System for Evaluation of Cognitive Performance under the Emotional Stressors

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***Abstract*—It is well known that emotional stressors may have adverse effects on cognitive-motor performance. The system for evaluation of cognitive-emotional interactions, described in this paper, is based on real-time interplay between a selected cognitive task and selected emotional stressors, and may facilitate insight into an individual's variation of cognitive and emotional parameters and variables. To illustrate the effects of emotional distraction on cognitive-motor performance, specific cognitive-motor test has been designed and combined with aversive highly arousing emotional distractions, including pictures, sounds, acoustic startle impulses and air blasts, while measuring multimodal physiological, vocal, facial, and electroencephalography (EEG) responses. Preliminary two-phase experimental paradigm has been conducted: Phase 1 – cognitive-motor performance testing with neutral distractions, and Phase 2 – cognitive-motor performance testing under aversive highly arousing emotional distractions. Aversive emotional distractions delivered in Phase 2 transiently reduced cognitive-motor performance and produced stronger skin conductance changes in comparison to Phase 1 neutral distractions.**

Keywords-cognitive-emotional interactions; cognitive performance; emotional distractions; cognitive-motor test; multimodal physiological, vocal, facial, and EEG responses.

I. INTRODUCTION

It is well known that emotional stressors may have harmful and damaging effects on cognitive-motor performance. While some individuals are resilient, others are extremely vulnerable to such emotional disturbances. Cognitive-emotional interactions are mediated by functional connectivity between the PreFrontal Cortex (PFC) and limbic dynamic neural networks, which shape behavior [1][2][3][4]. The amygdala as the emotional hub is extensively interconnected with the PFC, especially the posterior OrbitoFrontal Cortex (OFC), and the Anterior Cingulate Cortex (ACC). The influence of emotional distractors and stressors on cognitive capacities is challenging to study due to the complexity of interconnection and interaction PFC and limbic neural networks that mediate cognitive-emotional interactions. Protective higher-order cognitive performance within an emotionally stressful environment is extremely important for individual judgment, reasoning, decision making and maintaining cognitive abilities in psychologically demanding environments. Therefore, this paper presents the design and implementation of a synthetic experimental environment for assessment of individual cognitive-motor performance under stressful emotional distractions. Real-time monitoring of individual cognitive-motor performance based on appropriate cognitive metrics, real-time generation of emotional distractions and measurements of the individual's multimodal physiological, EEG, vocal and facial responses enable real-time tracking of individual cognitive-emotional interaction. Such real-time tracking of cognitive and emotional performance over time can be used as a predictor of individual cognitive deficits prior to a negative impact of hard emotional stressors on strategic decision-making failures. Identification and recognition of individuals with a low level of emotional stability and robustness is very important to avoid the negative impact of reduced higher-order cognitive capacities, such as judgment, planning, and attention on effective decision-making. Therefore, the prediction of individual cognitive performance within stressful environments, which may significantly reduce their cognitive performance, is of foremost importance.

Section 2 describes the technical aspect of the system used for evaluation of cognitive-emotional interactions. The proposed novel computerized testing of subject's cognitive-motor performance, as well as the corresponding cognitive-motor performance metrics is introduced in Section 3. The process of generation of emotional distractions and measurement of their impact on subject's physiological, acoustic, facial and EEG reaction is shown in Section 4. Section 5 describes the experimental paradigm and preliminary results conducted using the proposed system. The last section gives a brief overview of experimental results.

II. SYSTEM FOR EVALUATION OF COGNITIVE-EMOTIONAL INTERACTIONS

The system for evaluation of cognitive-emotional interactions is shown in Figure 1, which is based on real-time interplay between a selected cognitive task and selected emotional stressor, and enables better and deeper real-time insight into an individual's variation of cognitive and emotional parameters and variables.

