Measuring Neural, Physiological and Behavioral Effects of Frustration

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Abstract— **We conducted a visual search experiment with varying task-loads to elicit frustration. Eight participants were asked to sort postal codes in a computer simulation with varying levels of task difficulty, from low to high. We collected electroencephalography (EEG), galvanic skin response (GSR), and gaze tracking data, and subjective data from a NASA Task-Load-Index based questionnaire to assess frustration during task performance. Such studies can help with work-flow process planning.**

We found that low beta EEG had greater power in tasks with higher difficulty. Eye blink rate and blink duration were higher as task difficulty increased. Finally, subjective frustration scores increased with task difficulty. We hypothesize that frustration can be detected by monitoring power in the low beta band, and rate and blink of eye duration, although this is by no means conclusive. Future work will focus on creating tasks that can directly measure frustration while keeping task difficulty the same.

Keywords— **Electroencephalography (EEG); Eye-tracking; Galvanic skin response (GSR); Multi-modal; NASA Task Load Index (TLX).**

I. Introduction

The investigation of human interactions in the real world is an intriguing topic with varying applications spanning from the study of nature to the study of human behavior in varied settings such as at work or home. In that connection, observing how feelings (frustration, anxiety etc) influence or impact the execution of work tasks can offer some insight to develop countermeasures that enhance work performance when a decline in performance is detected. We hypothesize that user levels of frustration and mental exhaustion in relation to task difficulty are valuable indicators which can be utilized to come up with ways and means to enhance work process forms and planning [1, 2].

Frustration can occur in an individual when, during a task execution, hindrance or interruptions from task completion or goal attainment are experienced. Many possible factors have been identified to cause frustration at work, including both incidental and individual factors. Incidental factors include the severity of interruptions during task execution, and loss of time [3]; individual factors include emotions such as anxiety, attitude, state of mind and mood while performing tasks. If frustration is not controlled, it can cause further impediments to performance of work, more negative emotions and stress-related reactions.

II. Materials and Methods

The participants' feedback on the workload demands of the experiment was collected electronically via a questionnaire at the beginning and at selected intervals based on NASA Task-Load-Index self-reporting instrument [4]. Total number of correct responses (CR) and response times (RT) were collected continuously throughout the experiment (behavioral response data). Pick-A-Mood (PAM) characters were also used as stimuli to collect gender information and the negative mood of the participant right before the experiment and then, after the experiment (moods used: Neutral, Bored, Sad, Irritated and Tense) [5].

Electroencephalographic (EEG) signals, eye gaze patterns, and Galvanic Skin Response (GSR) were captured for analyzing physical and physiological responses. These signals were time-stamped for time-series alignment.

A. Apparatus

An EEG ASALab system (from Advanced Neuro Technology or ANT, Enschede, Netherlands) with a Waveguard head cap (32 Channels EEG) and with provision to capture GSR and other modalities was employed. GSR data was acquired by attaching a finger-worn sensor to the participants' non-dominant hand index and middle fingers. GSR signals were recorded synchronously with EEG. LEDALAB, a Matlab-based toolbox [6, 7], was used to analyse the GSR data in terms of the Phasic and Tonic Skin Conductance levels (unit in microSiemens) after pre-processing (downsampled to 10Hz, 4th order IIR filter, cutoff frequency 2Hz, smoothing with moving average window of 100 span and segmentation of data using the event triggers). EEG data was analysed using EEGLAB [8]. A 30Hz eye-tracker (SMI REDn Scientific eyetracker from SensoMotoric Instruments GmbH) was used for eye-gaze capture. A Logitech webcam (Logitech C920) captured video of the participants. The experiments were conducted in a spacious room with lighting condition kept to about 80 lux, measured using a light meter (ISO-TECH ILM 1335). Sound levels were monitored using a Soundmeter (Sauter SU 130) with ambient sound levels maintained at about 60 dB SPL (Sound Pressure Level). A Cedrus StimTracker (Cedrus Corporation, San Pedro, CA) was used to collect the event triggers due to stimulus changes (light sensor), and the user key presses from a Cedrus RB730 Response Pad. The response pad had colour coded buttons (keys), and the participant was asked to indicate his/her choices by pressing the appropriate colour-coded button according to the task given. The STIMTracker simultaneously sent out corresponding event triggers to the EEG amplifier via a 25 pin parallel port connection. Thus, timing was synchronised for EEG, GSR, Stimulus presentation and user response. The exact time stamps capturing stimulus onsets and user responses were also captured in SuperLab and screen recording of the visual stimulus presented via the eyetracking software SMI Experiment Center.

B. Participants

A cohort of healthy subjects (6M/2F, 24-55 years of age, median age of 30) were selected to participate in the study. All participants had good vision, corrected or uncorrected. Two were left eye dominant, and withal, right eye dominant. For one of the participants wearing spectacles, eye-tracking data was discarded because the eye-tracker could not reliably capture the eye-gaze patterns. Written informed consent was gathered from the participants prior to the experiment [NUS IRB Ref: B-15-038].

