Stress exposure and postural control in young females

MARINELLA COCO[1], ANGELO SARRA FIORE[1], VINCENZO PERCIAVALLE[1], TIZANA MACI[2],
MARIA CRISTINA PETRALIA[1] and VALENTINA PERCIAVALLE[3]

Departments of [1]Biomedical Sciences - Physiology Section, [2]'G.F. Ingrassia' and [3]Education Sciences,
University of Catania, Catania, Catania 95125, Italy

Abstract. The aim of this study was to determine if heightened stress had an adverse affect on the postural control of 14 young right-handed females during quiet standing in either the presence or the absence of visual input. The level of stress was evaluated by measuring the free cortisol response to awakening (cortisol awakening response; CAR) and by employing the perceived stress scale (PSS). Overall mood disturbance was measured using the profile of mood states (POMS). Postural control was evaluated using a force platform by measuring the 95% confidence ellipse area described by the center of pressure during 5 balance positions maintained for at least 52 sec, each with open and closed eyes. The results of this study revealed a significant positive correlation between CAR, PSS and POMS for each of the studied subjects. Furthermore, it was observed that whilst the level of stress was capable of influencing postural stability, this influence was particularly evident when no visual information was available. Additionally, it was determined that maintenance of posture is easier when the dominant foot is ahead, regardless of visual input.

Introduction

The ability to maintain a standing position is fundamental in gait and the initiation of rapid voluntary movements, the two of which are essential for undertaking everyday activities. This capability is commonly investigated through the traces of the center of pressure (COP). Several factors influence postural control, including the time of day (1-3), general and local fatigue (4), and age (5-7). It has been proposed that diminished

Correspondence to: Professor Vincenzo Perciavalle, Department of Biomedical Sciences - Physiology Section, University of Catania, 6 Viale Andrea Doria, Catania, Catania 95125, Italy
E-mail: perciava@unict.it

central cognitive processing is primarily responsible for the impairment in balance performance with advancing age (8).

Emotions and mood can have a direct impact on the physical and mental health of an individual, such as sadness, apprehension, addiction and stress (9), and the physiological responses to stress are important determinants of overall health and susceptibility to disease (10). The consequences of stress can be either harmful or beneficial, depending on the intensity, duration, and frequency of the stress (11). It has been observed that high levels of stress are associated with worsening of executive functions, abstract reasoning, processing speed, and visual-spatial memory (10,12-14). Furthermore, it has been observed that mood states are capable of influencing balance control (15) and anticipatory postural adjustments (16).

The purpose of the present study was to assess whether heightened stress and negative mood experiences adversely affect the postural control in young females. The task undertaken by participants consisted of quiet standing in 5 positions selected from those proposed by Kirby *et al* (17): 3 of these positions had the feet on the same anteroposterior level but separated by different distances, whilst in the other 2 positions one of the feet was placed 10 cm in front of the other (in position D, the dominant foot and in position E, the non-dominant foot).

The perceived stress of the participants was assessed using the perceived stress scale (PSS), devised by Cohen *et al* (18), whilst overall mood disturbance was measured with the profile of mood states (POMS). As a second measure of stress, the cortisol awakening response (CAR) of participants was studied. The CAR is a rapid increase of free cortisol levels which occurs within 30 min of awakening and subsequently returns to baseline levels ~1 h later (19). It has previously been reported that chronic stress has an important role in the CAR (as reviewed in 20,21); and so in the present study saliva samples were collected from participants in order to measure their CAR.

Materials and methods

Participants. A total of 14 healthy young females, students at the University of Catania (Catania, Italy), participated in this study. Only female participants were recruited for this study due to the gender-related differences in the brain structures that control the activity of the hypothalamic-pituitary-adrenal (HPA) axis, as well as differences in the levels of corticosteroid-binding

globulins, which influence the basal and stress-induced activation of the HPA axis (as reviewed in 22). Participants were selected on the basis of similar anthropometric characteristics. The participants had a mean age of 23.79 years (± 3.49), a mean height of 163.86 cm (± 4.88), a mean weight of 57.36 kg (± 3.77), a mean body mass index of 21.35 (± 0.89) and all were right-handed. The dominant hand was determined by the Edinburgh Handedness Inventory (23). All the subjects signed informed consent documentation in accordance with the Ethical Committee of the University of Catania prior to their participation in the study.

