Effect of stress on hand movement in a laboratory setting of high school students - preliminary research

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Abstract

**Purpose.** The purpose of this study was to investigate the effect of stress on movement before and after a computer, application-based simulated stress task.

**Methods.** Differences in the movement of participants was examined by measuring movement quality described by wrist accumulated distance, velocity, acceleration, jerk, and smoothness. Ten high school students performed three horizontal and vertical hand circling movements before and after a simulated concentration-based stress task. Blood pressure was measured, and a saliva sample was collected before and after stress test execution. Participants were instructed to take a 10 minutes relaxation period, perform three horizontal and vertical circling movements, a 20-minute stress task, and then perform three horizontal and vertical movements.

**Results.** There were significant differences between before and after the stress task in the level of cortisol ($p<0.05$), heart rate ($p<0.01$), smoothness ($p<0.01$) and jerk movements ($p<0.05$) in the vertical plane. The stress-related variables were lower after the relaxation phase than the stress task. Likewise, movements were smoother and had less jerk in the vertical plane after relaxation.

**Conclusions.** This study indicates the possibility that stress may affect hand movement quality in the vertical plane and therefore, we recommend that any movement behavior adaptive therapy should focus on movements in the vertical plane.

**Key words:** movement, health behavior, stress, Laban Analysis, behavior
INTRODUCTION

Korea is known for its high technology and rapid development, however, this came with a price of growing social issues, such as mental health problems (depression, anxiety, learning disabilities, and aggressive behavior). Furthermore, as a result of the fast economic growth, Korean society has become ultra-competitive in many social arenas, especially the academic sector, which has a high suicidal rate [1]. According to the Organization for Economic Co-operation and Development [2], Korea produces high-ranking students in mathematics and science. However, its educational system is reported to be one of the most significant stressors of depression and suicide in youths (7.8 per 100,000 people) [1]. Academic stress in high school is high due to the difficulties of entrance into a high-ranking university, making career choices, student’s low academic achievement, amount of academic work, and a lack of rest [1]. The pressure to perform successfully at school is a heavy burden for adolescents, as there is a strong Korean culture of having high expectations and an aspiration to accomplish high academic scores [3]. More importantly, this time of high stress and consequently poor academic performance is reported to be a major trigger for depression, anxiety, and suicidal ideation [3][4].

With the high importance that students place on academic achievement to get into a good university, engagement in class and high levels of concentration are reported to be a strong predictor of academic achievement [5]. The authors conclude that for engagement to occur, concentration is a critical factor, and if stress exists it can have a negative effect on concentration levels. Similarly, Lee [6] suggests that educational interventions should focus on improving student concentration, whereas other research states that maintaining a stress-free environment is vital for effective academic performance [7].

In this study, we were interested in how stress could affect movement and how movement could affect stress. Our hypothesis was that movement can affect stress, on the recent findings explained by Shafir [8] that movement can regulate motion, i.e. motor behavior, such as engaging specific facial expressions, posture, and whole-body movements. We developed a horizontal and vertical plane hand circling movement as we were interested in how stress affects movement in both the horizontal and vertical planes. Upward movements have been associated with emotions such as joy, surprise, and admiration [9]. Moreover, there is an increase in emerging research describing the ability of motion capture systems to quantify emotions by analyzing certain
movement qualities [9]. These automatic emotion classifying systems are based on the movement qualities and posture positions, such as an open and closed posture which are associated with different emotional states [9]. The movement using the upper body segments was selected because breathing is known to affect stress levels and therefore, would influence the movement of the scapula and arms [10].

Lefter and associates have developed and investigated novel methods of measuring stress from human-human interactions by analysing of audiovisual recordings [11]. Moreover, automatic methods were developed to recognize stress from semantic messages, such as spoken words for speech and meaningful gestures, and stress conveyance by the modulation of speech intonation, and the speed and rhythm of gestures [11]. A distinct advantage of the methods developed by Lefter and associates [11] for measuring stress is the non-invasive measurement technique, which can be applied in numerous situations. Thus, in this study, we hypothesize that stress can affect movement characteristics (movement distance, and kinematics) and movement quality (smoothness). Based on the hypothesis, our ultimate aim is to understand how stress during concentration tasks alters movement characteristics. By knowing how movement might be affected by stress we plan to develop and test the bidirectional relationship between movement behavioral correction methods and its ability to reduce stress in additional studies.

