Activation of the arousal response can impair performance on a simple motor task

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Noteboom, J. Timothy, Monika Fleshner, and Roger M. Enoka. Activation of the arousal response can impair performance on a simple motor task. J Appl Physiol 91: 821–831, 2001.—The purpose of this study was to determine the effect of arousal in men and women on the moment-to-moment performance of a simple motor task. We examined the control of a precision task in the presence and absence of imposed stressors. Twenty-nine subjects (14 men, 15 women; 18–44 yr) were randomly assigned to either a control group or one of two stressor groups, Mental Math or Electric Shock. Subjects presented with Math and Shock stressors, which lasted 10 min, experienced significant increases in cognitive and physiological arousal compared with baseline and control subjects. Heart rate, systolic blood pressure, and electrodermal activity were elevated 5–80% with presentation of the stressors, whereas diastolic blood pressure and salivary cortisol were unchanged. The greater levels of cognitive and physiological arousal were associated with reductions in steadiness of a pinch grip for the Shock subjects (~130% reduction from baseline) but not for the subjects in the Math group, who experienced heightened arousal but no change in steadiness (10% reduction from baseline). Although women exhibited more of a reduction in steadiness than men, the effect was largely unrelated to the magnitude of the change in arousal.

stressor; steadiness; pinch task; force

AROUSAL IS A COMPONENT of several emotional responses, including anxiety and fear, and is characterized by feelings of apprehension, nervousness, and tension. The physiological manifestations of arousal include increased blood pressure, heart rate, sweating, dryness of the mouth, hyperventilation, and musculoskeletal disturbances, such as restlessness, tremors, and feelings of weakness (2, 3, 18, 30, 44). Although emotions can be perceived in the cerebral cortex, the predominant outcome is the automatic effects mediated by the autonomic, endocrine, and neuromuscular systems. The automatic responses involve subcortical parts of the nervous system, especially connections between the nuclei of the amygdala, hypothalamus, and brain stem (19). The neurotransmitters and hormones that elicit these responses, however, can potentially modulate the function of the spinal circuits underlying motor performance (10, 21, 27). Because of this interaction, elevated neuroendocrine activity during heightened arousal has been implicated as a factor that can alter motor output (22, 23).

One theory, known as the inverted-U hypothesis (46), suggests that performance is maximized at intermediate levels of arousal (28, 30, 38, 45). For example, scores in rifle shooting (40) and performance on a throwing task (45) were found to vary with the level of anxiety. Such studies, however, have not examined the variation in arousal and performance during the execution of a task and usually did not consider possible sex differences in arousal. For example, female rats exposed to various stressors, including electric shock, alcohol, and immobilization, responded with elevated levels of several neuroendocrine substrates compared with male rats (20, 34, 35). Similarly, psychologically demanding tasks evoked elevated cardiovascular adjustments, immune system substrates, and neuroendocrine responses in women compared with men (25, 29). These differences in the arousal response are likely associated with sex-specific variations in the level of neuromodulatory agents in the central nervous system.

To investigate the association between arousal and motor output, we examined the ability of men and women to perform a precision task in the presence and absence of imposed stressors. Subjects were exposed to one of two laboratory stressors, mental math or electric shock. The purpose was to determine the effect of arousal in men and women on the moment-to-moment performance of a simple motor task. We expected to find that the steadiness of a submaximal pinch task would be reduced during the stressor conditions and that the effect would be greater in women. Preliminary results have been presented in abstract form (33).

METHODS

Twenty-nine subjects (14 men, 15 women; 18–44 yr) were tested in this study. The subjects were recruited from the general population. The subjects had no history of mental pathology or neuromuscular disease, including any diagnosis of an anxiety disorder or upper extremity injury for at least 6 months. Twenty-nine subjects (14 men, 15 women; 18–44 yr) were randomly assigned to either a control group or one of two stressor groups, Mental Math or Electric Shock.

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were randomly assigned to one of three groups: a control group (5 women, 4 men; mean ± SE age: 28.2 ± 2.7 yr; range: 18–45 yr), a Mental Math group (5 women, 5 men; 25.1 ± 1.2 yr; 19–30 yr) or an Electric Shock group (5 women, 5 men; 24.2 ± 2.7 yr; 18–45 yr). Each subject in the Mental Math and Electric Shock groups participated in one testing session that comprised a 10-min baseline and a 10-min stressor condition. The subjects in the control group performed two 10-min baseline conditions. The Institutional Review Board at the University of Colorado approved all experimental procedures, and all subjects gave their informed consent before participating in the study.