Stress measurement. Participants' perceptions of stress were evaluated using the 10-item version of the PSS (18), which consists of 10 questions graded on a five-point Likert scale. Scores range from 0-40, with a higher score indicating greater subjective distress. The PSS is designed to allow individuals to rate how frequently they felt overwhelmed by stressful events during the previous 30 days, using a scale which ranges from 0 (never) to 4 (very often). One such question from the test is as follows: 'In the past week, how often have you felt difficulties were piling up so high that you could not overcome them?'. The mean score for normative females in the general population is 13.7±26.6 (24).

Overall mood disturbance was evaluated using an abbreviated 30-item version of the POMS test developed by McNair *et al* (25). Participants rated each item on a 5-point Likert scale with anchors ranging from 'Not at all' to 'Extremely'. Items were combined to form 6 separate subscales: Tension-anxiety (T), depression-dejection (D), anger-hostility (A), vigor-activity (V), fatigue-inertia (F), and confusion-bewilderment (C). For each of the 6 subscales, the raw scores were subjected to a T-score transformation using the following formula: $T = 50 + 10(n - m)/s$ where n= raw score, m = mean and s = standard deviation. This transformation converted the raw scores to scores on a standard scale with a mean value of 50 ± 10 (26). The 6 subscale T-scores were then be combined to form an overall measure of affect that is known as total mood disturbance (TMD = T+D+A-V+F+C).

Salivary cortisol assay. Saliva samples were collected on two consecutive workdays, immediately upon awakening (sample 1), and 15 min (sample 2), 30 min (sample 3), 45 min (sample 4) and 60 min (sample 5) thereafter, resulting in five samples per day and a total of ten samples for each individual. Participants were requested to wake at the same time between 06.00 and 08:00 h on the two days and asked to remain in bed until all 5 saliva samples were obtained. Each sample was obtained by instructing participants to chew on a dental roll (Richmond Dental, Charlotte, NC, USA) for ~1 min and then samples were stored in sterile containers which were provided. Samples were frozen at -70°C until assay. All saliva profiles were sampled during the winter between January and February 2013. A radioimmunoassay cortisol test (AKS18EW; Radim SpA, Rome, Italy) was used to measure salivary free cortisol levels according to previously described methods (27).

Balance performance. COP excursion data were collected using an AMTI force platform (model OR-6-7-1000; AMTI, Newton, MA, USA). As shown in Fig. 1, COP measurements

Table I. Scores obtained in the 14 subjects.

Subject	PSS	POMS - TMD	Mean AUCr (nmol/l)
1	12	143	20.63
2	14	157	24.93
3	24	239	22.46
4	21	195	24.28
5	16	169	26.74
6	18	175	23.15
7	19	184	24.27
8	27	297	23.13
9	22	198	23.24
10	17	176	22.57
11	14	168	23.37
12	13	166	24.72
13	23	164	22.23
14	15	200	23.57
Mean	18.21	187.93	23.52
SD	4.59	39.14	1.45

Mean values of salivary cortisol are expressed as the AUCr. PSS, perceived stress scale; POMS - TMD, profile of mood states expressed as total mood disturbance; AUCr, area under the response curve.
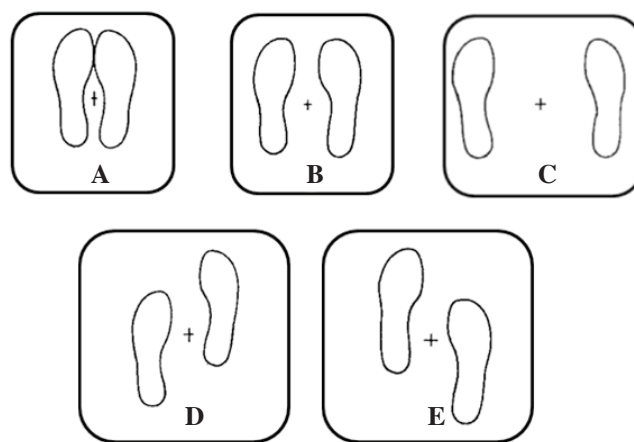

Figure 1. Balance positions used in the present study. (A) Feet together, (B) feet 15 cm apart, (C) feet 30 cm apart, (D) right foot forward 10 cm, (E) left foot forward 10 cm. Image adapted from Kirby *et al* (17).

were conducted in 5 balance positions adapted from a study by Kirby *et al* (17): (A) Feet together; (B) feet 15 cm apart; (C) feet 30 cm apart; (D) right foot forward 10 cm; and (E) left foot forward 10 cm. Each of these 5 positions was held for 52 sec with eyes open and then 52 sec with eyes closed.