As shown in Figure 1, it can be divided into three subsystems:

1. Cognitive-motor subsystem for generation and delivering of a variety of cognitive tasks and evaluation of cognitive-motor performance such as motor reaction time, tracking accuracy, latency, inhibition of distractions, recovery time, etc.
2. Emotional subsystem for generating of emotional distractors like images, sounds, narratives, stories, video clips, acoustic startle, air blast, etc.
3. Multimodal acquisition subsystem for monitoring subject's physiological, acoustic, linguistic, facial and EEG features, etc.

Multimodal acquisition subsystem include: Biopac MP150 unit with ECG100C, RSP100C, EMG100C, GSR100C and SKT100C modules for physiology acquisition; voice acquisition system headset Sennheiser PC 360; video acquisition system Logitech C920 webcam; and EEG acquisition system NeuroSky ThinkGear AM. The air blast delivery module [5][6] includes Messer air tank, solenoid valve, camelback with nozzle attached to hose and solenoid controller. The 140 p.s.i. air blast is triggered by Measurement Computing DIO24 PCI Card, which is also used for synchronization of cognitive-motor, emotional and multimodal acquisition subsystem. The acoustic startle module generates 108 dB (A) Sound Pressure Level (SPL) 40-msec white noise bursts with 0-msec rise and fall times, which are delivered by a Samson headphone amplifier and Sennheiser PC 360 professional audio headphones. Aggregated longitudinal real-time analysis of cognitive-motor and emotional performance offers considerable potential in deeper and better understanding of a specific individual's cognitive-emotional strengths or weaknesses and enables comprehensive training and selection.

III. COMPUTERIZED COGNITIVE TESTING

Cognitive-motor performance in a complex, dynamically changing environment in which emotional and cognitive processes continuously influence each other depends on an individual's perception, reasoning, feeling, and action tendencies. The system shown in Figure 1 can facilitate a variety of cognitive, motor and neuropsychological tests that have their own metrics for evaluation of specific aspects of an individual's higher cognitive-motor competencies and functions in stressful environments. The human abilities of reasoning, thinking, analyzing and problem solving as valid measures of individual performance are widely recognized as excellent predictors of job performance. But, such approach could not capture and predict cognitive competencies and cognitive-motor performance within stressful emotional environments. Therefore, this paper describes the design and testing of an experimental testbed where subjects are faced with a complex set of cognitive tasks and conditions as well as a variety of environmental emotional distractors.

