Available online at www.sciencedirect.com
SCIENCE DIRECT®

Biological Psychology 69 (2005) 149–166

BIOLOGICAL PSYCHOLOGY

www.elsevier.com/locate/biopsycho

Socioeconomic position and cardiovascular and neuroendocrine responses following cognitive challenge in old age

Andrew Steptoe*, Sabine R Kunz-Ebrecht, Caroline Wright, Pamela J. Feldman

Psychobiology Group, Department of Epidemiology and Public Health, University College London, 1-19 Torrington Place, London WC1E 6BT, UK

Received 4 April 2004; accepted 22 July 2004
Available online 15 December 2004

Abstract

Social disparities in health persist into old age, and differences in psychophysiological responsivity may contribute to this pattern. We assessed whether higher socioeconomic status (SES) is associated with attenuated cardiovascular and neuroendocrine responses elicited by cognitive tasks in old age. We tested 132 community-dwelling men and women aged 65–80 years, divided on the basis of educational attainment into higher and lower SES groups, and compared them with 26 higher educated participants aged 27–42 years. Blood pressure, hemodynamic variables and salivary cortisol were assessed in response to the performance of three cognitive tasks, and then during recovery. Older groups showed smaller heart rate and larger cortisol changes than younger participants. Post-task recovery in heart rate, stroke volume, pre-ejection period, and systolic blood pressure was greatest in the younger group, least in the older/lower education group, and intermediate in the older/higher education group. SES did not influence the increased cortisol responsivity of older participants. The results are consistent with the notion that higher SES protects against age-related changes in cardiovascular response profiles, particularly during recovery.

Keywords: Ageing; Cognitive testing; Socioeconomic status; Heart rate; Cortisol; Blood pressure; Recovery

* Corresponding author. Tel.: +44 207 679 5628; fax: +44 207 916 8542.
E-mail address: a.steptoe@ucl.ac.uk (A. Steptoe).

0301-0511/$ – see front matter
doi:10.1016/j.biopsycho.2004.07.008

1. Introduction

There is an inverse relationship between coronary heart disease and socioeconomic status (SES), with higher levels of disease incidence and mortality in lower SES groups (Kaplan and Keil, 1993; Marmot and Bartley, 2002). There are also higher levels of subclinical atherosclerosis in lower SES groups (Lynch et al., 1995), and these associations are only partly accounted for by health behaviors such as smoking and physical inactivity (Lynch et al., 1996; Steenland et al., 2002). It has been proposed that low SES is characterized by greater activation of autonomic and neuroendocrine processes that in turn promote inflammatory responses, metabolic dysfunctions and atherogenesis (McEwen and Seeman, 1999; Steptoe and Marmot, 2002).

Laboratory mental stress testing has been used to evaluate SES differences in cardiovascular and neuroendocrine responsivity, but results to date have been mixed, with lower SES being associated with both increased and decreased reactivity (Steptoe and Marmot, 2002). Analyses of post-task recovery may show more consistent effects. We recently tested 228 middle-aged men and women who were members of the Whitehall II epidemiological cohort, using occupational position as the indicator of SES. Differences in blood pressure reactivity were observed in women but not men, with greater systolic and diastolic pressure reactions in lower SES participants (Steptoe et al., 2002). In addition, men and women in lower SES categories showed impaired post-stress recovery in systolic and diastolic pressure and in heart rate variability, suggesting that lower SES might induce failure of homeostatic regulation. The association of lower SES with delayed cardiovascular recovery has been confirmed in a second investigation (Brydon et al., 2004), and is consistent with the notion of greater allostatic load in lower SES groups (Seeman et al., 2004a,b). By contrast, no differences in salivary cortisol stress responses were observed (Kunz-Ebrecht et al., 2003). Other studies of white women (Adler et al., 2000) and African American men (Kapuku et al., 2002) have also shown no SES differences in cortisol responses to acute stress, although Kristenson et al. (2001) observed lower cortisol responsivity in lower SES men from Sweden and Lithuania.

Our studies and others in the literature were carried out with men and women of working age. However, SES differences in cardiovascular disease persist and are even accentuated in absolute terms in old age (Manton et al., 1997; Marmot and Shipley, 1996). Advancing age is characterized by a number of changes in cardiovascular and neuroendocrine regulation. Heart rate responses to mental stress are typically reduced at older ages (Barnes et al., 1982; Ditto et al., 1987; Garwood et al., 1982; Steptoe et al., 1996). Blood pressure results have been less consistent, but several studies have shown that systolic pressure reactions increase with age (Ditto et al., 1987; Gotthardt et al., 1995; Steptoe et al., 1990). Heart rate variability is lower in old age (Hrushesky et al., 1984; Kingwell et al., 1994), but evidence concerning changes in responses to behavioral stimuli have not been reported. These cardiovascular responsivity changes appear to be due to reduced cardiac reactivity to sympathetic stimulation (Stratton et al., 1992), but there is also some evidence that cardiac vagal control is reduced with advancing age (Stratton et al., 2003).