To avoid influences of time of day on postural stability (1), the experiments were performed between 10:00 and 13:00 h. The force plate of the platform had a metal surface and all tests were conducted with subjects barefoot. The AMTI force platform simultaneously measures three force components along the x (medio-lateral); y (antero-posterior); z (vertical) axes and three moment components about the x-, y- and z-axes. Signals
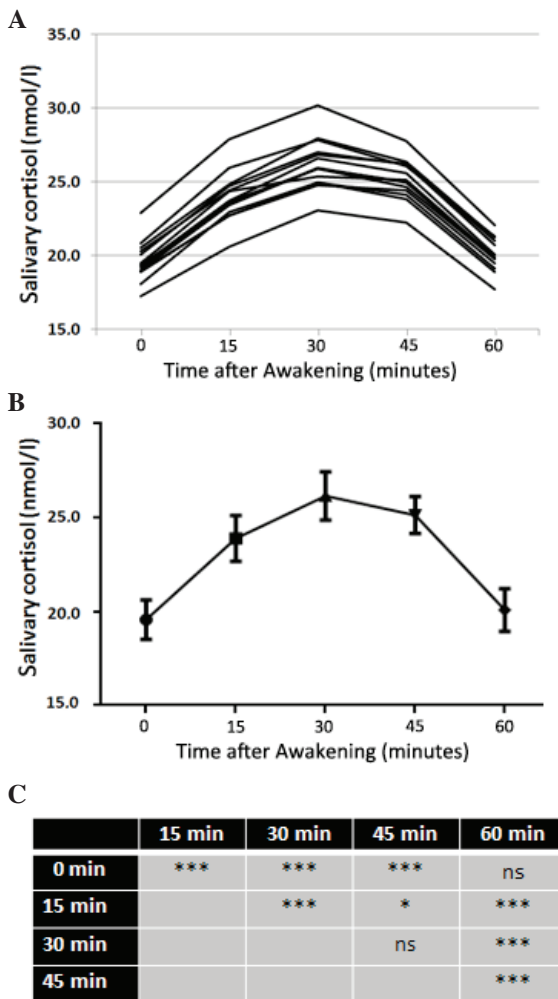
Figure 2. (A) Cortisol awakening profiles of each of the 14 subjects. (B) Mean values of cortisol awakening profiles. (C) Results of Tukey's multiple comparisons test between the mean values. *P<0.05, ***P<0.001. ns, not significant.
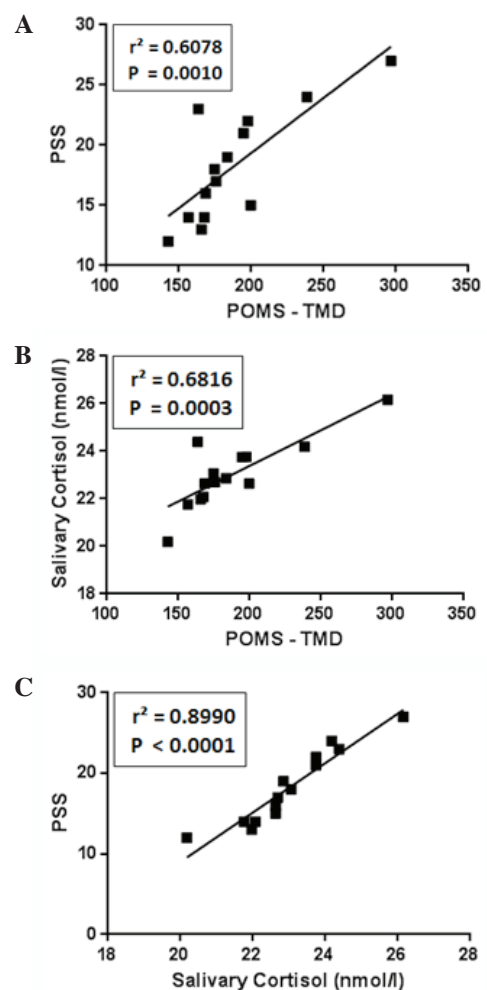