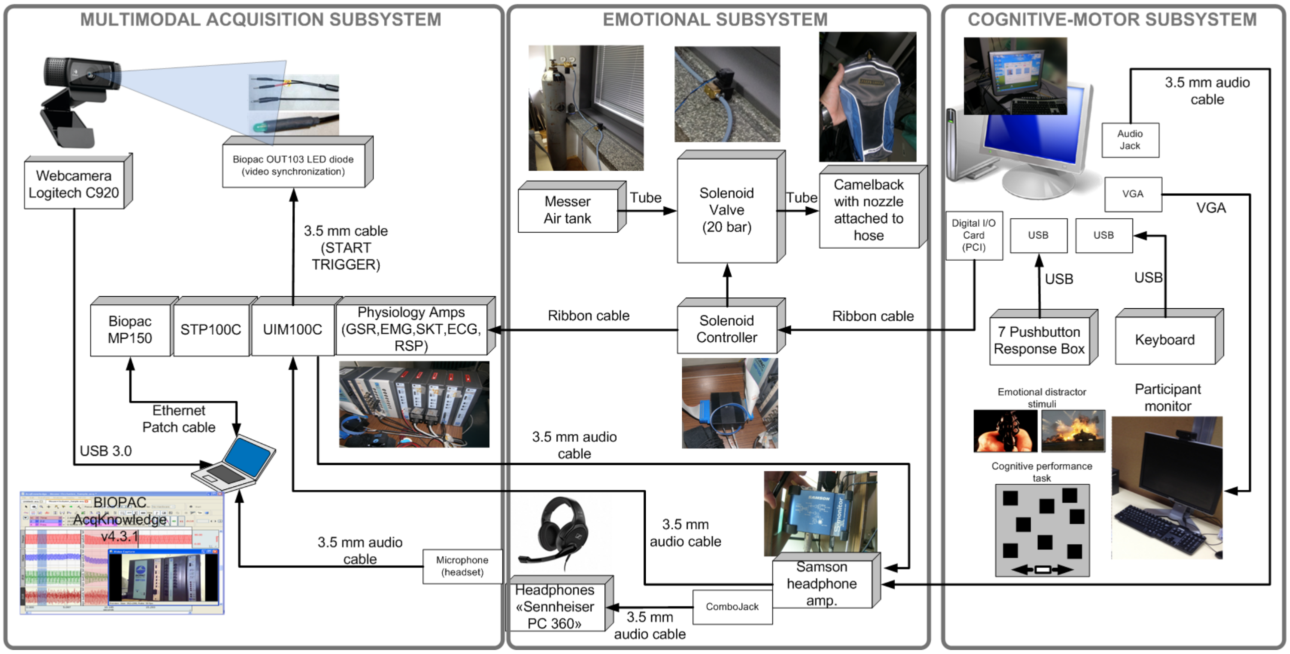

Figure 1. Block diagram of the system for evaluation of cognitive-emotional interactions

Cognitive performance might be related to: fluid reasoning as mental operations for solving novel problems; spatial ability as the ability to generate, retain, retrieve and transform visual images, including spatial visualization and spatial orientation; situation awareness as a mental process of knowing what is going on around you and is closely related to the accuracy and completeness of situation awareness, which imposes a heavy demand on working memory; executive function related to planning and organization, initiation and inhibition of behavior, strategizing, problem solving, flexible thought processes, behavior monitoring, self-awareness, and judgment [7]. Real-time measurements of all these individual's cognitive-motor abilities in a rapidly changing complex and stressful environment deserve more attention.

To illustrate the effects of emotional distraction on cognitive-motor performance the following cognitive-motor test has been designed as a computer game displayed on the computer screen, in which the subject's task is to avoid collisions with falling objects. The subject uses two buttons on the response pad to evade the falling objects by moving left or right. In this example the cognitive effectiveness of the individual could be studied and measured by correctly headings cursor surface to effectively engage joystick pads through dynamically moving obstacle surfaces. The cognitive-motor test is used in two phases of experimental paradigm: in Phase 1 the test is delivered to the subjects mixed with emotionally neutral distractions, while in Phase 2 the test is mixed with fear-related emotional distractions and stressors, which are described in the next section. Before Phase 1, there is practice session to stabilize the subject's performance on this test when no distractions occur at all. During the game, collision area with falling objects is calculated in real-time, from which cognitive-motor performance can be computed. Development and evaluation of relevant quantitative measures of joystick manipulations enable appraisal of the individual's current skill levels. During the execution of cognitive-motor test, the collision area with falling objects is computed in real-time, as the basis of cognitive-motor performance metric. Configurations of falling objects are randomized, in order to avoid learning effects. However, in order to maintain maximum comparability between subjects, they are exposed to the same order and the same configurations of falling objects.

Cognitive-motor performance in time interval [t_i, t_i+1], which is large enough to smooth the stochastic relationship between cursor surface $CS(t_j)$ and dynamically moving obstacle surfaces $OS(t_j)$, can be defined based on intersection areas:

$$CP(t_i, t_{i+1}) = 1 - \frac{\sum_{t_i \le t_j < t_{i+1}} \mathrm{area}(CS(t_j) \cap OS(t_j))}{\sum_{t_i \le t_j < t_{i+1}} \min[\max_{o \in OS(t_j)}(\mathrm{area}(o \cap CSZone)), \mathrm{area}(CS(t_j))]} \quad (1)$$

which measures the ratio of the subject's cumulative intersection area with falling objects versus the worst possible cumulative intersection area. The worst cumulative intersection area would be achieved if, at each moment t_j, the subject was always in the spot of the falling object, which had the largest intersection with the subject's zone of motion. This computerized cognitive-motor test can be configured flexibly with different levels of difficulty, in order to avoid floor or ceiling effects on performance.