C. Stimuli

The stimulus presentation consists of a postal code in red font, picked randomly from a list of postal codes. A look-up list to infer from was shown to the participant on the left side of the screen, with colour coded tabs and ranges of postal codes assigned to each colored tab respectively. Participants were asked to look at the given postal code shown on screen, and compare the entry with the look-up list to make the selection of the matching categorized range the given postal code belongs to.

On the top right corner of the stimulus screen, a light sensor patch was used to enable tracking of stimulus screen changes via the CEDRUS StimTracker. This was also captured by the EEG amplifier as event triggers signifying stimulus presented or user response detected upon button press onset of the RB730 Response Pad. Visual feedback to participants included the number of trials they have to answer (as they progressed in the experiment), the number of correct entries, and also a pie chart which indicated their progress (0%, 10%, ... 100%).

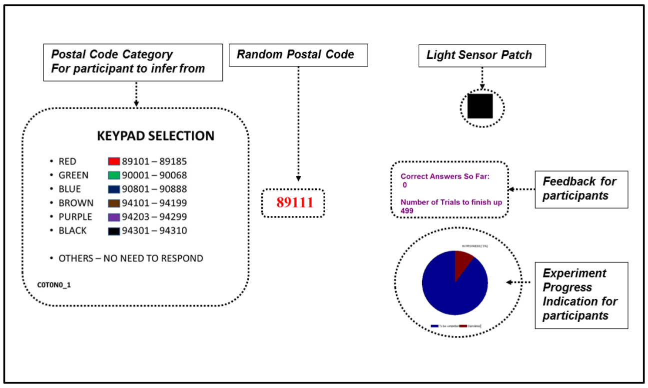

Fig. 1: Stimulus presentation (generated in Superlab 5).

D. Procedure

The stimulus presentation consisted of 9 segments in total, with the last 2 segments being identical (CTN111 and CTN111A). The tasks given to the participant varied in difficulty from low to high over 8 levels in total with 40 trials each (shown in Fig.3). Factors which contributed to task difficulty include response time, and visual search activity. Hypothetically, CTN000 was defined as the baseline segment.However, distractions were presented just before the last segment CTN111A (such as the Blue Screen of Death; 10 seconds duration) that hindered the participant from performing the task.

The arrangements of the colour codes(C), the postal code category (N) displayed on screen as well as time to respond (T) were manipulated. Brain responses (via EEG and ERP), eye gaze patterns (via Eye-tracking), physiological responses due to varying stimuli (via Galvanic Skin Response) and real-time EEG-synchronised video acquisition were collected and analysed. To keep up consistency in the test environment, the experiments were directed in low-light and relatively quiet conditions (see above).

To vary the difficulty levels, the arrangement of the colored tabs (C), the postal code range arrangement (N) and/or the time (T) given to the participant to make a choice selection after the randomly given postal code is shown were manipu-

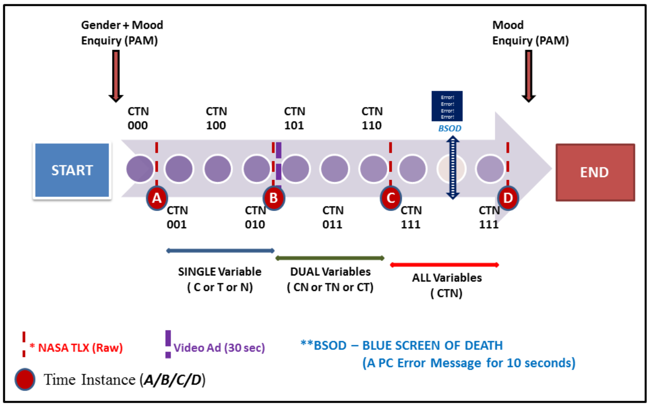

Fig. 2: Experiment protocol.

lated. The difficulty was increased sequentially, from single variable (C or T or N), dual variable (CT or CN or TN) to all variables (CTN).

Total number of correct responses (CR) and response times (RT) were collected continuously throughout the experiment (behavioral response data). The participants' feedback on the workload demands of the experiment was collected electronically at the beginning and selected intervals (time instances A/B/C/D referring to Fig. 2) based on questions adapted from the NASA Task-Load-Index (NASA TLX) self-reporting instrument, which measures the perceived demands of the experiments (mental, physical, temporal, performance, effort and frustration). The 15 piece-wise comparison was not administered in this experiment to keep the experiment under about 1 hour.

III. Results

In this paper, we report the significance of the different modalities (EEG/GSR/Eye-tracking) in correlation with the assigned hypothetical levels of difficulty in the experiment protocol. One-way Analysis of Variance (ANOVA) was done for each of the modalities with respect to the protocol and the hypothetical level of difficulty (from easy to very hard).

A. Behavioral Data

Behavioral data was collected via Superlab. In general, the rate of correct responses by the participants followed a general trend of decline from the start of the experiment (CTN000) to the end of the experiment (CTN111) as can be observed from Fig. 3. The parameters measured include the total number of correct responses, incorrect responses (also called erroneous response rate), absence of response, and the response/reaction times (RT). A correct response is recorded when the expected response (match or no response required) is the same as the participant's response. There were also instances where the participant was not required to key in any response for the given postal code, which was counted as a valid correct response for that particular trial.