Average cortisol levels over 24 h tend to increase with age (Van Cauter et al., 1996), but changes in stress responsivity with age are less well understood. Animal research would suggest poorer post-stress recovery in cortisol in older individuals due to a decrease in resilience (Seeman and Robbins, 1994), but recovery effects are difficult to study in experimental settings owing to the prolonged time course of responses. Gotthardt et al. (1995) observed larger cortisol responses to a signal detection task in older participants, while the reverse pattern was described by Nicolson et al. (1997) in responses to a speech task. No differences in cortisol response to the Trier Social Stress Test with age have been noted in studies of men (Rohleder et al., 2002) and women (Kudielka et al., 1999). Sex differences in age-related changes in response to a battery of cognitive challenges were reported by Seeman et al. (2001), with older women showing larger responses than older men.

One way that higher SES might contribute to reducing risk of coronary heart disease with advancing age is by maintaining the cardiovascular regulatory profile of younger individuals. We therefore carried out a study in which cardiovascular and cortisol responses during the mild challenge of cognitive testing were compared in older adults divided into higher and lower SES groups. Educational attainment was used as the marker of SES. A third group of younger, higher educated men and women was also tested. We hypothesized that old age would be associated with diminished heart rate and enhanced blood pressure responses, but that these differences would be greater in lower SES older individuals. We also predicted that in old age, higher SES participants would show more effective post-task recovery in blood pressure than lower SES groups, as has been observed in middle-aged adults. We anticipated that enhanced systolic pressure reactions in the presence of reduced heart rate responses might be due in part to greater increases in stroke volume. Baseline differences in heart rate variability and in indices of myocardial contractility were expected, but no firm predictions concerning differences in responsivity with respect to age or SES were made. We hypothesized that cortisol responses would be greater in older individuals, and that if higher SES protects against age-related changes, then responsivity would be less in higher than lower SES groups.

Older age is characterized by increasing body mass, chronic illness and medication use. Selecting older participants who are free of chronic illness would introduce bias into the comparison. We therefore measured body mass index (BMI) and collected information concerning medication and chronic illness from patients and physicians' notes, and included these factors as covariates in the cardiovascular and neuroendocrine analyses.

2. Method

2.1. Participants

Participants in this study were 132 men and women aged 65–80 years (mean 70.5 years), and 26 aged 27–42 years (mean 33.5 years). The older participants were recruited from two general practices in the London area. The patient databases were searched for men and women aged between 65 and 80 who were dwelling in the community, and had no record of coronary heart disease, tachycardia, aortic valve regurgitation, dementia, or psychosis, and no cancer evident in the last 5 years. Names were selected at random from these screened lists, and individuals were invited to participate in a study of aging and health. Participants were divided into higher and lower SES groups on the basis of educational attainment: 57

had completed only elementary education and had no educational qualifications, while 75 had some qualifications, ranging from high school certificates to university degrees. In addition, 26 younger volunteers were recruited from university staff with the same exclusion criteria. All had high school or university education, so were of higher SES according to the criteria used here. The analysis therefore involved three groups: younger, older/higher education and older/lower education. Ethical approval was granted by Camden and Islington Local Research Ethics Committee.

2.2. Cognitive tasks

Three cognitive tasks were selected from the Wechsler Adult Intelligence Scale (WAIS-III) and Wechsler Memory Scale (WMS-II). The first was Verbal Paired Associates (VPA-WMS-III), which primarily taps declarative-episodic memory. The participant was read a list of eight unrelated word pairs. The first word of each pair was then repeated, and the participant was asked to supply its associated pair. This procedure was repeated three times with the first words presented in a different order each time, and the test was scored by summing correct responses, so results could range from 0 to 32. The second task was matrix reasoning (MR-WAIS-III), a non-verbal analogy-like test tapping perceptual-organising abilities and fluid reasoning. Participants were shown a series of picture cards and asked to complete the picture with one of the five options presented. No feedback was given during the procedure, which was stopped either after 5 min, or once the participant had given three consecutive incorrect responses. The third task was verbal paired associates recall and recognition (VPA-II), and was performed after the matrix task. The participant was given a word from each pair of those presented in VPA, and asked to recall the matching word. Scaled scores for all tests were calculated using the norms detailed in the manual (Kaufman and Lichtenberger, 1999), and were used in analysis.

