, using color-labeled keys on the keyboard. The Stroop task consisted of two lists with stimuli presented on either a white or a black background, counter-balanced between participants. Half of the participants got to see the list on a white background first, whereas the other half received first the list on a black background. Furthermore, the contents of each list were again counterbalanced, meaning each list was presented on the white background half of the time, and on the black background the other half. Each list contained 14 general emotional, 7 pilot specific emotional, 7 student pilot specific emotional, and 28 neutral words, as well as 30 congruent, 30 incongruent, 5 negative priming and 15 inverse negative priming trials. Stimuli appeared in red, blue, yellow or green, in a pseudo-randomized order, limiting consecutive appearance of same color to 2.

For the numerical Stroop task, as described by Pavese and Umiltà (1998), participants had to respond to the amount of stimuli present on the screen. Stimuli were either numbers (2, 3, 4 or 5) or crosses