The Stress Touch: Detecting Stress from Touchpads

Leave Authors Anonymous
for Submission
City, Country
e-mail address

Leave Authors Anonymous
for Submission
City, Country
e-mail address

Leave Authors Anonymous
for Submission
City, Country
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ABSTRACT
Stress is associated with many physiological and mental health problems. Unobtrusive monitoring of stress levels would enable intervention techniques to combat stress, but current methods are often inconvenient and expensive. Here we explore stress measurement from common operations performed while using a laptop touchpad. We built upon previous work using pressure and biomechanical models to calculate muscle stiffness from computer mouse operations and extended these models to study laptop touchpad operations, allowing us to indirectly measure stress through touchpad activity. In our study, we show that the within-subject stress measured from finger pressure is comparable to stress measured concurrently from physiological sensors. We argue that background tracking of touchpad usage "in the wild" is feasible and can enable widespread, inexpensive and unobtrusive health tracking.

ACM Classification Keywords
H.5.2. User Interfaces (H.1.2, I.3.6): Human Centered Computing, Human Computer Interaction, HCI Theory, Concepts, and Models

Author Keywords
Health - Wellbeing, Touch/Haptic/Pointing/Gestures, Stress Detection

INTRODUCTION
Repetitive daily acute stress (short-term response to a perceived threat or challenge [13, 22]) is linked to several health risks such as cardiovascular disease and immune deficiencies, which can diminish quality of life and shorten life expectancy [5]. In recent times several authors have shown that using everyday devices, such as a computer mouse, a PC keyboard, mobile phone swipes, mobile keyboard strikes, or even a steering wheel, we can detect the presence of acute stress [21, 8, 7, 16, 6].

We present evidence that binary levels of stress can be detected via a finger pressure approximation from laptop touchpads while performing clicking and steering tasks. Laptops are the largest (42%), and the fastest growing segment of sales among personal computing devices [1]. Given its growing prevalence in the office and at home, touchpads can become a reliable sensor for acute stress in the future. We contrast our measurement with metrics derived from muscle tension estimation [21], and with traditional psychophysiological measurements such as Electro-Dermal Activity (EDA). Our new detection method can be added to these measurements to increase the reliability of stress measurement, and potentially stress prediction.

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CHI'20, April 25–30, 2020, Honolulu, HI, USA

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ISBN 978-1-4503-6708-0/20/04. . . $15.00

DOI: https://doi.org/10.1145/3313831.XXXXXXX

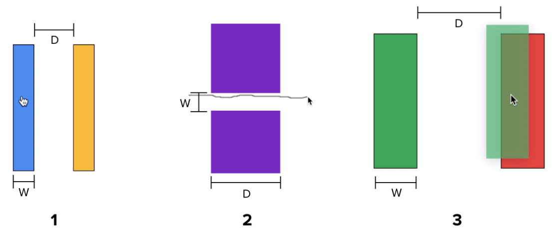

Figure 1. Example abstractified computer tasks used in the study - click tasks (1), steer tasks (2), and drag and drop tasks (3).

We performed a within-subjects study (N=22) counterbalancing relaxed and stress conditions. We replicated the study design by Sun et al. [21] to evaluate canonical input device tasks, namely *click*, *drag and drop*, and *steer* (see Figure 1). We focused our analysis on finger pressure exerted during common tasks, which seem to have the strongest signal in past studies [21, 8, 7]. Our results confirm a significantly higher finger pressure for the stressed condition for *click* and *steer* tasks.

BACKGROUND AND PRIOR WORK
In this section we present basic information on stress measurement ground truth, the direct links between stress and muscle tension, and the indirect effects of stress on the manipulation of computer input devices.

Stress Measurement Ground Truth
Stress can be measured via self reports or from physiological signals. Stress self-report (SSR) is usually measured through some variation of the widely used Perceived Stress Scale (PSS) [3, 18]. Usually, a simplified version with a single 10-item scale of stress is used in repeated measure studies.

Stress can be measured by an indirect observation of the Autonomic Nervous System (ANS) signal. One common way to detect this is through electrodermal activity (EDA). EDA,

[1]https://www.statista.com/statistics/272595/global-shipments-forecast-for-tablets-laptops-and-desktop-pcs/

which is also known as the Galvanic Skin Response (GSR), is a measurement of skin conductance due to the activation of the eccrine sweat glands, which are only innervated by the Sympathetic Nervous System, which is one of the branches of the ANS linked to the "fight or flight" response, i.e., the coordinated response by the body organs to a threat signal (stressor). High average levels and increased number of EDA peaks have been shown to be associated with stress [1].