MATERIAL AND METHODS

1.1 Participants

The group of participants, high school students included a total number of 10 people (mean age 15.7±0.48 years, mean height 1.7±0.08 m and mean weight 68.3±13.2 kg), recruited from a local high school. Each participant provided an oral and written consent, together with permission from parents or guardians. The recruitment procedure was public and a poster was placed on the high school’ notice board after permission was obtained from the school. All procedures for this study were approved by the XXX Universities Institutional Review Board (PNU# 2017_33_HR).

1.2 Stress Task Development
Common stress tasks such as, Trier stress task and the sing-a -song test, were deemed unsuitable for high school students and that many stress tasks are commonly criticized for their lack of potency as a stressor [12] so we developed our own. Upon the advice of a group of 5 local psychology experts (content validity ratio>0.99 for n=5) [13], we developed our stress task (total 20 mins) by mixing and editing the contents of 3 cognitive tasks (that were deemed essential by all experts questioned); Korean FAIR concentration test (10 minutes based on Moosbrugger & Goldhammer [14] (reliability ranging between 0.9 to 0.94 [15], Korean Stroop test (3 mins) (reliability Cronbach’s alpha 0.78 [16]), and filling in of a 10 x 10 concentration grid task (7 mins) (1 week test-retest reliability 0.79 [17]). These 3 tests were selected to stimulate what factors are needed in an academic setting, i.e. concentration, attention, and selective attention. The total time for the stress task was 20 minutes as Hellhammer & Schubert [18] have reported that it takes between 10 to 20 minutes for saliva cortisol level to reach a maximum [18]. Furthermore, we altered these tests and converted them from the standard paper format to a format that could be used on an iPad [19] (details shown in methods section Figure 1).

| Test                  | Actual Test | Altered for ICT version | Contents                                                                                                                                                                                                 |
|-----------------------|-------------|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| FAIR Concentration    | ![FAIR Concentration Test](image) | ![FAIR Concentration Test](image) | • We created 6 patterns based on existing checklists and adjust the number of questions to control time and difficulty for high school student                                                                 |
| Test                  | ![Stroop Test](image) | ![Stroop Test](image) | • We added more rows (20*5) and rearranged the colors, icons, etc. to control the level of difficulty.  
• We created 7 A4 page size worksheets based on the existing paper form. |
| 10x10 Grid            | ![10x10 Grid](image) | ![10x10 Grid](image) | • We created a grid with numbers increasing in size to increase the difficulty  
• We started at 10x10, 15x15, then 20x20.                                                                                                          |
1.3 Testing Procedure

The experimental setup and procedure had the following steps:

1. Participants’ consent and exclusion criteria
   After an introduction to the test procedure and obtaining participants, parents, or guardians consent, the study proceeded. To ensure that all participants had no high stakes examinations close to the time of testing, recruitment and testing took place early in the academic school calendar. Furthermore, prior to arrival all participants were instructed not to have any caffeinated and or acidic drinks up to 24 hours before participating in the study.

2. General stress questionnaire.
   The participants filled in a general stress questionnaire [20], which consisted of 21 questions (appendix 1), and focused on their expectations, internal feelings, and their expression of the stress response. The internal consistency, Cronbach’s $\alpha$, of the academic stress scale ranged from 0.83 - 0.89 [20]. The stress questionnaire was used to ensure the homogeneity of the participants. One of the 11 participant’s data had to be removed because the motion capture data were corrupt.