Figure 3. Correlations between profile of mood states expressed as total mood disturbance (POMS - TMD), perceived stress scale (PSS) and salivary cortisol for all of the studied subjects. (A) TMD and PSS, (B) TMD and salivary cortisol and (C) salivary cortisol and PSS. There is a significant positive correlation between all three variables.

from the force platform were amplified through an AMTI MiniAmp MSA-6 Strain Gauge Amplifier system (AMTI) prior to being digitized into an IBM-compatible Pentium computer (Asus S550C; ASUSTeK Computer Inc., Taipei, Taiwan). The signals were digitized using a Cambridge Electronic Design 1401 acquisition unit (CED, Cambridge, England) at a sampling rate of 100 Hz. Routines were developed with MATLAB software (The MathWorks Inc., Natick, MA, USA) to calculate the area corresponding to 95% of the area described by the COP trajectory (A95), since previous studies have demonstrated that this is a more sensitive measure of postural stability (28,29).

Data analysis. All data are reported as the mean±standard deviation. For each of the 5 time points, cortisol levels were averaged over the 2 days to obtain a single mean cortisol level.

The cortisol increase was defined as the difference between the individual cortisol peak value (e.g., sample 2, 3, 4 or 5) and the cortisol level immediately after awakening (sample 1). The area under the response curve

(AUCr) was computed including individual baseline cortisol levels, as described in a previous study (30).

Data collected from the participants were compared by means of a non-parametric Wilcoxon signed-rank test. The correlation between variables was analyzed using a linear regression. Statistical analysis was performed according to the guidelines for reporting statistics in journals published by the American Physiological Society (31).

Results

PSS and TMD vary greatly between participants. Table I summarizes the results obtained for the mood measurements of all 14 subjects in the group. The level of stress experienced by participants varied greatly, the PSS ranged from 12 to 27 (mean: 18.21±4.59), TMD ranged from 143 to 297 (mean: 187.93±39.14) and the salivary cortisol, expressed as area under the response curve (AUCr), ranged from 20.63 to 26.74 nmol/l (mean: 23.52 nmol/l±1.45).

Salivary cortisol increases rapidly within 30 min of awakening. Fig. 2 shows the cortisol awakening profiles of the

Table II. Area (95% confidence ellipse expressed in cm^2) of the center of pressure measured in the 14 subjects when stood in each of the five balance positions (A-E) presented in Fig. 1.

Subjects	A OE	A CE	B OE	B CE	C OE	C CE	D OE	D CE	E OE	E CE	Mean value OE	Mean value CE
1	1.29	2.27	0.41	0.29	0.45	0.80	0.67	0.97	1.37	1.71	0.84	1.21
2	1.13	1.38	1.59	3.58	2.88	0.80	2.24	2.38	3.84	4.05	2.34	2.44
3	5.69	8.68	3.28	3.23	2.06	3.83	4.31	6.86	3.67	5.77	3.80	5.67
4	5.06	4.60	3.84	1.71	1.52	1.69	1.95	2.01	3.53	3.57	3.18	2.72
5	2.82	1.99	2.35	2.69	1.86	2.36	1.60	3.49	2.30	3.23	2.19	2.75
6	3.11	4.96	1.39	2.37	1.05	0.77	3.46	3.61	1.41	1.80	2.08	2.70
7	3.35	6.41	2.01	2.12	0.98	1.35	3.81	5.50	3.17	4.17	2.66	3.91
8	0.10	5.87	1.35	1.53	2.28	2.36	6.37	13.35	4.61	6.98	2.94	6.02
9	2.27	1.97	2.27	1.36	0.91	1.12	2.35	6.06	2.23	4.94	2.01	3.09
10	2.93	2.85	2.18	2.27	1.20	0.98	2.88	3.51	1.66	1.95	2.17	2.31
11	2.15	2.20	3.05	2.92	1.75	1.85	2.05	2.18	3.75	3.80	2.55	2.59
12	1.44	1.97	1.05	1.15	0.80	0.80	1.02	1.15	1.58	1.82	1.18	1.38
13	3.55	3.45	3.56	3.80	2.55	3.75	4.05	5.23	3.88	4.85	3.52	4.22
14	1.55	1.60	1.78	2.22	2.45	2.35	2.54	2.66	3.54	4.56	2.37	2.68
Mean	2.60	3.59	2.15	2.23	1.62	1.77	2.81	4.21	2.90	3.80	2.42	3.12
SD	1.53	2.20	1.00	0.98	0.75	1.05	1.50	3.19	1.10	1.60	0.81	1.40
W-test	NS		NS		NS		P<0.05		P<0.01		P<0.05	