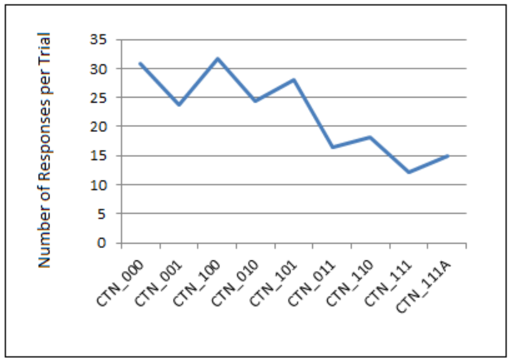

Fig. 3: Number of correct responses per segment (SuperLab).

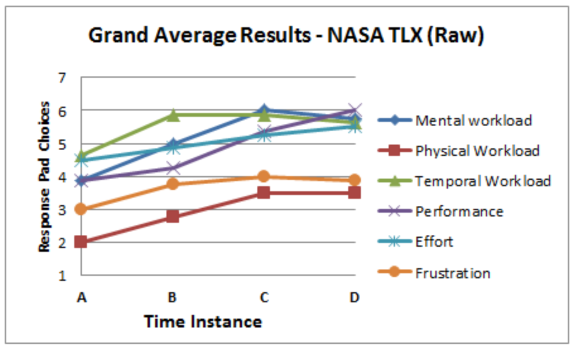

Fig. 4: Grand average NASA Task Load Index results (raw).

The GSR was elevated during CTN000, decreased afterwards and only increased again in the CTN111 and CTN111A segments. Between the CTN111 segments, the GSR was higher after the presentation of the distractors (in which the participants had to face a situation where they were unable to interact with the computer). However, in general, GSR data showed that the participants were aroused at the beginning of the experiment and during the last 2 segments of the experiment.

B. Eye Tracking Data

Blink rate increased as difficulty levels increased ($p = 0.0467$) and also in segments where time was manipulated ($p = 0.0084$). Blink duration decreased for blocks where postal code categories varied (N=1). In other words, blink durations were significantly shorter in segments where variable N was varied (condition N=1) with $p = 3 \cdot 10^{-7}$.

Fixation rate was shorter in the blocks with worst performance ($p = 0.06$). Fixation duration was longer in blocks with better performance ($p = 0.0283$).

C. EEG Data

Low beta frequency (12.5 to 18 Hz) was more prominent in later parts of the experiment when task difficulty was increasingly higher, especially in the frontal lobe, parietal and the occipital regions. Alpha frequency (7.5 to 12.5Hz) was also more prominent during the harder tasks, which we advocate was due to the task over-challenging the ability of the participants.

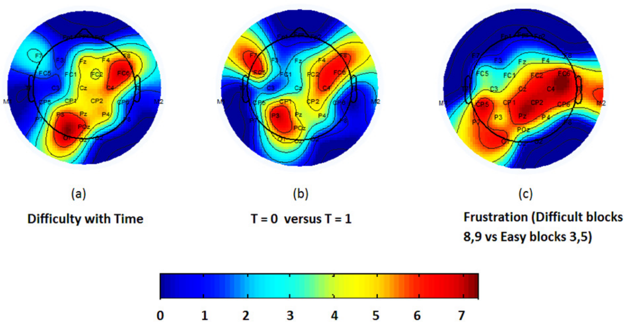

Fig. 5: EEG topography plots based on most active electrode regions.

IV. Discussion

This was a nomothetic study where we studied a group of participants with a common task in similar conditions to extract multi-modal information relating to frustration. EEG, GSR and eye-tracking were used to collect the data and correlated with the participants' subjective ratings (NASA TLX based questions) and their performance (Superlab). The data was grand-averaged, and the findings indicate the elicitation of frustration in terms of Beta frequency waves (EEG), higher levels of arousal (GSR), and higher blink rates (eye-tracking) in more difficult segments. This is a preliminary study, and our population size was small. The experimental protocol demonstrated some issues. Most importantly, frustration levels were not directly controlled, but were only inferred indirectly from correlations with level of task difficulty. Further, the NASA TLX based questions should have been implemented after each segment to gather a more accurate representation of the participants subjective ratings. The 15 piecewise comparison based on the NASA TLX could yield a more accurate representation of the subjective component in this experiment. We are currently redesigning the experiment so that the level of frustration can be changed directly while maintaining a given level of task difficulty. These and other experimental design changes will be taken up in future work.

V. Conclusions

This experiment was aimed at collecting data that can provide cues and signature information about frustration onset during work tasks. While we have some preliminary evidence that frustration may be elicited based on the task difficulty, this is by no means conclusive. Future work will include modifications to the experiment protocol to directly vary frustration levels (which was not directly controlled), taking surveys at more appropriate points in the experiment, and recruiting a larger number of participants.

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