Cognitive Assessment of Anxiety

To determine the general level of trait anxiety, each subject completed the trait portion of the State-Trait Anxiety Index (STAI) of the Spielberger Index, which consists of 20 questions that are answered by using a four-point Likert-type scale. The level of state anxiety was assessed at the beginning and end of the experiment with the STAI-State (STAI-S) test and at multiple intervals throughout the experiment with the visual analog mood scale (VAS). The VAS is a 100-mm line anchored at either end with descriptive polar phrases, such as “Not at all anxious” on the left side of the 100-mm line and “Very anxious” on the right. The subjects were asked to place a vertical line bisecting the 100-mm line to indicate the perceived level of anxiety at the moment.

Physiological Assessment of Arousal

Several variables were assessed during the experiment to quantify the level of physiological arousal. Moment-to-moment changes in heart rate, blood pressure, and electrodermal activity were recorded by use of electrodes placed on the left hand. Heart rate and blood pressure were measured with an inflatable cuff that was placed over the proximal portion of the middle finger and connected to a Finapres device (Ohmeda, Louisville, CO). Electrodermal activity was measured with electrodes (Biopac, Santa Barbara, CA) that were placed on the distal pads of the fourth and fifth fingers. Electrodermal activity measures the bioelectrical characteristics of the skin by applying a direct current to the skin and recording the resulting output as skin conductance (4). The flow of current along the skin is influenced by the activity of the eccrine sweat glands, which are located primarily in plantar and palmar surfaces of the feet and hands. Because these sweat glands are innervated by the sympathetic branch of the autonomic nervous system, the change in skin conductance is often used as an index of sympathetic activity. A Biopac data-acquisition system was used to collect the electrodermal activity, heart rate, and blood pressure data. The data were sampled at 200 Hz and stored on computer disks for later analysis.

In addition to these moment-to-moment measures, salivary cortisol samples, which are a measure of adrenal output of free cortisol (24, 36), were collected at the beginning and end of the session, similar to procedures used by Kirschbaum et al. (24). Each subject chewed a cotton swab for 20 s, which was then placed in a salivette for later analysis. Cortisol levels were assessed using an enzymatic immunosolvent assay (Diagnostic Systems Laboratories, Webster, TX) to determine levels of free cortisol. Previous studies have established the reliability of this technique (13, 37).

Motor Performance Task

The effect of heightened arousal on motor performance was examined with a submaximal isometric pinch task, which was assessed at multiple intervals during the experimental session. The experiments were conducted with the subjects seated in a quiet room. The right arm rested on the arm of the chair with the elbow at a right angle and the wrist midway between maximum supination and maximum pronation.

The apparatus used for the pinch task was 4 cm wide and weighed 1.2 N. It comprised a force transducer (ATI Mini-40) mounted on a wooden platform. The sensitivity of the force transducer was 0.06 N/V. The apparatus was held between the distal pads of the thumb and index finger of the right hand. Contact surfaces of the apparatus had a rough texture (sandpaper) to ensure a secure grip.

Data from the force transducer were displayed on an oscilloscope that was positioned 1 m in front of the subject at eye level. The target force of 4 N was presented as a line on the oscilloscope. The subject was instructed to match the exerted force with the target force as accurately as possible. Subjects were given up to 1 min of practice with this task. Force was sampled at 200 Hz with the Biopac data-acquisition system and stored on computer disks for later analysis.

Experimental Protocol

The session lasted ~25 min and was divided into two phases: a nonarousal baseline phase and an arousal-induction phase. For the baseline phase, the subject sat quietly for 10 min and was instructed to relax. At the end of 10 min, the pinch task was performed for 10 s. The VAS was assessed three times during the baseline session: at the beginning, middle, and end. Subsequently, subjects were either exposed to one of the stressors (Mental Math group or Electric Shock group) or performed a second baseline period (control group).

Mental math stressor. Subjects in the Math group performed serial subtraction of a four-digit number. In the first 5 min of the stressor, the subjects counted backward by 13, starting from 1,022. Subjects were instructed to count as fast and as accurately as possible. When a subject made a mistake, the investigator would say, “Stop. Begin again. 1,022.” and the subject would repeat the task. To increase the difficulty of the task, subjects were asked to keep pace with a metronome that produced an auditory signal once every 3 s. After 5 min, the subject was told to stop counting and to perform the pinch task and complete a VAS assessment. Subsequently, the math task was continued for another 5 min. The subject was told, “This task is obviously too difficult for you. Instead, please count backward by 7, again starting from 1,022. Begin.” Immediately after the second bout of the math stressor, the 10-s pinch task was repeated, and the VAS was assessed. The subject was then instructed to sit quietly for a 2-min recovery period, after which the VAS, state anxiety (STAI-S), and salivary cortisol assessments were performed.