Detecting Stress through Muscle Tension and Manipulations

Muscle tension increases due to mental stress [2, 4], affecting the forehead, neck, and arms [20, 10]. The shoulder's trapezius muscle has direct changes due to mental arithmetic [14], as well as biceps and triceps [23]. Sun, et al. showed a direct effect of stress on the way a PC mouse is handled [21], while others have shown a relationship between stress and a PC mouse click pressure and keyboard typing pressure [8], or touch device pressure [7]. To our understanding this is the first paper that links stress to the pressure exerted on a laptop's touchpad.

Neuromuscular Stress Modeling

Prior work has successfully shown the use of a Mass Spring Damper (MSD) system to model a human arm motion [9] in diverse tasks ranging from handwriting [11] to robotics [15] to assistive technology [19]. More recently Sun, et al. successfully modeled the arm as a single degree of freedom MSD system applied to interactions with computer peripherals [21], while Paredes, et al. showed its effects in a car steering wheel [16]. In this work, we approximate single finger displacements, observed during the *click* tasks, using an MSD system.

METHOD

In this section, we introduce our hypothesis, the experimental design, and apparatus (data collection).

Hypothesis

We propose two hypotheses linked to two fundamental functions of touchpads :

(H1): The finger pressure (approximated by the area under the finger) is higher due to stress compared to a relaxed baseline.

(H2): The damping frequency ω (derived from single finger displacement) is higher due to stress compared to a relaxed baseline.

Participants

We recruited 22 participants (12 females), with ages ranging from 19 to 68 (M = 37.32, SD = 15.65), not screened for prior preference between mouse or touchpad. Based on SRS evaluations we eliminated four outliers, leaving a total of N=18 users (10 females).

Of the remaining 18 participants, 11 participants reported using a computer mouse on a daily basis and 9 reported using a laptop touchpad on a daily basis. Despite similar usage frequencies, self-reported typical usage duration of the laptop trackpad was generally lower than that of the computer mouse, and 16 participants reported preferring using a mouse over a touchpad when given a choice.

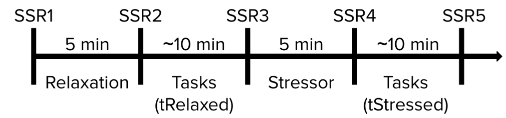

Figure 2. The normal procedure (relaxed to stressed).

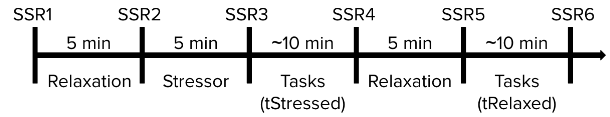

Figure 3. The counterbalanced procedure (stressed to relaxed).

Experiment Design

In this section, we describe the procedure, the task and the stressors for our experiment.

Testing Procedure

The experiment contained four distinct phases:

- Relaxation phase - a five minute destressor task designed to normalize the effects of external factors and to destress the participant towards baseline levels
- tRelaxed phase - a ten minute phase taking place immediately after the Relaxation phase. The subject performs a series of computer tasks using the laptop trackpad. Task orders within each category (clicking, dragging, steering) are fully randomized.
- Stressor phase - a five minute stress-inducing task.
- tStressed phase - a ten minute phase taking place immediately after the stressor phase. The subject performs a series of computer tasks using the laptop trackpad. Task orders within each category (clicking, dragging, steering) are fully randomized.

To control for order effects, subjects were assigned to one of two orders of the stressed-relaxed task pairs (see Figure 3). The experimental groups for each protocol were balanced by gender, with 5 males and 6 females completing each protocol.

Apparatus

In this subsection we describe the experimental setup and the logger used to capture mouse events.

Experiment setup: The experiment was performed in an office setting. We used an unfurbished 15-inch 2015 Macbook Pro (see Figure 4) to run the touchpad tasks, a camera to capture hand movements from touchpad operations, and a logging software to capture touchpad events and cursor events.

Touchpad operations were performed on the MacBook's built-in 140 by 70 millimeter touchpad. During the study, trackpad sensitivity was preset to a scaling level of 1.0.