2.3. Measures

Blood pressure was assessed using an electronic sphygmomanometer (A&D UA779, Tokyo, Japan). Heart rate, heart rate variability and other cardiac variables were assessed by impedance cardiography using a VU-AMS (Amsterdam, the Netherlands), as described by Willemsen et al. (1996). The VU-AMS uses six disposable pre-gelled Ag/AgCl electrodes to record both electronic and impedance cardiogram signals (ECG/ICG). Electrode resistance was kept below 10 kΩ by first cleaning the skin with alcohol. One electrode, a combined ECG/ICG electrode, was placed 4 cm above the jugular notch on the sternum. The other 'measuring electrode' was placed at the apex of the heart over the ninth rib, while a 'ground electrode' was placed above the right iliac crest. The second ICG 'measuring electrode' was placed directly over the tip of the xiphoid process of the sternum. The two current electrodes were placed on the back at the base of the neck (C3/C4) and over vertebrae T8-T9. The VU-AMD device was used to measure pre-ejection period and stroke volume, while heart rate variability was assessed as the root mean square of successive differences in R–R intervals. Cortisol was assessed from saliva samples using a time-resolved immunoassay with fluorometric detection.

Other measures included body weight and height (from which body mass index was calculated), and waist and hip circumference (for assessment of waist/hip ratio). Subjective stress was assessed periodically using 7-point scales from 1 = *no stress* to 7 = *very high stress*, and tasks were rated for difficulty and level of involvement using similar scales.

Prior to the test session, an extensive questionnaire was completed from which a number of measures were included in this analysis. Subjective SES was assessed with the ‘‘ladder’’ measure (Adler et al., 2000). Participants were shown a drawing of a ladder with 10 rungs, representing where people stand in society. They were told that at the top of the ladder are the people who are best off—those who have the most money, most education, and best jobs. At the bottom are the people who are the worst off, have the least money, least education and the worst jobs or no job. They were asked to place themselves on the rung on which they felt that they stood. Alcohol consumption was assessed by asking people if they drank alcohol at all, and if so how many measures they drank in the average week; a division was subsequently made between those who drank fewer than five measures or five or more. Physical activity was assessed by asking participants the number of times over the past 4 weeks that they had engaged in moderate or vigorous activities (e.g. swimming, keep fit exercises, bicycling) for at least 20 min.

The index of chronic illness was derived from medical notes coupled with patients' reports by summing the number of serious medical conditions from which the participant suffered (e.g. diabetes, arthritis, bronchial asthma, hypertension). Medication was assessed by summing the number of classes of long-term medication, including antihypertensives, statins, steroids, and anti-inflammatory medications. Similar measures have been used in a number of studies of older age (e.g. Benyamini et al., 2004; Seeman et al., 2004a,b).

2.4. Procedure

Participants were tested individually in the morning or afternoon in a clinical examination room in the health centre or the Department of Epidemiology. After anthropometric measures, the impedance cardiogram was fitted and the participant rested quietly. The impedance cardiogram was monitored for five minutes for the baseline assessment, followed by two readings of blood pressure, two saliva samples and baseline subjective stress ratings. Participants then performed the first task (VPA-I). Impedance cardiography continued throughout, and blood pressure, saliva, subjective stress and task appraisals were measured immediately afterwards. After 10 min rest, participants performed the second cognitive task (MR), again followed by task impact ratings, saliva and blood pressure assessments. The third cognitive test (VPA-II) was then administered before the third impact questionnaire, blood pressure and saliva measures. Finally, the participant lay down for 5 min, with impedance measures continuing throughout and measures of blood pressure and stress at the end.

2.5. Statistical analysis

Heart rate, heart rate variability, stroke volume and pre-ejection period were averaged over each 5 min trial period. Cardiovascular data from the three cognitive task trials were then averaged to produce an aggregate response. This procedure has been recommended in the psychophysiological stress testing literature as a means of obtaining more robust estimates of responsivity than are produced with individual tasks (Kamarck, 1992). Cardiovascular data were then analyzed with three trials (baseline, tasks, and recovery). Repeated measures analysis of variance with group (younger, older/higher education and older/lower education) and gender as between-subject factors, and the Greenhouse-Geisser correction was applied where appropriate. Reactions to tasks were analyzed as changes between baseline and task trials, adjusted for BMI, index of chronic illness and medication count, while recovery effects were analyzed as changes between task and the recovery trials. Preliminary analysis indicated that reported physical activity did not influence the results, so this factor was not included as a covariate.