3. Preparation and physiological data collection phase.
   Before the stress task was performed the participants had their blood pressure measured (MDF Instruments, USA) and provided a sample of saliva (5ml) (JMBio Care, Republic of Korea). Then each participant changed into an outfit required for better data acquisition (tight-fitting top, spandex shorts) and was equipped with a heart rate monitor (Polar, Electro Oy, Kempele, Finland) chest strap.

4. Relaxing phase.
   The goal of the relaxation phase was to create a condition in which participants would be able to relax. The student was instructed to go to a designated area (enclosed for privacy) to relax sitting with their eyes closed on a large bean-bag, and during this relaxing 10 minutes, the participants’ heart rate was continuously monitored [21].

5. Motion Capture Data Acquisition and Stress Task Phase.
   Participants were fitted with 11 reflective markers (25mm) on the upper body wrists and head (left and right shoulder, elbow, wrist, forehead, back of the head, and the sternum).
The student was instructed to perform a T-pose static position followed by 2 types of
dynamic arm circling movements (Figure 2); first on the horizontal (transverse) plane and then on the vertical (frontal) plane, each movement was repeated 3 times. For the horizontal movement, the left and right hand began at the anatomical position (standing straight with the palms of your hands facing anteriorly) moving in an anterior direction in the coronal plane followed by a lateral movement (Figure 2) and returning to the anatomical position. For the vertical movement, the left and right hand begin at the anatomical position moving in a superior direction in on the frontal plane followed by a lateral movement (Figure 2) and returning to the anatomical position. The student was instructed to perform these two circling movements as large, smooth, and relaxed as possible, with no audio stimulation for the timing.
After that the student performed a stress task, sitting down at the desk. The stress task consisted of 10 minutes of the FAIR concentration test, 3 minutes of the Stroop test, and 7 minutes of filling in a 10x10 grid. To make a more stressful environment each student was instructed that their parents or guardians were watching and that they were to do their best. After the stress task, the participants were asked to perform the same circling arm movements in the horizontal (transverse) plane and then on the vertical (frontal) plane, as before the stress task. Directly after the participants were requested to provide a saliva sample (post-stress task) and had their blood pressure measured.
1.4 Equipment and Data Processing

Kinematic data was recorded by a 3D tracking system (Optitrack, USA) which consisted of 12 high-resolution cameras (Prime 41, USA). The positional data of reflective markers were recorded at 60 Hz by the Optitrack software “Motive” (version 1.10.3). The data was post-processed: labeled and noise and jitter trajectories eliminated. Afterward, the data was exported to the C3D file format for further analysis in Visual 3D (c-motion, USA). Kinematic data was filtered with a 2nd order zero-lag low pass filter (cut-off frequency of 8Hz), which was determined by applying a Fast Fourier Transformation. Data is available upon request to the corresponding author (Supplementary A & B).

1.5 Movement Features and Physiological Measures Extraction

In order to perform the movement analysis and explore how stress affects movement, we calculated and extracted movement features from the position of right and left wrists markers.
changing through time: accumulated distance, smoothness and jerkiness. The accumulated distance was calculated as a cumulative sum of the absolute values of the displacements, the total distance traveled by the marker of the left and right wrist. Smoothness was defined as the ratio between velocity and acceleration of the normalised and averaged motion capture data. “Smoothness value” is the value in the range [0,1] (e.g., the higher the value, the higher the smoothness). Jerkiness was calculated as the rate of change of acceleration; that is, the derivative of acceleration over time, and as such it is the second derivative of velocity, or the third derivative of position. The Jerk is the rate of change of acceleration and its units are meters per second cubed. The movement features were computed using a motion capture Toolbox in Matlab for computational analysis of movement data.

For physiological data, heart rate (bpm), systolic blood pressure (mmHg), diastolic blood pressure (mmHg), and cortisol (µg/dL) was recorded. This study recorded various physiological factors to strengthen the validity of the stress level measurement due to the differences in stress according to different personality types. Heart rate data was recorded by a Polar sensor (RS400, Electro Oy, Kempele, Finland) at a frequency of 100 Hz during the entire testing period. Blood pressure was measured manually by the same research assistant who was specifically trained for internal consistency. Salvia samples were taken by the same research assistant and stored in an icebox, which was delivered the next day to an independent company (JMBio Care, Republic of Korea) for analysis.