Touchpad logger: The touchpad logger running on the MacBook was implemented in C. Touchpad events, recorded with

Figure 4. Apparatus: an unfurbished 15-inch 2015 MacBook Pro was used for the experiment.

a sampling period of about (M= 8.17,SD= 3.75) milliseconds, logged touchpad location coordinates precise to the nearest hundredth of a millimeter in addition to an ID number that could be used to distinguish simultaneous touches.

Stimulus

The relaxing and stress conditions were replicated from prior studies [21, 16]. For the relaxing stimulus, we instructed participants to breathe deeply while viewing a smoothing video; this is recommended by other researchers as opposed to doing nothing to engender calm [17]. The acute stressor was a math stressor derived from the Trier Social Stress Test (TSST) [12]. The task involved participants performing a series of subtractions out loud (e.g., 13 from 2017, 13 from 2014, and so forth). If the participant made a mistake, the researcher asked the participant to start again. To add more stress, we created penalties associated with long response times – if users took more than four seconds to respond, they had to start over.

Data Acquisition & Pre-processing

Self-report stress (SRS) was obtained using a simplified version of the Perceived Stress Scale (PSS) [18], a 10-point scale question: "What is your current level of stress?" with end points "Low" and "High" immediately after completion of each phase (see Figure 2).

EDA was measured with the Empatica E4 sensor with a sampling frequency of ($4Hz$). The Empatica E4 band was wrapped around the participant's wrist of the non-dominant arm. The device was mounted to allow proper skin contact without restricting blood flow. Two processing steps were applied. First, the data was sliced into (Relaxation,Stressor, tStressed, tRelaxed) phases. Second, we computed the average skin conductance μs for each phase.

Finally, we obtained the level of self-reported *Concentration* and measured the *Time* to complete a task, and its *Speed* to verify that the stressor did not induce changes that could be attributed to cognitive alterations or performance. Finally we

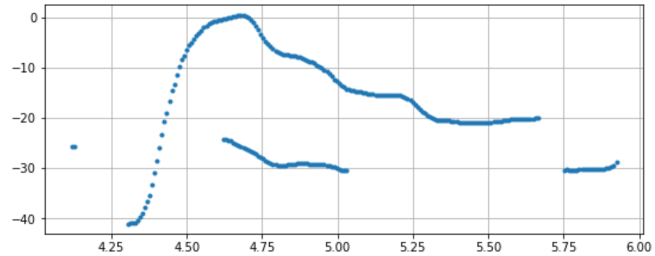

Figure 5. time (x-axis) vs. x coordinate feature (y-axis) for a Clicking task.

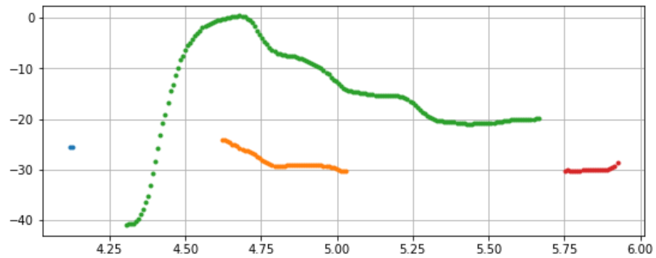

Figure 6. time (x-axis) vs. x coordinate feature (y-axis) for a Clicking task.

captured ancillary data to validate correlations with muscle *Tension* from 0-"Low" to 10-"High".

Touch Data Pre-processing

Touch data requires pre-processing, each participant completed several tasks, and for each task he/she made several movements. Our data set consisted of a series of points composing these movements. 1) We made sure that each point was correctly associated to its task (see Figure 5). 2) Then we cut (adopting a distance based approach: each N point is associated to the closest N-1 point) the series to reconstitute each movement of the participant (see Figure 6). 3) We removed the very short movements and the "static-finger" movements (see Figure 7). These movements are characterized by a small variation in x and y coordinates over time and are therefore useless for our linear predictor coding (LPC) analysis. 4) To further remove artefacts and noise on (x,y) coordinate data series, a fourth order butterworth low pass filter[2] was applied.

LPC analyses

As described by Sun et al. and Paredes et al., we applied a linear predictor coding (LPC) algorithm to approximate a second order MSD system. We extracted under-damped poles (imaginary part larger than 0), which has a direct relationship with the k coefficient of a MSD system representing a human muscle-skeletal system, in this case a finger.