Electric shock stressor. The Shock group followed a similar protocol to the Math group, except that a variable-intensity electric shock was used as the stressor. After the 10-min baseline (nonarousal) condition, two 1 × 1-cm carbon electrodes were attached to the dorsal surface (back) of the left hand. The electrode leads were attached to an electric stimulation device (Grass Instruments, Quincy, MA) that was used to deliver a strong shock to the hand. The shock was delivered as a twin-pulse rectangular waveform with a 0.2-s duration and intensity ranging from 60 to 120 V. Two indicator lights were used to cue the subject regarding the possibility of an electric shock. When a red light was on, it was not possible for the subject to receive the electric shock. Alternatively, when a yellow light was on it was possible to receive an electric shock. These no-threat and threat periods
alternated in 20-s durations. During the threat condition (yellow light), the subject was told that it was possible to receive up to eight electric shocks. The pattern of electric shocks was variable across the alternating 20-s cycles; however, this pattern was consistent across subjects. To further heighten the arousal response, the subject was told that the magnitude of the electric shock would vary across repetitions. Similar to the math stressor, there were two 5-min bouts. Immediately after each bout, the 10-s pinch task was performed, along with the VAS. After the 2-min recovery period, a salivary cortisol sample was obtained, and the posttest state anxiety was assessed.

Control condition. Similar to the two experimental groups, the control group participated in the 10-min baseline period. However, this group experienced no stressors during the second 10-min period, and, as with the stressor groups, pinch tasks were performed at the beginning, middle, and end of each 5-min interval. At the end of the 20-min session, state anxiety (STAI-S), VAS, and salivary cortisol were assessed.

Data Analysis

The dependent variables for the cognitive assessment of anxiety were trait anxiety, before and after state anxiety, and multiple VAS scores. The trait and state variables were quantified by using standardized scoring techniques (43). The VAS data were quantified by measuring the distance, in millimeters, from the left end of the 100-mm line to the point on the line where the subject marked the perceived level of anxiety. The VAS was administered eight times during the experimental session: two before baseline (time points 1 and 2); at the middle and end of the baseline (time points 3 and 4); after giving instructions for the stressor condition, but before stressor initiation (time point 5); at the middle and end of the stressor condition (time points 6 and 7); and at the end of recovery (time point 8).

The dependent variables for the physiological variables were heart rate, blood pressure, and electrodermal activity, which were assessed during three 10-s epochs. These 10-s intervals were after the baseline period (time point 4) and at the middle (time point 6) and the end (time point 7) of the stressor. The three 10-s epochs were also analyzed for the control subjects, except that time points 6 and 7 occurred during a second baseline period. In addition, an assessment of salivary cortisol was performed at the beginning and end of the protocol in all subjects.

The dependent variable for the pinch task was the coefficient of variation (SD/mean force × 100) of the force during the 10-s intervals at time points 4, 6, and 7. Increases in the coefficient of variation indicate a reduction in steadiness.

Statistical Analysis

A two-factor ANOVA (SPSS for Windows, SPSS) was used to compare the dependent variables of trait and state anxiety for the three groups. A three-factor ANOVA with one repeated-measure design (two factors between and one within) was used to compare the dependent variables for the heart rate, blood pressure, electrodermal activity, and salivary cortisol between the sexes and the three groups, across time points, and the interactions. A three-factor ANOVA with repeated measures was applied to the cognitive assessment data of the VAS scores between the sexes and the three groups, across time points, and the interactions. A similar three-factor ANOVA with repeated measures was applied to the coefficient of variation for force between the sexes and the three groups, across time points, and the interactions. An alpha level of 0.05 was chosen for all initial statistical comparisons. Significant F statistics were followed by post hoc tests to determine pairwise differences, using 95% confidence interval methods. Data are reported as means ± SE in Figs. 1–6 and means ± SD in Tables 1 and 2.

RESULTS

The effects of a stressor condition on physiological and cognitive measures of arousal and pinch task performance were determined for two types of stressors and were compared with baseline conditions and with a control group. The Math stressor consisted of paced, serial subtraction from a four-digit number, whereas the Shock stressor involved random-intensity, noxious-level stimulation to the left hand. The physiological and motor performance data are presented as 10-s epochs at three time points during the 25-min experimental session: near the end of the 8-min baseline and at the midpoint and the end of an 8-min stressor. Figure 1 displays representative data across each epoch for one subject in the Shock group.