Analysis was based on planned contrasts across the three groups, ordered as younger, older/higher education and older/lower education. Linear effects would indicate that the responses of the older/higher education group were intermediate between those of the younger and the older/lower education groups (consistent with our main hypotheses). Quadratic effects would indicate that the older/higher education group showed responses that were either similar to those of the younger group, or of the older/lower education group; the latter result would not be consistent with hypotheses. Time of day of testing did not affect cardiovascular results, so was not included as a factor.

Cortisol responses to tasks are delayed in comparison with cardiovascular reactions, and the timing of cortisol responses also varied between individuals. Cortisol responses to cognitive tasks were therefore analyzed by selecting the highest cortisol measured post-tasks, and repeated measures analysis of variance was carried out on baseline and task values. Time of day of the test session was added to the covariates for the cortisol analyses, and participants taking steroid medication were excluded from the cortisol analyses. There was insufficient saliva in some samples, so cortisol analyses were carried out on 24 younger, 61 older/higher education 48 older/lower education and participants. Subjective appraisal of tasks and objective cognitive performance were analyzed using analysis of variance with group and gender as between-subject factors. Results are presented as means (±standard deviations).

3. Results

The characteristics of participants of the three groups are summarized in Table 1. Sixty seven men and 91 women took part, and the proportion of men and women did not differ across groups. The average age of the two older groups was just above 70 years. All the participants were of white European origin. The three groups differed not only in objective SES defined by education, but also in self-reported SES. The younger and older/higher education groups rated themselves higher on the social ladder than did the older/lower education group, $F(2,151) = 5.37$, $p = .006$. Marital status and the proportion of smokers did not differ significantly between groups, although overall, more med than women were married, $\chi^2 = 14.2$, $p < .001$. There were significant differences in body size, with the highest BMI and greatest body weight in the older/lower education group, and the lowest in the younger group, $F(2,152) = 19.0$ and 6.53, respectively, $p < .001$. In *post hoc* tests, all three groups differed from one another in BMI. The three groups did not however differ in

Table 1
Characteristics of the three groups

	Younger group ($n = 26$)		Older/higher education ($n = 75$)		Older/lower education ($n = 57$)	
	Men	Women	Men	Women	Men	Women
N	11	15	35	40	21	36
Age (years)	33.1 ± 4.5	33.7 ±5.0	69.7 ± 3.8	71.6 ± 3.9	69.4 ± 3.6	70.9 ± 4.1
Social position (self-rated)	6.5 ± 0.8	6.0 ± 2.2	6.2 ± 1.6	5.8 ± 1.7	5.2 ± 1.7	5.2 ± 1.3
Married	8 (73%)	6 (40%)	26 (74%)	13 (32.5%)	17 (81%)	22 (61%)
Current smokers	2 (18%)	3 (20%)	1 (3%)	4 (10%)	2 (10%)	3 (8%)
Body mass index (kg/m^2)	24.9 ± 2.6	23.0 ± 2.0	26.4 ± 3.4	25.5 ± 4.0	29.7 ± 4.8	28.9 ± 4.8
Body weight (kg)	79.1 ± 1.3	62.8 ± 6.8	79.4 ± 11.7	66.4 ± 13.6	86.3 ± 15.6	75.0 ± 13.7
Waist/hip ratio	0.92 ± .08	0.84 ± .13	0.95 ± .04	0.87 ± .13	0.96 ± .05	0.84 ± .08
Alcohol intake						
Non-drinkers	0	0	2 (6%)	13 (33%)	4 (22%)	17 (47%)
<5/week	2 (18%)	10 (67%)	11 (31%)	16 (41%)	5 (28%)	14 (38%)
≥5/week	9 (82%)	5 (33%	22 (63%)	10 (26%)	9 (50%)	5 (14%)
Active sports						
Any in past 4 weeks	11 (100%)	10 (67%)	17 (50%)	19 (48%)	8 (38%)	11 (33%)
N in past 4 weeks	14.5 ± 7.7	9.1 ± 10.5	6.8 ± 12.1	6.7 ± 11.1	1.6 ± 3.1	2.8 ± 6.8
Chronic illness index	0.45 ± .8	0.07 ± .3	1.29 ± 1.2	1.08 ± 1.1	1.33 ± 1.4	1.64 ± 1.3
Medication count	0.18 ± .4	0.07 ± .3	1.17 ± 1.1	1.25 ± 1.2	1.05 ± 1.2	1.67 ± 1.4

Means ± standard deviation and number (percent).

central adiposity as indexed by waist/hip ratio. In addition, men were heavier than women, and had greater waist/hip ratios, $F(1, 152) = 37.1$ and 28.2, respectively, $p < .001$.