OE, open eyes; CE, closed eyes; SD, standard deviation; W-test, Wilcoxon signed-rank test; NS, not significant.
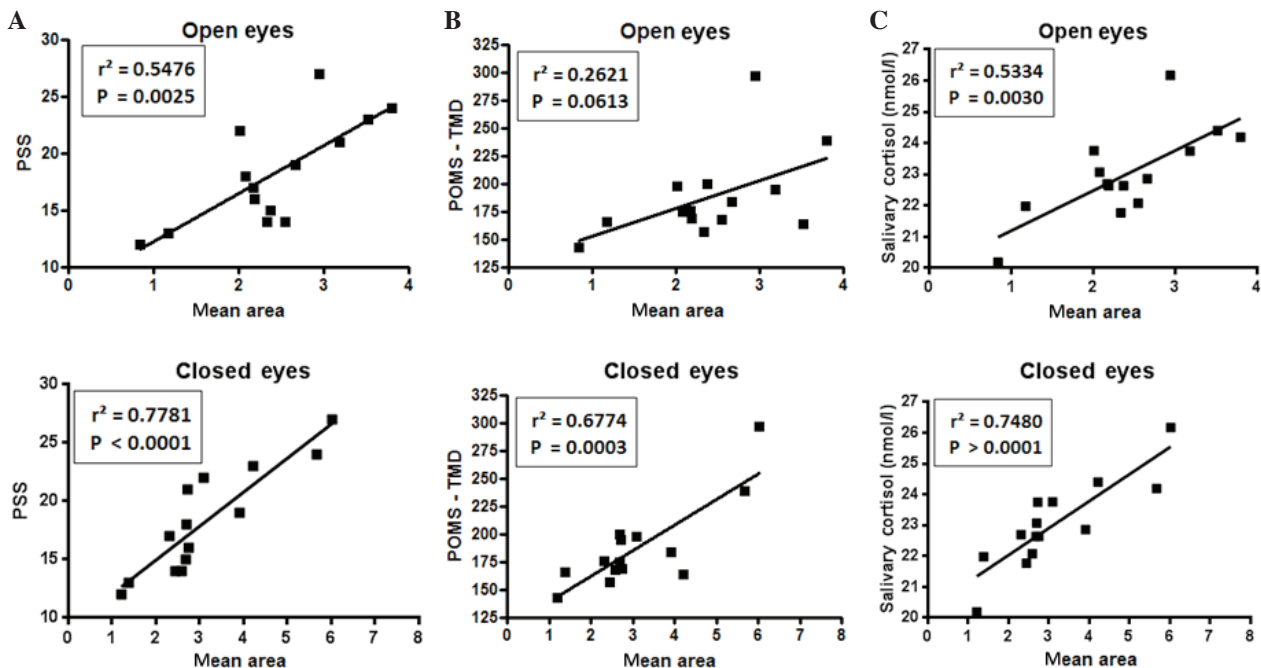

Figure 4. Correlations of the (A) perceived stress scale (PSS), (B) profile of mood states expressed as total mood disturbance (POMS - TMD) and (C) salivary cortisol with the mean 95% confidence ellipse area of COP (A95) value measured in balance position E with open and closed eyes for each subject. The mean A95 was significantly correlated with the PSS and salivary cortisol levels when eyes were both open and closed, but was only significantly correlated with POMS when eyes were open, not with closed eyes.

single subjects of the sample, as well as the mean values of the cortisol awakening profiles and the results of Tukey's multiple comparisons test between the mean values. In all studied subjects, there was a significant increase in the levels of salivary cortisol immediately after awakening (time 0), with levels reaching their maximum value after 30 min. However,

60 min after awakening, salivary cortisol concentration was not significantly different from that at time 0.