Cognitive Component of Arousal

Trait anxiety scores did not differ significantly for the three groups (Fig. 2A). The scores ranged from 21 to 62, which are considered low-to-moderate levels of trait anxiety. All subjects also completed a before and after state anxiety survey. The scores for the control, Shock, and Math groups at the beginning of the protocol were 27.0, 28.6, and 30.8, respectively. Subjects in the control group had end scores that were lower than the initial scores (−5.6%), whereas the after values for the Shock and Math stressor groups were elevated significantly to 27.2% and 30.0%, respectively, above the initial values (Fig. 2B).

The cognitive component of arousal was also assessed with the VAS. Each subject completed the VAS at eight time points during the experiment: four times (time points 1 to 4) during the baseline period, three times (time points 5 to 7) during the stressor, and one time (time point 8) at the completion of the stressor. There were no between-group (P = 0.22) or within-group (P = 0.59) differences during the baseline period, nor were the tests significant for simple main effects on sex (P < 0.41) or group (P < 0.06). In contrast, the main effect of time was significant (P < 0.001), as was the time-by-group interaction when comparing the stressor conditions (P < 0.007). The VAS scores during the stressor (time points 5, 6, and 7) for the Shock (31.1 ± 5.8, 35.6 ± 7.0, and 39.7 ± 7.4 mm, respectively) and Math groups (33.2 ± 5.8, 45.4 ± 7.0, and 36.1 ± 7.4 mm, respectively) were significantly greater than those for the control group (7.1 ± 6.2, 8.6 ± 7.5, and 6.7 ± 7.9 mm, respectively). The VAS score at time point 5 represents anticipatory anxiety as this was elevated after the subjects were informed about the stressor conditions but before the actual presentation of the stressor. One minute after completion of the stressor (time point 8), subjects in the Shock group (25.3 ± 5.0 mm) had significantly elevated VAS scores compared with the control subjects (5.1 ± 5.3 mm) (P <
However, the time-by-sex interaction was not significant ($P = 0.54$). The women and men in the two stressor groups combined (Fig. 3B) and for the Shock group (Fig. 3C) and Math groups alone had similar VAS scores. Taken together, these data indicate that subjects in the two stressor conditions experienced greater levels of cognitive arousal.

**Physiological Arousal**

Heart rate, systolic blood pressure, diastolic blood pressure, and electrodermal activity were measured at three time points during the study: baseline (time point 4), midstress (time point 6), and end-stress (time point 7) (Fig. 4). For heart rate, the simple main-effect test for groups was not significant ($P = 0.32$), although the main-effects test for time ($P < 0.02$) and sex ($P < 0.001$) were significant. Heart rate at the end-stress time point ($70.9 \pm 1.7$ beats/min) was significantly elevated over baseline ($67.4 \pm 2.0$ beats/min) and midstress ($68.3 \pm 1.8$ beats/min) time points, whereas average values for women ($76.3 \pm 2.4$ beats/min) were elevated compared with average values for the men ($61.4 \pm 2.5$ beats/min) (Table 1).

Simple main effects for sex ($P = 0.27$) and group ($P = 0.38$) were not significant for electrodermal activity. In contrast, the simple main effect for time ($P < 0.001$) was significant, with the midstress value ($113.7 \pm 42.0$ S) being significantly greater than baseline ($83.8 \pm 37.6$ S) (Table 1); however, the end-stress value ($113.0 \pm 47.7$ S) was not significantly different from baseline ($P = 0.06$). Similarly, when the data are presented as percent change from baseline (Fig. 4B), the simple main-effects test for group was significant ($P < 0.04$), with electrodermal activity for the Shock group ($75.3 \pm 15.9$%) significantly different from the control group ($12.7 \pm 16.9$%), whereas the values for men and women were similar ($P = 0.28$).

The results were similar for systolic blood pressure, with a significant main effect for time ($P < 0.01$) and sex ($P < 0.02$), whereas the main effect for group was not significant ($P = 0.08$) (Table 1). In addition, there was a significant time-by-group interaction, with the end-stress value for the Shock group significantly different compared with both the baseline value for the Shock group and the end-stress time point for the control group (Table 2). When expressed as percent change (Fig. 4C), the main effects test for group was significant ($P < 0.04$), with the Shock group ($11.8 \pm 3.1$%) exhibiting elevated values compared with the control group ($-0.3 \pm 3.3$%), whereas values for men and women were similar ($P = 0.06$). There were no significant changes in diastolic blood pressure (Fig. 4D).

In addition, salivary cortisol was assessed immediately before and after the session. No group, sex, or time differences were noted (Tables 1 and 2).