IV. Emotional Distractions Generation and Measurement

Multimodal emotional elicitation [8] includes a variety of audio and visual stimuli like images, video clips, multimedia picture databases with universal facial expressions like NimStim Face Stimulus Set [9], International Affective Picture System (IAPS) [10], natural and manmade sounds, International Affective Digitized Sounds (IADS) [11], recorded speech, written text messages, virtual reality synthetic environments, spoken narratives, stories, face-to-face conversation, acoustic startle, air blast, fear conditioning/fear extinction paradigm, etc. Sounds and suitable narratives can be played and read along the visual stimuli enhancing the effects of the pictures and thereby taking full advantage of the multimodal emotion elicitation paradigm. As specific multimodal composite stimuli to enhance arousal level during emotion distraction we include highly arousing aversive IAPS video images and IADS sounds, in combination with 40 ms acoustic impulses of 108 dB (A) SPL broadband noise and 250 ms 140 p.s.i. air blasts startle delivered to the subject's larynx. Additional aversive stimuli include a 500-ms electric shock ranging from 0.5 to 5.0 mA, delivered through electrodes attached to the fourth finger of the non-dominant hand, which can be selected to be highly irritating but not painful. The goal of multimodal emotion elicitation is to provide a variety of stimuli, which are capable of eliciting broadband emotional distractions to analyze the subject's vulnerabilities related to the decline of specific cognitive performance due to deficits in attention, anticipation, speed of motor reactions, etc. Cognitive-emotional interactions can be measured by cognitive task performance and multimodal bodily physiological and motor reactions, as well as subjective feelings.

Estimation of elicited emotion is based on data fusion of *Physiological-Features(t)*, *Vocal-Features(t)*, *Facial-Features(t)* and *EEG-Features(t)* extracted from individual's physiological, facial, speech, and EEG signals [12] (Figure 2). *Physiological-Features(t)* include: $F_{HR,mean}$ heart rate mean value, $F_{HR,std}$ heart rate standard deviation, $F_{SC,mean}$ skin conductance mean value, $F_{SC,std}$ skin conductance standard deviation, LF/HF low frequency/high frequency ratio (heart rate variability measure), $\mathrm{F}_{\mathrm{SCR,freq}}$ frequency of SCRs and $\mathrm{F}_{\mathrm{SCR,mag}}$ mean magnitude of SCRs, etc. Altogether, over three hundred physiological features can be computed from the acquired signals [13]. *Vocal-Features(t)* include: F_{T,kw_vec} keyword vector, $F_{E,std}$ standard deviation of a speech signal energy, $F_{P,jitt}$ jitter of a pitch frequency contour, $F_{S,F1\_bw\_mean}$ mean value of a first formant bandwidth and $F_{ZCR,mean}$ mean value of a zero cross rate, etc. More than four hundred vocal features can be computed [14]. *Facial-Features(t)* include: F_{MW} mouth width, F_{MH} mouth height, F_{REW} right eye width, F_{REH} right eye height, F_{LEW} left eye width, F_{LEH} left eye height of the current facial expression, etc. *EEG-Features(t)* include: *alphaPSD* power spectral density of frequency band alpha (8-12 Hz), *betaPSD* power spectral density of frequency band beta (12-30 Hz), *gammaPSD* power spectral density of frequency band gamma (30-100 Hz), etc., *sig_avg* average EEG signal value, *sig_max* maximal value of EEG signal, etc. [15].

Based on this set of multimodal features it is also possible to estimate the individual's discrete emotions, e.g., fear intensity, happiness, sadness, disgust, or intensity of valence and/or arousal [16] and current level of perceived stress (e.g., see [9][17]).