Statistical analyses

All the data were first checked for normality using Shapiro-wilk test. If normal, then we used parametric tests for pair wise comparisons i.e., paired t-test, else we used Wilcoxon Signed rank test. IBM SPSS 21.0 was used for all analyses and $p < 0.05$ was used as a measure of statistical significance.

[2] Cutoff-frequency = 50Hz

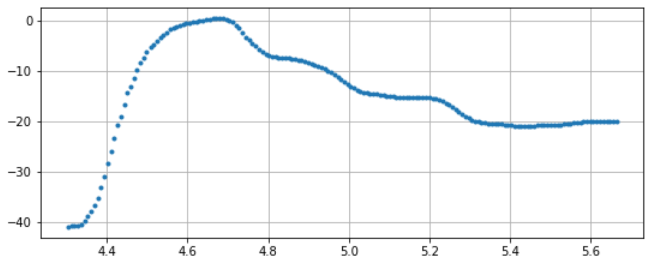

Figure 7. time (x-axis) vs. x coordinate feature (y-axis) for a Clicking task.

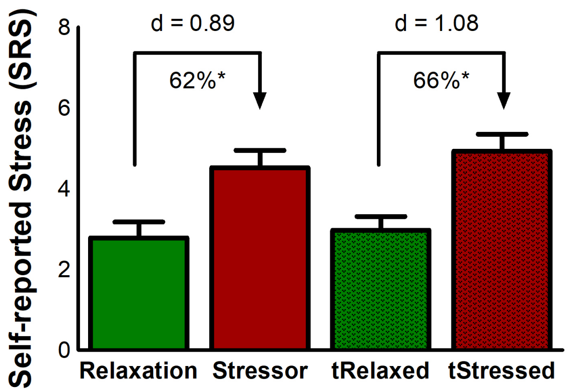

Figure 8. Perceived levels for Self-Reported Stress (SRS). Error bars represent standard errors. d represents Cohen's effect size (large-very large effect).

RESULTS

We present the validation of the stress measurements, and present the finger pressure and muscle tension values.

Mental stress validation

We controlled for concentration effects and task-related performance. We found no statistically significant differences for concentration, nor completion time per task.

Self-reported Metrics

On average the self-reported stress (SRS) was significantly higher during the *Stressor* phase (M = 4.52, SE = 0.43), compared to the *Relaxation* phase (M = 2.80, SE = 0.39) ($t(21)$ = 5.23, p = 0.003). The SRS indicator was also significantly higher during the *tStressed* (M = 4.93, SE = 0.42) phase compared to the *tRelaxed* phase (M = 2.97, SE = 0.34) ($t(21)$ = 6.78, $p < 0.001$). In addition to *SRS*, we found that *Tension* was significantly higher for *tStressed* (M= 5.40, SE = 0.35) than for *tRelaxed* (M = 3.10, SD = 0.32) ($t(21)$ = 8.611, $p <$ 0.001). Furthermore, perceived tension and stress were highly correlated ($r = 0.87$, $p < 0.001$), which indicates a perceived relationship between stress and muscle tension. Further four subjects were found to have no change in SRS across the two extreme phases of our experiment (*Stressor* and *Relaxation*), and thus were excluded from further analyses (results presented in this section are across all participants, n = 22).

Physiological Stress

The average EDA was significantly higher during the *Stressor* phase (M = 4.17, SE = 1.20), compared to the *Relaxation* phase (M = 1.58, SE = 0.38) ($Z(21)$ = 2.29, p = 0.011). The average EDA was also significantly higher during the *tStressed* (M = 2.60, SE = 1.07) phase compared to the *tRelaxed* phase (M = 1.34, SE = 0.41) ($Z(21)$ = 2.04, p = 0.02).

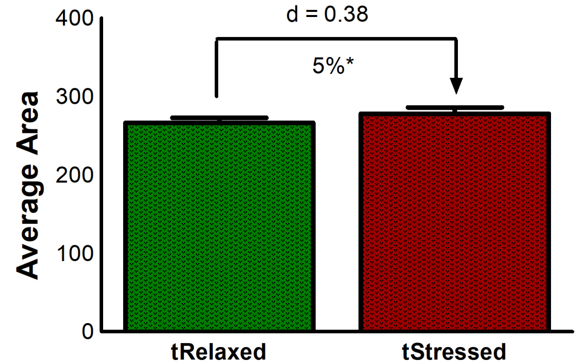

Figure 9. Finger pressure (area under the finger in mm^2) in *click* tasks under *tRelaxed* and *tStressed* phases. Error bars represent standard errors. d represents Cohen's effect size (medium effect).