**Pinch Task Performance**

The submaximal pinch task was performed at multiple times during the baseline and stressor conditions. Steadiness during the task was quantified as the coefficient of variation for force. Accordingly, increases in the coefficient of variation indicate a reduction in steadiness. Fluctuations in the force...
during the pinch task (Fig. 1) varied across groups, sex, and time. There were no significant differences in coefficient of variation during the baseline period across groups: 1.65 ± 0.60, 1.65 ± 0.51, and 2.15 ± 0.52% for the control, Shock, and Math groups, respectively. Although the main effects for time ($P < 0.01$) and group ($P < 0.02$) were significant, the main effect for sex was not significant ($P = 0.10$). The coefficients of variation for mid- and end-stress time points (2.3 ± 0.2 and 2.8 ± 0.3%, respectively) were significantly different from baseline values (1.8 ± 0.1%), whereas the coefficient of variation for the Shock group (3.01 ± 0.33%) was significantly greater than that for the control group (1.58 ± 0.35%) (Fig. 5A). Similarly, there were significant differences between groups at the mid- and end-stress time points. The coefficients of variation at these times for the Shock group (3.25 ± 0.38 and 4.33 ± 0.57%, respectively) were elevated compared with baseline (1.64 ±

Fig. 2. Trait and state anxiety of the subjects in the 3 groups. A: trait anxiety scores based on the Spielberger State-Trait Anxiety Index. B: percent change in state anxiety score from beginning to end of the experiment. Values are means ± SE. *Subjects in the 2 stressor groups experienced a significant increase in state anxiety compared with the control group ($P < 0.03$). %Δ, percent change.

Fig. 3. Scores on the visual analog scale (VAS) for the 3 groups of subjects at 8 time points during the 25-min experiment. Data are means ± SE. *Subjects in the 2 stressor groups experienced a significant increase in state anxiety compared with the control group ($P < 0.03$). %Δ, percent change.
0.17%), along with a significant increase over each corresponding time point compared with the control group (1.65 ± 0.18, 1.55 ± 0.41, 1.52 ± 0.61%, respectively) \((P < 0.001)\) (Fig. 5B). The sex-by-time interaction was not significant \((P > 0.05)\) (Fig. 5C), whereas the sex-by-group interaction was significant \((P < 0.01)\) (Fig. 5D). In addition to a significant elevation from baseline (1.64 ± 0.17%), the mid- and end-stress values (3.25 ± 0.38 and 4.33 ± 0.57%, respectively) for the Shock group were significantly elevated over the corresponding time points for the control group (1.55 ± 0.41 and 1.52 ± 0.61%, respectively) (Fig. 5D). The change in coefficient of variation for the Math group did not differ statistically across the three time points, nor was there a difference between the Math and the control or Shock groups. These data indicate that subjects exposed to the electric shock stressor experienced a reduction in steadiness during the pinch task.

There were several statistical interactions involving differences between the men and women, including a significant time-by-sex interaction \((P = 0.05)\) (Fig. 5C). Post hoc analysis indicated that the coefficient of variation values for the women at the end-stress interval (3.45 ± 0.47%) were significantly greater than baseline (1.81 ± 0.14%) but were not different from the men at the end-stress interval (2.16 ± 0.49%). In contrast, the coefficient of variation did not vary across time for the men. The other significant sex effect involved the sex-by-group interaction \((P = 0.04)\) (Fig. 5D). The coefficient of variation values for the women at the end-stress interval (3.45 ± 0.47%) were significantly greater than baseline (1.81 ± 0.14%) but were not different from the men at the end-stress interval (2.16 ± 0.49%). In contrast, the coefficient of variation did not vary across time for the men.

The data indicate that subjects exposed to the electric shock stressor experienced a reduction in steadiness during the pinch task.