1.6 Statistical Methods

The statistical analysis was carried out using SPSS (version 23.0). The before and after data was calculated then a paired t-test was used to investigate if there were statistical differences, using a significance level of < 0.05. To further investigate the meaning of the significant differences, we followed with Dunlop et al. [22] recommendations for calculating the effect size of the paired t-test to see how large the significant differences were. Based on Cohen’s effect size recommendations d = 0.2 – 0.5 as small; d = 0.5 – 0.8 as a medium, and d > 0.8 as large effect size [23]. Due to the difficulty of recruiting, we had 10 participants and so to check the statistical power we performed a post-hoc power analysis using G-Power, with the sample size of 10 and
the alpha level of 0.05, resulting in a power of 0.839, which is deemed an acceptable power according to Cohen [23].

RESULTS

The paired t-test showed significant differences between the before and after the stress task for the systolic and diastolic blood pressure. Among the physiological variables, there were significant differences and medium to strong effect sizes between the levels of cortisol ($t = 2.35$, $p < 0.04$, $d = 0.61$) and heart rate ($t = 3.93$, $p < 0.003$, $d = 0.53$) before and after the stress task. However, there were no significant differences in the blood pressure before and after.

Table 1. Comparison of physiological data between before and after the stress task

|                      | Before         | After          | p-value | Effect Size (d) |
|----------------------|----------------|----------------|---------|-----------------|
| Blood Pressure – systolic (mmHg) | 117.21 ± 7.60 | 116.62 ± 10.70 | 0.71    | NA              |
| Blood Pressure – diastolic (mmHg) | 73.20 ± 6.12  | 72.40 ± 9.27   | 0.62    | NA              |
| Cortisol (μg/L)      | 3.30 ± 0.81   | 4.30 ± 1.61    | < 0.04* | 0.61            |
| Heart Rate (bpm)     | 76.50 ± 8.87  | 81.20 ± 9.40   | < 0.003** | 0.53          |

Values are expressed as mean ± standard deviation. * $p < 0.05$, ** $p < 0.01$, NA: Non-applicable

Among the kinematic variables from the motion data, the smoothness and jerkiness showed statistical differences only for the vertical hand circling movement. Among the kinematic data there were significant differences and medium to strong effect sizes for the smoothness (left wrist $p < 0.008$, $d = 0.67$; right wrist $p < 0.042$, $d = 0.41$) and jerk (left wrist $p < 0.023$, $d = 0.82$, right wrist not significant) during the vertical hand circling movement. There were no significant differences reported for any of the variables, such as accumulated distance, velocity, acceleration,
smoothness, and jerk for the horizontal hand circling movement between the before and after stress task.

Table 2. Comparison of kinematic and movement quality data between before and after the stress task