For illustration, acoustic startle, which induces muscle contractions can be detected by orbicularis oculi electromyography (EMG) response and can be computed by

$$F_{EMG,mean} = \frac{1}{N}\sum_{i=0}^{N} EMG(t_{noise\_onset} + 20ms + i\cdot\Delta T),\ \text{where}\ N\cdot\Delta T = 180ms \qquad (2)$$

Equation (2) represents the mean level of the orbicularis oculi EMG response in the period of 20–200 ms after the onset of the white noise burst, during any high-threat aversive time interval in Phase 2. The obtained EMG signal is acquired at 1 kHz, and rectified and smoothed by a moving average of 10 data points.

Skin conductance features during each high-threat aversive time interval [t_i, $t_i+k\Delta T$] of Phase 2 are computed by

$$F_{SC,diff\_mm} = \max(\overline{SC}(t_i, t_i + k\Delta T)) - \min(\overline{SC}(t_i, t_i + k\Delta T)) \qquad (3)$$

where $\overline{SC}$ represents normalized skin conductance signal and $k\Delta T$ is the duration of any high-threat aversive time interval.

Heart rate features during each high-threat aversive time interval [t_i, $t_i+k\Delta T$] of Phase 2 are computed by

$$F_{HR,max\_offset} = \max(HR(t_i, t_i + k\Delta T)) - \text{mean}(HR(t_i - k\Delta T, t_i)) \qquad (4)$$

where HR represents the values acquired by measurement during high-threat aversive time intervals of Phase 2. The features like $F_{EMG,mean}$, $F_{SC,diff\_mm}$, and F_{HR,max_offset} can be appropriately combined and integrated as a single physiological measure. Aggregated fluctuations in emotional distraction multimodal metrics are computed by:

$$EMR(t_i, t_{i+1}) = f(F_{EMG,mean}, F_{SC,diff\_mm}, F_{HR,max\_offset}, \ldots) \qquad (5)$$

where f is some function that aggregates all emotional multimodal response features.

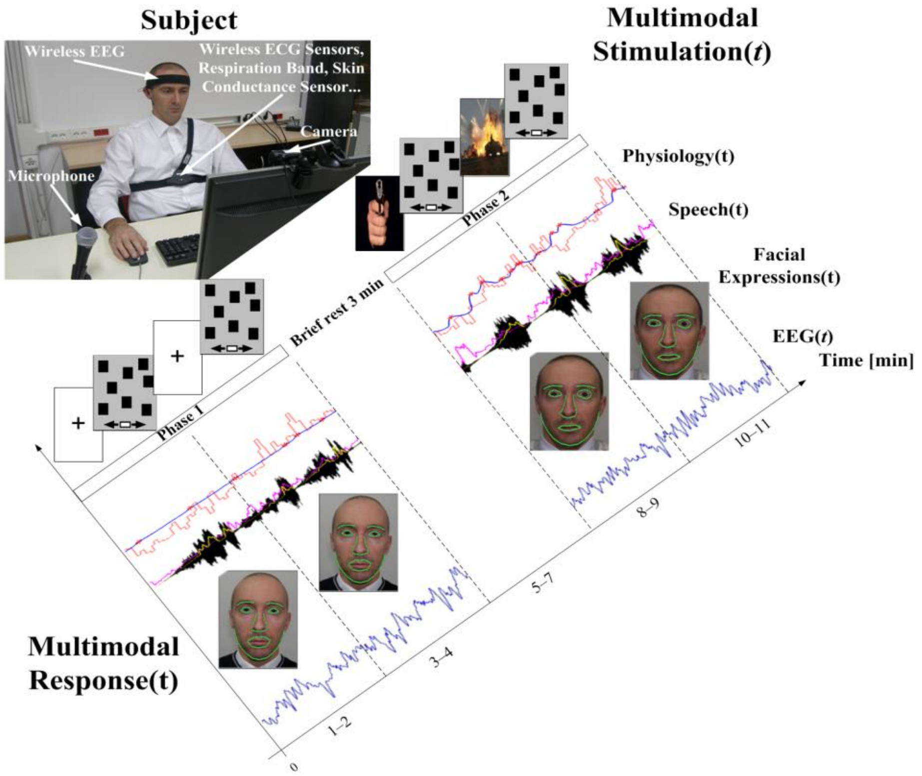

Figure 2. Illustration of multimodal measurements of subject's response based on physiology, speech, facial and EEG signals.