### Table 1. Comparison of physiological data for women and men and across all time points

<table>
<thead>
<tr>
<th>Sex</th>
<th>Heart Rate, beats/min</th>
<th>Systolic Blood Pressure, mmHg</th>
<th>Diastolic Blood Pressure, mmHg</th>
<th>Electrodermal Activity, S</th>
<th>Salivary Cortisol, μg/dl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>61.4 ± 10.6</td>
<td>136.5 ± 18.5</td>
<td>77.2 ± 9.9</td>
<td>94.9 ± 42.6</td>
<td>1.27 ± 0.78</td>
</tr>
<tr>
<td>Women</td>
<td>76.3 ± 9.2*</td>
<td>120.4 ± 18.7*</td>
<td>70.5 ± 9.2</td>
<td>111.9 ± 41.7</td>
<td>1.95 ± 1.60</td>
</tr>
<tr>
<td>Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>67.4 ± 12.9</td>
<td>123.1 ± 20.2</td>
<td>72.0 ± 10.1</td>
<td>83.8 ± 37.6</td>
<td>1.62 ± 1.31</td>
</tr>
<tr>
<td>Midstress</td>
<td>68.6 ± 12.1</td>
<td>131.7 ± 19.9†</td>
<td>75.2 ± 9.9</td>
<td>113.7 ± 42.0†</td>
<td></td>
</tr>
<tr>
<td>End-stress</td>
<td>71.3 ± 12.0</td>
<td>130.4 ± 20.8</td>
<td>74.7 ± 10.2</td>
<td>113.0 ± 47.7</td>
<td>1.55 ± 1.37</td>
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<tr>
<td>Group</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>65.5 ± 8.9</td>
<td>121.8 ± 15.6</td>
<td>72.8 ± 10.6</td>
<td>96.0 ± 35.7</td>
<td>1.6 ± 1.3</td>
</tr>
<tr>
<td>Shock</td>
<td>72.3 ± 14.0</td>
<td>136.7 ± 18.6</td>
<td>76.2 ± 11.8</td>
<td>118.6 ± 45.2</td>
<td>1.42 ± 0.5</td>
</tr>
<tr>
<td>Math</td>
<td>68.9 ± 12.1</td>
<td>127.0 ± 21.8</td>
<td>72.7 ± 8.3</td>
<td>95.7 ± 47.7</td>
<td>1.81 ± 1.9</td>
</tr>
</tbody>
</table>

Data are means ± SD. *P < 0.05, vs. men; †P < 0.05, vs. baseline.
tion values for women (4.2 ± 0.47%) in the Shock group were significantly greater than those for the women (1.67 ± 0.47%) and men (1.49 ± 0.52%) in the control group, the women in the Math group (2.09 ± 0.47%), and the men (2.03 ± 0.47%) in the Shock group (P < 0.04) but did not differ significantly from values in men (2.47 ± 0.47%) in the Math group (Fig. 5D). In contrast, the three-way interaction between sex, group, and time was not significant (P > 0.06).

When the coefficient of variation was expressed as a percent change from baseline for the two stressor time points, the main effects tests were significant for

Table 2. Comparison of physiological data by group and time

<table>
<thead>
<tr>
<th></th>
<th>Heart Rate, beats/min</th>
<th>Systolic Blood Pressure, mmHg</th>
<th>Diastolic Blood Pressure, mmHg</th>
<th>Electrodermal Activity, S</th>
<th>Salivary Cortisol, μg/dl</th>
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</thead>
<tbody>
<tr>
<td><strong>Control</strong></td>
<td></td>
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</tr>
<tr>
<td>Baseline</td>
<td>65.7 ± 9.6</td>
<td>121.6 ± 17.0</td>
<td>72.8 ± 7.3</td>
<td>87.7 ± 31.2</td>
<td>1.47 ± 1.05</td>
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<tr>
<td>Midstress</td>
<td>66.2 ± 7.2</td>
<td>123.5 ± 16.5</td>
<td>73.9 ± 11.3</td>
<td>106.3 ± 35.4</td>
<td>1.86 ± 1.46</td>
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<tr>
<td>End-Stress</td>
<td>66.4 ± 8.9</td>
<td>117.2 ± 15.7</td>
<td>71.9 ± 10.6</td>
<td>92.0 ± 35.7</td>
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<tr>
<td><strong>Shock</strong></td>
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<tr>
<td>Baseline</td>
<td>72.3 ± 14.9</td>
<td>128.5 ± 23.3</td>
<td>73.8 ± 11.9</td>
<td>85.2 ± 31.9</td>
<td>1.61 ± 1.24</td>
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<tr>
<td>Midstress</td>
<td>70.0 ± 13.4</td>
<td>140.6 ± 19.9</td>
<td>77.3 ± 10.3</td>
<td>132.3 ± 37.2</td>
<td>1.14 ± 0.46</td>
</tr>
<tr>
<td>End-Stress</td>
<td>74.4 ± 14.0</td>
<td>141.1 ± 18.6*</td>
<td>77.4 ± 11.8</td>
<td>138.2 ± 45.2*</td>
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<tr>
<td><strong>Math</strong></td>
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<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>64.8 ± 13.3</td>
<td>119.1 ± 20.4</td>
<td>69.5 ± 10.9</td>
<td>78.8 ± 49.7</td>
<td>1.79 ± 1.70</td>
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<tr>
<td>Midstress</td>
<td>69.3 ± 15.0</td>
<td>130.2 ± 20.9</td>
<td>74.1 ± 8.8</td>
<td>101.7 ± 46.8</td>
<td>1.70 ± 1.91</td>
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<tr>
<td>End-Stress</td>
<td>72.5 ± 12.1</td>
<td>131.8 ± 21.8</td>
<td>74.4 ± 8.3</td>
<td>106.7 ± 52.0</td>
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Data are means ± SD. *P < 0.05 vs. baseline.
group, sex, and time. The Shock group (121.3 ± 18.1%) differed significantly from the control (−2.5 ± 19.2%) and Math (8.8 ± 18.1%) groups (P < 0.001) (Fig. 6A). Similarly, women increased by 67.3 ± 14.8% compared with 17.8 ± 15.4% for the men (P < 0.03) (Fig. 6B), and the end-stress time point (56.9 ± 14.6%) was elevated from the midstress time point (28.2 ± 8.7%) (P < 0.02) (Fig. 6C).