|                         | Horizontal Circling | Vertical Circling |
|-------------------------|---------------------|-------------------|
|                         | Left Wrist          | Right Wrist       | Left Wrist | Right Wrist |
| **Accumulated Distance (m)** |                     |                   |            |            |
| Before                  | 4.79 ± 1.57         | 4.65 ± 1.82       | 4.03 ± 1.88 | 4.99 ± 1.51 |
| After                   | 4.33 ± 1.61         | 4.11 ± 1.38       | 5.32 ± 1.73 | 4.47 ± 1.34 |
| p-value                 | 0.609               | 0.502             | 0.160      | 0.571      |
| **Velocity (m/s)**      |                     |                   |            |            |
| Before                  | 0.0361 ± 0.04       | 0.0291 ± 0.03     | 0.006 ± 0.01 | 0.010 ± 0.01 |
| After                   | 0.0349 ± 0.04       | 0.0339 ± 0.03     | 0.020 ± 0.02 | 0.0171 ± 0.02 |
| p-value                 | 0.947               | 0.782             | 0.108      | 0.065      |
| **Acceleration (m/s²)** |                     |                   |            |            |
| Before                  | 0.0523 ± 0.05       | 0.0343 ± 0.04     | 0.0287 ± 0.03 | 0.0359 ± 0.04 |
| After                   | 0.0833 ± 0.15       | 0.0793 ± 0.14     | 0.0568 ± 0.09 | 0.0543 ± 0.08 |
| p-value                 | 0.562               | 0.373             | 0.333      | 0.230      |
| **Smoothness**          |                     |                   |            |            |
| Before                  | 0.22 ± 0.025        | 0.23 ± 0.021      | 0.27 ± 0.045 | 0.27 ± 0.049 |
| After                   | 0.22 ± 0.028        | 0.23 ± 0.030      | 0.24 ± 0.032 | 0.25 ± 0.027 |
| p-value                 | 0.939               | 0.871             | 0.008**    | 0.042*     |
| Effect Size             | 0.67                | 0.41              |            |            |
| **Jerk (m/s³)**         |                     |                   |            |            |
| Before                  | 30.71 ± 8.66        | 27.33 ± 7.99      | 24.53 ± 8.89 | 25.07 ± 9.26 |
| After                   | 34.61 ± 12.36       | 30.75 ± 8.34      | 31.87 ± 9.61 | 29.09 ± 9.91 |
| p-value                 | 0.245               | 0.167             | 0.023*     | 0.161      |
| Effect Size             | 0.82                |                   |            |            |

Values are expressed as mean ± standard deviation. * p < 0.05, ** p < 0.01, NA: Non-applicable
DISCUSSION

In summary, this study demonstrates how a simulated stress task may influence the movement quality of high school students in a laboratory setting. The kinematic results in this study show that a stress task can affect the smoothness and the jerk of the movement. Interestingly, before the stress task was employed the movements could be described as more efficient, as the movement distance tended to be reduced, i.e. less mechanical work was performed, however, this was not statistically significant. Similar to skill levels in sports and dance, more skilled athletes and dancer’s movements are reported to be smoother and have less jerk (Golf [24], dancing [25]). Likewise, the participants’ movements upward hand circling movements were smoother after the relaxation period at the start, and had lower jerk values than after the stress task. Furthermore, high jerk values in the movement have been linked with various health issues, such as Parkinson’s disease [26] and poor gait function [27].

Among the physiological data, cortisol level, and heart rate, indicate that the participant’s stress level increased as a result of our stress task as both increased significantly (moderate to strong effect size) [28]. There was not a significant effect of the stress task on the systolic and diastolic blood pressure. There seem to be some contradictions in published research as some of the stress-related studies show an increase in the blood pressure [29], whereas some studies show that there are no significant effects [30]. In an interesting study, the authors show that there were no significant differences between the blood pressure and heart rate between stress and control conditions. Remarkably, just performing one 30 minutes session of hatha yoga was reported to significantly accelerate the recovery of blood pressure and heart rate after doing a paced auditory serial addition test as a psychological stress task [31]. Additionally, as stress is known to affect breathing patterns and can induce differential emotional states [32] we hypothesized that stress can be reduced by controlling breathing which can reduce muscle tension, and thus help the movement to become more smooth.

Another study that measured heart rate variability and blood pressure during a mental stress task during computer work [33] showed that there were significant differences between the heart rate variability during rest and stress task. Contradictory to our study, Hjortskov et al. [33] observed differences in blood pressure during different testing periods as a response to combined
physical and mental workloads, as well as during and after periods of rest. Our study did not show any significant variations in the blood pressure but there was an overall lowering of systolic blood pressure after the stress task, which can be viewed positively in an educational setting as it indicates that the participants were more relaxed as soon as the stress task was finished, and is linked to better memory function [34]. In a study investigating the effect conflict had on cortisol levels, it was reported that there is a rapid reduction of cortisol level after conflict is terminated [35], which might explain the lack of significant differences between the before and after blood pressure. However, at this moment we are unsure why the stress task affected the cortisol levels and heart rate, but not the systolic and diastolic blood pressure. Further studies should be carried to investigate the relationship between different stressors and individual responses for varied age-groups, i.e. from teenagers to older adults.