V. EXPERIMENTAL PARADIGM AND RESULTS

To develop cognitive performance predictive models as specific indicators of individual effective performance we need quantifiable variables and metrics to systematically evaluate cognitive performance within environments characterized with a variety of specific emotional distractors. A methodology for evaluation of the degradation of cognitive-motor performance will be presented, including metrics of cognitive-motor tasks, metrics of emotional response, as well as metrics of combined cognitive-motor-emotional interaction. Evaluation of cognitive-motor metrics under emotional distraction might be used as a measure of individual cognitive resilience within stressful environment, like high individual situational awareness, cognitive orientation, focused attention and situational assessment, etc. under the influence of environmental emotional noise. Such an approach enables evaluation and better understanding of complex higher-order cognitive processes and emotional vulnerability as well as better prediction of individual behavioral performance.

For evaluation and selection of resilient or vulnerable subjects in the presented cognitive-motor-emotional game the following metric is introduced:

$$CP_{Phase1} = \sum_{i=-m}^{-m+k} CP(t_i, t_{i+1}) \qquad (6)$$

where CP_{Phase1} is cumulative cognitive-motor performance on selected time interval of $k\Delta T$ in Phase 1, and represents aggregated baseline cognitive-motor performance on selected time interval;

$$CP_{Phase2}(t_n) = \sum_{i=n}^{n+k} CP(t_i, t_{i+1}) \qquad (7)$$

where CP_{Phase2} is cumulative cognitive-motor performance on selected time interval of $k\Delta T$ in late period of Phase 2;

$$e(t_n) = \left| CP_{Phase1} - CP_{Phase2}(t_n) \right| < \varepsilon_1 \qquad (8)$$

where $e(t_n)$ describes cognitive-motor performance difference between baseline value in Phase 1, CP_{Phase1}, and cognitive-motor performance $CP_{Phase2}(t_n)$ in Phase 2. The optimal solution is to fulfill condition (8) in the minimum amount of time $t_n = t_{\min}$, and represents cognitive recovery time $t_{\min}$ in which the subject converges to baseline cognitive-motor performance within ε range.

The cognitive-emotional game can be additionally enhanced by the following condition:

$$\begin{gathered} EMR_{Phase1} = \sum_{i=-m}^{-m+k} EMR(t_i, t_{i+1})_{Phase1} \\ \left| EMR_{Phase1} - \sum_{i=n}^{n+k} EMR(t_i, t_{i+1})_{Phase2} \right| < \varepsilon_2 \end{gathered} \qquad (9)$$

which represents the mean difference between emotional multimodal response EMR along time interval $k\Delta T$ in Phase 1 and emotional multimodal response along time interval $k\Delta T$ in Phase 2.

The optimal solution of the presented cognitive-emotional game for special tasks or jobs can be given by the Index of Performance (*IP*)

$$\begin{aligned} & IP = t_{\min}, \text{ which satisfies conditions below:} \\ & \Delta CP = \left| CP_{Phase1} - CP_{Phase2}(t_{\min}) \right| < \varepsilon_1, \\ & \Delta EMR = \left| EMR_{Phase1} - \sum_{i=n}^{n+k} EMR(t_i, t_{i+1})_{Phase2} \right| < \varepsilon_2 \end{aligned} \qquad (10)$$