DISCUSSION

The purpose of this study was to determine the effect of arousal in men and women on the moment-to-moment performance of a simple motor task. Subjects performed a series of submaximal pinch tasks during a baseline period and during a stressor condition. We expected to find that the stressor conditions would elevate arousal and result in a reduction in the accuracy of the pinch task. The main finding was that subjects in the stressor groups, especially the Shock group, displayed significantly reduced steadiness at the midstress and end-stress time points. Furthermore, women in the Shock group exhibited more of an impairment than men. This selective effect on performance was in contrast to the common effects of the interventions on the arousal of the men and women in the two stressor groups.

Previous studies have used the mental math and shock stressors to heighten arousal. For example, Kirschbaum et al. (24) combined mental arithmetic and simulated public speaking to induce moderate psychological stress, as indicated by elevated heart rate and salivary cortisol levels. Similarly, Al’Absi and colleagues (1) demonstrated elevated systolic and diastolic blood pressure, heart rate, and salivary cortisol with mental arithmetic and simulated public speaking. However, all physiological measures were attenuated with repeated bouts of the same stressor. In addition to measuring neuroendocrine and cardiovascular responses, Breznitz et al. (5) asked subjects to rate their level of tension at multiple intervals during shock stressors. Tension, as rated with a seven-point scale, was significantly elevated during the shock stressor compared with baseline, as were heart rate and plasma epinephrine levels.

We used two assessments of the cognitive component of arousal, the Spielberger state anxiety index and VAS. The anxiety scores at the end of the test were significantly elevated compared with those before the test for the two stressor groups, whereas scores for the control group actually decreased. Similarly, the VAS scores for the Math and Shock groups were elevated significantly compared with the control group scores during the three stressor intervals. Although the state anxiety index has frequently been used to assess temporal changes in state anxiety (14, 40, 42), the time required to complete the 20-item questionnaire makes it an impractical tool for the assessment of moment-to-moment changes in anxiety. In contrast, the VAS can be used to assess emotional states rapidly. In a reliability study of the Spielberger state anxiety test and
VAS, Cella and Perry (7) reported that the VAS measure of anxiety was significantly correlated ($r = 0.53$) with the state anxiety scores and concluded that the VAS is capable of measuring emotional states in a quick, reliable, and relatively sensitive manner. We found that state anxiety immediately after the stressor increased by $\sim 30\%$ for the two stressor groups, whereas the VAS scores at the three time points during the stressor conditions increased by $200\%$ from baseline values.

In addition to cognitive assessment, physiological markers were used to measure the arousal response. Generally, the two stressor conditions produced similar changes in heart rate, systolic and diastolic blood pressure, electrodermal activity, and salivary cortisol. However, diastolic blood pressure and cortisol measures were not different compared with the control group, as found previously (1, 12). Although salivary cortisol is frequently used as a marker of physiological arousal, the delayed time course may explain the absence of group or time differences in this study. For example, Kirschbaum et al. (24) noted peak cortisol levels to occur at $\sim 40$ min after a laboratory stressor, compared with the 25-min duration between our initial and final measurements. The brevity of our testing session likely explains the minimal changes in salivary cortisol values we observed. Other authors using similar testing procedures have demonstrated good reliability for within- and between-day assessments (13, 37).

Increased neuroendocrine activity, especially enhanced activation of the sympathetic nervous system, can result in changes in heart rate, blood pressure, and electrodermal activity (6, 24). Stressor exposure also activates the hypothalamus–pituitary–adrenal axis, resulting in elevated cortisol. In laboratory settings, changes in these variables due to a stressor are usually small, with substantial variability between subjects. Consequently, the moment-to-moment assessment of multiple variables has been recommended for a more accurate interpretation of the arousal response (31). Al’Absi et al. (1) assessed psychological and physiological variables, including heart rate, blood pressure, and cortisol, at multiple intervals during both mental math and public speaking stressors. Correlations between the endocrine, cardiovascular, and psychological variables were significant for the speaking stressor, but not the math stressor, although all values were significantly elevated over baseline. The $\sim 19\%$ increases from baseline for heart rate and blood pressure found by Al’Absi et al. (1) for the math stressor are similar to the $14–18\%$ increases that we found for the math and electric shock stressors.