There is a strong positive correlation between TMD, PSS and salivary cortisol. Fig. 3 illustrates the correlation between the POMS, expressed as TMD, the PSS and the salivary cortisol levels for each of the studied subjects. A strong significant positive correlation between these three measures was identified.

A95 varies greatly between participants. Regarding the postural control, Table II summarizes the results obtained when measuring (in cm^2) the A95 in positions A-E (Fig. 1). A significant variation was observed between individuals, with the differences between 39 and 66% in the eyes open experiments and between 43 and 76% with eyes closed. Furthermore, when comparing the data from a single position measured with open eyes with those calculated with closed eyes, significant differences ($P>0.05$) were observed only in positions D and E, with the worst values recorded in with eyes closed (Table II).

When comparing, for each subject, the scores of PSS, TMD and salivary cortisol with the A95 mean value measured in the position E (Fig. 4), a significant correlation was observed between the A95 and the salivary cortisol levels and the PSS with open and closed eyes. For POMS no significant correlation was observed when eyes were open, whereas a strong positive correlation was detected when eyes were closed.

Discussion

Previous evaluations of kinematic and kinetic variables have revealed their cognitive influences on gait and postural stability (32-36) and it has been observed that high levels of stress are associated with poorer executive function, abstract reasoning, processing speed, and visual-spatial memory (12-14). Furthermore, mood state is capable of influencing balance control (15) and anticipatory postural adjustments (16).

The main aim of the present study was to investigate the impact of stress on postural stability with or without visual input, whilst the secondary objective was to evaluate the effect of laterality.

The level of stress was measured with PSS whilst overall mood disturbance was assessed with POMS as TMD. Stress was also evaluated by measuring the rapid increase of free cortisol levels after awakening. Chronic stress exhibits an important role in the CAR but studies examining how chronic stress modulates the CAR have reported conflicting results (reviewed in 20,21). Certain studies observed a reduced CAR in association with chronic stress (37-41), whereas other studies described an increased CAR in individuals chronically exposed to stressful events (42-45).

Several elements have been suggested to explain these contrasting results. Fries *et al* (21) postulated that the duration of chronic stress may exert positive or negative influences on the CAR. This theory is supported by the results of a meta-analysis conducted by Miller *et al* (20), which concluded that 'timing is an especially critical element, as hormonal activity is elevated at stressor onset but reduces as time passes'. In the present study, a strong positive correlation was observed

between CAR and psychological rating scales evaluating stress (PSS) or, more in general, mood states (POMS). Therefore, by accepting the conclusions of Miller *et al* (20), it is reasonable to assume that the subjects in the present study were exposed to relatively recent stressful conditions.

Postural stability was inferred from the A95 measured in five postural conditions, which were maintained for at least 52 sec with open and closed eyes. A95 was selected as previous studies showed that this measure is the primary measure for postural stability (28,29). Data regarding the COP indicated an increased significant body sway in two specific conditions, i.e. when eyes were closed in position D and E, where the dominant foot was 10 cm behind the other. Therefore, when the two feet are not at the same level, maintenance of posture is easier when the dominant foot is ahead, regardless of visual input. This effect of laterality is in agreement with the observations of previous studies (46,47).

In the present study, a strong correlation for each subject was observed between the PSS and TMD scores, as well as the levels of salivary cortisol and the mean value of A95 measured in the 5 positions when eyes were closed, whereas between the mean of A95 and PSS a significant correlation was only observed only with open eyes. It is worth noting that in previous studies aimed at evaluating the association between mood and postural control (15,16) only the POMS was used. Although PSS and POMS co-vary linearly, on the basis of the results of the present study the former may be more appropriate than the latter to demonstrate heightened stress.

In conclusion, the present study demonstrated not only that the level of stress is capable of influencing postural stability, but also that this influence is particularly evident when no visual information is available during postural control.

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