Finger Pressure Approximation

The logger used provided us information on the contact area between the finger and the touchpad. More precisely an ellipse major-axis a and minor-axis b. We computed the area $a \times b \times \pi$ of this ellipse to get a pressure approximation at each point of the participant movement.

The mean area (a.k.a. finger pressure) during *click* tasks was significantly higher during the *tStressed* (M = 278.11, SE = 8.09) phase compared to the *tRelaxed* phase (M = 266.17, SE = 6.66) ($t(21)$ = 1.949, p = 0.034). 9 The mean area during *steer* tasks was significantly higher during the *tStressed* (M = 291.48, SE = 9.33) phase compared to the *tRelaxed* phase (M = 283.49, SE = 9.29) ($t(21)$ = 1.783, p = 0.046). However, the mean area during *drag* tasks was not significantly different between the *tStressed* (M = 289.27, SE = 7.88) phase and the *tRelaxed* phase (M = 283.05, SE = 7.62) ($t(21)$ = 1.06, p = 0.152).

Displacement

We implemented a mass-spring damper model (MSD) of the human finger using a linear predictive coding (LPC) technique. We expect that the spring coefficient k representing muscle stiffness increases with stress, but in a lesser degree than in bigger muscles of the arm. We didn't find any statistically significant difference for damping frequency across *tRelaxed* and *tStressed* phases.

DISCUSSION

In this short paper we present clear evidence of the robustness of the finger pressure measurement to detect stress. We prove its strong correlation with subjective stress, subjective muscle tension, and EDA measurements.

We didn't find a signal for an MSD associated with muscle tension. This result is somehow not unexpected, as the 'fight of flight' response generated by stress, present in upper and lower limbs, is mostly present in larger muscle groups of

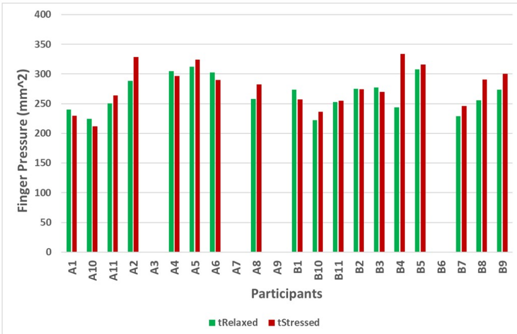

Figure 10. Individual differences for finger pressure mm^2 for the *click* Task.

the arms such as the flexor, extensor and trapezius, as measured by Visser et al. via electromyography readings (EMG) while subjects performed cognitively demanding tasks [24]. Visser's study, however indicates that the accumulation of muscle tension has a significant effect on the clicking force during pointing tasks.

We removed four subjects (A3,A7,A9,B6) who were not affected by the two extremes of our experimental conditions *tRelaxed* and *tStressed*. It is possible that the mental arithmetic stressor task was not sufficient to increase their stress levels. Looking at individual differences (see Figure 10), we observe that the majority of the participants showed an increase in finger pressure with stress, while only 6 of 18 experienced a decrease. Given the nature of the stressors, we believe that the number of users responding to stress is expected and in line with prior studies.

Next steps

In the future we plan to expand the results by including some more commonly used actions using touchpads, like scrolling, and also include EMG measurements for finger extensors like First Dorsal Interosseous (FDI) to build a more robust MSD model for fingers. Furthermore, we plan to run longitudinal evaluations to obtain stress labels using empirical sampling methods, and would require the design of algorithms to detect different types of events (clicks, drag drop, etc.).

CONCLUSION

We have shown the efficacy of using a laptop's touchpad to obtain a strong measurement of mental stress by observing the finger pressure estimated via the area under the finger (mm^2) for click and steering tasks. We didn't find a signal for an MSD model. We calibrated our sensing algorithm against well known stress measurements metrics such as self-reports, and electrodermal activity (EDA). The possiblility to use the touchpad as a robust stress sensor needs to be validated in the wild, but our work presents a strong baseline towards this goal.

ACKNOWLEDGEMENTS

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