Of the two stressors used to elevate arousal, electric shock had the greater impact on the steadiness of the pinch task. The coefficients of variation for force at the midstress and end-stress time points were significantly elevated for the Shock group compared with baseline values and for the control group. In contrast, the coefficient of variation for the Math group did not change across the time points and was not different from that of either the Shock or control groups. The coefficient of variation for force has been used in other studies as an index of fine motor control (11, 26). In the present study, the coefficient of variation ranged from $1.4\%$ for men in the control group during baseline to $6.1\%$ for women in the Shock group at the end-stress time point, which is similar to the range reported previously (11).

Electric shock has been used to examine the startle response. Grillon and colleagues (14–16) used a lighting system to provide threat and nonthreat conditions while delivering noxious levels of shock. Electric shock potentiated the acoustic startle response, elevated perceived tension, and enhanced reflex responses. Similarly, inescapable tail shock has been used to induce acute and chronic stress in rats, resulting in long-term neural, behavioral, and immune changes (9, 32). Several neural mechanisms may contribute to the association between electric shock and altered motor output. Chua et al. (8), for example, identified a number of paralimbic structures that were active during and immediately after unpredictable electric shock, perhaps mediating changes in arousal associated with anticipatory states. This likely includes the amygdala, which is involved in the initiation and maintenance of integrated stress responses that include projections to areas affecting stress hormones via anterior pituitary/adrenal cortex, sympathetic activity, and descending motor activity to the ventromedial horn of the spinal cord. By influencing the prefrontal–striatal system at both the cortical and striatal levels, the amygdala is profoundly involved in motor, cognitive, and complex behavioral functions (17).

Although men and women had similar arousal responses to the shock stressor, the reduction in steadiness during the pinch task was greater for the women. The steadiness exhibited by women, as indicated by the coefficient of variation for force, was reduced significantly at the end-stress time point compared with baseline, whereas there was no change for men. In addition, the coefficient of variation for the women in the Shock group was significantly different from women and men in the control group and for the men in the Shock group. Although no sex effect was found for the Math stressor, these findings indicate that the accuracy of the pinch task was reduced in women who experienced the electric shock stressor compared with men.

There may be several explanations for the dissociation between arousal and performance for the women. First, the measures of arousal used in this study may not have been sensitive enough to identify sex differences. Levels of cognitive, cardiovascular, and electrodermal activity were elevated from baseline for the stressors using noninvasive techniques, whereas cortisol levels were unchanged from baseline. However, more invasive techniques may be needed to detect changes in other components of arousal that differ for men and women. The effects of electric shock in animals indicate that females respond with a greater level of neuroendocrine activation, including ACTH, corticosterone, oxytocin, norepinephrine, and serotonin re-
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 lease (39). Two of these neurotransmitters, serotonin and norepinephrine, appear to function as modulators of motor neuron excitability, enhancing motor neuron responses to excitatory input. Activation of these substrates, especially serotonin and norepinephrine, could explain the dissociation between our arousal measures and motor performance for the women. Quantifying these neuroendocrine substrates may identify the mechanisms linking arousal and performance, especially those related to sex differences.

A second possibility may be that men and women respond to stressors with similar levels of arousal, but tasks performed during states of increased arousal are characterized by altered motor output for women. For example, when a prolonged, submaximal fatiguing contraction is performed, which is a type of physical stressor, the longer endurance times produced after immobilization by the women can be associated with changes in the pattern of motor unit activation during this task (41). Although little is known about the underlying sex differences in motor performance, circulating sex steroids may play a significant role (35).

In summary, subjects presented with Math and Shock stressors experienced significant changes in cognitive and physiological arousal compared with baseline and control subjects. Of the physiological variables, heart rate, systolic blood pressure, and electrodermal activity were elevated with presentation of the stressors, whereas diastolic blood pressure and salivary cortisol were unchanged. The greater levels of cognitive and physiological arousal were associated with reductions in steadiness for the Shock subjects, but not for the subjects in the Math group who experienced heightened arousal but no change in steadiness. Although women exhibited more of an impairment than men, the reduction in steadiness was largely unrelated to the magnitude of the effect on arousal.

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REFERENCES


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