Monitoring cognitive-motor performance variations under stressful stimuli is important for evaluating how each individual copes with different emotional distractors and might be used to assess individual differences to inhibit fearful stimuli and retain higher levels of cognitive function. Prediction of how people will behave in emergency situations and how they perceive and anticipate stressful stimuli may have enormous practical values. Such experimental laboratory infrastructure enables prediction of the individual's cognitive-motor performance in stressful environments and can be used in progress monitoring during mental readiness training and selection of individuals with robust cognitive-motor performance under the stress. Evaluation of cognitive-motor performance degradation due to emotional distractors might be also used to develop predictive models of individual cognitive-motor performance in correlation with intensity of emotional distractors. The supervisor may select specific cognitive tasks and a variety of audio-visual stimuli distractors using the relevant user friendly interface.

The sensitivity analysis concerning the influence of emotional stressors on cognitive-motor performance under the impact of aversive IAPS images, IADS sounds, acoustic startle and air blast in the high-threat period of Phase 2, is shown in Figure 3. The purpose of this experiment is to investigate how emotional distraction affects performance of a cognitive-motor task described in Section 2. For illustration of the discrimination potential of the system, two-phase experimental paradigm has been conducted, as described previously: Phase 1 – cognitive-motor performance testing with neutral distractions, and Phase 2 – cognitive-motor performance testing under high-threat arousing emotional distractions. In Phase 2, aversive IAPS images and IADS sounds enhanced by an acoustic startle and air blast are delivered to the subject.

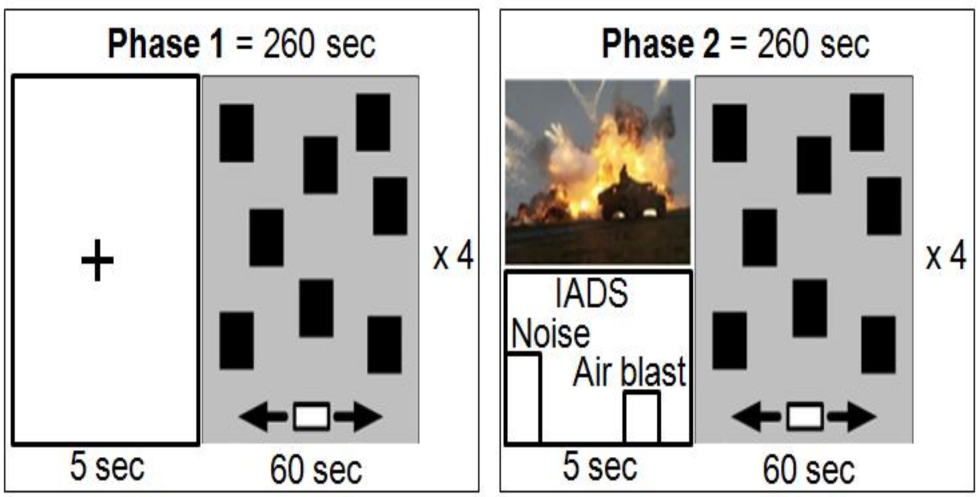

Figure 3. Experimental protocol for evaluation of cognitive-emotional interactions.