It is important to mention the various limitations of this study. Creating a stress task that is not too severe to be able to get institutional review board approval is difficult [12]. After examining the stress tasks used in previous research, there are a few tests, which have a very narrow application, such as The Trier Social Stress Test [36], sing-a-song stress test [37]. In the application of these tests, research highlights the large variation in the psychological and physiological effects of individual participants’ responses during these tests as a limitation of the application [36]. In this study, we were focused on investigating the effect of academic type stress situations which requires concentration/attention during the stress task so these existing tests (Trier Social Stress Test, and Sing-a-song Test) would not have been suitable for this study. This study can be used as a preliminary investigation of the use of analyzing movement quality characteristics to detect stress early and by understanding the dimensions in which movement is effected, a stress relief procedure may be developed though moving through the affected dimensions. The data in this study shows that the stress task affected the movement pattern in the vertical plane but did not affect it in the horizontal plane, therefore, we could develop a movement-based intervention focusing on movement in the vertical (frontal) plane to help reduce stress. In other psychological research focusing on the removal of a nervous habit and tics [38], the majority of nervous movement tended to be upward movements of the limbs, i.e. shoulder jerking, nail-biting, head jerking and eyelash plucking. To remove these habits and tics, the authors recommended and tested their theory of behavioral pattern opposite corrective exercises, such as depressing the shoulders, tensing of the neck, holding their hands and shoulders down.
Interestingly, these pattern opposite exercises were reported to be effective for 11 of the 12 clients participating in the study. We believe that the correlations between the physiological states and movement characteristics and movement quality data may be helpful to establish more detailed automated behavioral analysis techniques for an infield high school classroom-based study.

A major limitation was the difficulty of recruiting more than 10 students to participate in the study. Even though the IRB consent was given from the University Hospital, it was very difficult to get the 3 parties involved, the school principal, the students and their parents/guardians to agree to partake in the research. As the majority of high school students in Korea attend after school institutes for additional study and classes up until 10 or 11 pm during school days, all the testing had to be carried out during the weekend, which made the students even more resistant to partake in the study. We had planned to test 30 participants but even after recruiting students for 3 months, we were only able to recruit 10 participants.

As the stress levels affect both physiological and movement characteristics and movement quality, advanced computer vision techniques may be developed to analyze these so that they can be applied in stressful environments, such as schools, hospitals, flight control centers, where the tracking of the patrons’ stress level would be useful for improving quality of care and provide continuous monitoring of psychological status. Therefore, non-invasive behavior-based stress analysis can be a very useful method of detecting people’s stress-based behaviors for early detection. Based on the relationship between stress and behavior, Lefter and associates [11] are developing a system that can recognize stress through the analysis of semantics and modulation of speech and associated gestures. In Lefter’s [11] research the authors highlight the difficulty of measuring stress through behavior as it is conveyed by a large variety of combinations of various communicative acts. Furthermore, the authors suggest that it is easy to misinterpret a behavior without considering the overall gestures and other non-verbal cues such as postures facial expressions, and body language.
CONCLUSION

This study shows that our stress task affects the stress level and movement quality of male and female high school students. Secondly, we show that stress reactions from a simulated stress task can be measured by physiological methods, i.e. changes in heart rate and cortisol levels. More importantly, the data shows that stress affects our movement quality, which can be measured by movement features calculated from motion capture data, such as smoothness, and jerkiness of the movements. This study illustrates the possibility of being able to implement passive motion capture systems as a diagnostic tool for evaluating mental (stress) and physical health through the measurement of movement quality. In future studies, we plan to apply these movement quality analysis techniques in a high school classroom during class to see if there is a difference in movement quality according to student’s stress levels.

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CONFLICT OF INTEREST

All other authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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