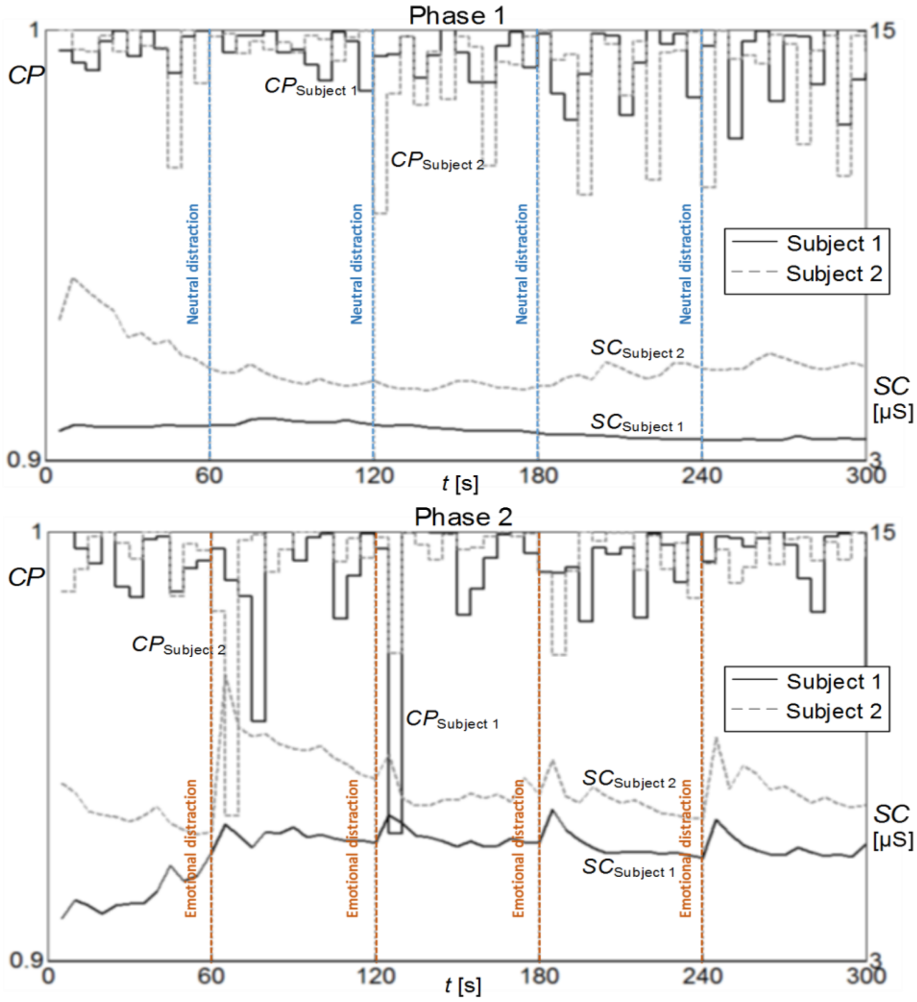

Figure 4. Illustration of experimental results for two subjects, showing their cognitive-motor performance (CP) and corresponding average skin conductance (SC) values in 5-second time intervals, with onsets of Phase 1 neutral distractions and Phase 2 aversive emotional distractions at 60, 120, 180 and 240 seconds.

Figure 4 illustrates that aversive emotional distractions delivered in Phase 2 can transiently reduce cognitive-motor performance relative to neutral distractions, since performance of both subjects decreased after first two emotional stressors at 60 and 120 seconds. Cognitive-motor performance was computed on 5-second intervals according to equation (1). Furthermore, aversive emotional distractions in Phase 2 produced stronger skin conductance changes for both subjects, in comparison with neutral distractions in Phase 1, and these changes were visible after all four emotional distractors. Despite this presence of emotions, the subjects seem to have habituated their cognitive-motor performance on the third and fourth emotional distractor.

Preliminary proof-of-concept testing with two subjects precludes broader statistical analyses, but the results illustrate that designed emotional distractors were able to produce reliable physiological changes, which may also transiently lead to decreased performance on this specific game.

VI. CONCLUSION

In this paper, we presented a computerized system for real-time monitoring of cognitive-emotional interactions. This paper also illustrates an approach to objective measurement of cognitive-motor performance simultaneously with measurements of subject's multimodal physiological, acoustic, facial and EEG response. Preliminary testing on two participants was conducted, which showed transient decrease in cognitive-motor performance induced by various emotional distractors in comparison to neutral distractors. Physiological response measurements also indicated apparent difference in subject's bodily response to emotional distractors in comparison with neutral distractors. The cognitive-emotional interaction in the experimental paradigm was illustrated by inverse relationship between the subject's cognitive-motor performance and physiological, i.e., skin conductance response.

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