There were significant differences in alcohol consumption, $\chi^2 = 14.2$, $p < .001$. No alcohol drinking was reported by 28.1% of the older participants, compared with none of the younger group. Differences between the two older groups are also present, $\chi^2 = 6.30$, $p = .012$, with less frequent drinking in the lower education participants. The three groups differed both in the proportion who were physically active, $\chi^2 = 13.3$, $p < .001$, and in the number of episodes of moderate or vigorous sport activity in the past 4 weeks, $F(2,148) = 9.18$, $p < .001$. The younger participants were more active, but *post hoc* tests indicated that the older/higher education group was also more active than the older/lower education group.

Mean scores on the chronic illness index differed markedly between groups, with very low levels in younger participants and an average of 1.17 and 1.53 medical conditions per person in the higher and lower education older groups, $F(2,152) = 9.70$, $p < .001$. The two older groups did not differ significantly in *post hoc* tests. Older participants took more medications, $F(2,152) = 11.0$, $p < .001$, but medication use did not differ between the two older groups. There were no interactions between group and gender in any of the analyses of background characteristics.

3.1. Subjective and behavioral responses

Subjective ratings indicated that the cognitive tasks were mildly stressful, with a significant trial effect in analysis of variance, $F(2,354) = 164.1$, $p < .001$. Ratings increased from a baseline average of 1.6 (S.D. .85) to 3.61 (1.81) during tasks, falling back to 1.50 (.92) during the recovery trial. This pattern did not vary by group or gender. The two older groups rated the VPA-I task as more difficult than did the younger group (means 5.42, 5.72 and 4.03 for the older/higher education, older/lower education and younger groups, respectively), $F(2,148) = 5.56$, $p = .005$, but the other tasks were perceived as being equally difficult by all groups. The three groups did not differ in ratings of task involvement, with mean scores of 5.08, 5.47 and 5.85 for VPA-I, VPA-II and MR, respectively. There was a significant group difference on performance of VPA-I, $F(2,138) = 19.9$, $p < .001$, with scaled scores of 10.7 ± 3.0, 9.11 ± 2.9 and 8.75 ± 2.8 in the younger, older/higher education, and older/lower education groups, respectively. In the analysis of VPA-II, the quadratic effect was significant, $F(2,148) = 14.7$, $p < .001$, since performance in the younger group (mean 6.62 ± 1.9) was greater than in the older/higher education (3.69 ± 2.3) and older/lower education (3.23 ± 2.3) groups. The scaled scores for the MR task averaged 12.4 ± 2.7, 12.2 ± 3.2 and 10.1 ± 3.4 in the younger, older/higher education, and older/lower education groups, respectively, $F(2,149) = 5.41$, $p = .005$.

3.2. Cardiac responses to task performance

Cardiovascular results across the three trials are summarized in Table 2. The group by trial interaction was significant in the analysis of heart rate, and did not interact with gender, $F(4,238) = 6.36$, $p < .001$. Heart rate did not differ between groups at baseline, but

Table 2
Cardiovascular results across the three trials in younger and older groups (means ± standard deviation)

	Younger group			Older/higher education group			Older/lower education group		
	Baseline	Tasks	Recovery (lying)	Baseline	Tasks	Recovery (lying)	Baseline	Tasks	Recovery (lying)
Heart rate (bpm)	67.3 ± 9.1	71.3 ± 7.7	62.3 ± 6.6	69.8 ± 10.8	69.7 ± 10.1	63.7 ± 9.6	70.2 ± 10.2	69.0 ± 8.9	63.2 ± 7.8
Heart rate variability (ms)	41.9 ± 20.7	33.8 ± 14.7	58.4 ± 23.3	38.2 ± 13.7	39.6 ± 27.9	40.5 ± 19.3	33.3 ± 32.9	37.6 ± 22.9	40.5 ± 25.7
Stroke volume index (ml/beat/m^2)	3.11 ± .9	2.63 ± 1.0	4.22 ± 1.2	2.91 ± .9	2.77 ± 0.9	3.55 ± 1.3	2.94 ± .9	2.85 ± 0.9	3.41 ± 1.1
Pre-ejection period (ms)	118.7 ± 21.1	118.2 ± 20.9	105.0 ± 22.7	113.2 ± 29.4	110.4 ± 27.3	106.1 ± 22.8	106.6 ± 28.6	98.6 ± 23.8	104.1 ± 25.1
Systolic BP (mmHg)	119.0 ± 13.4	119.7 ± 14.2	118.2 ± 10.8	134.7 ± 20.9	137.9 ± 19.5	140.2 ± 21.2	135.1 ± 17.1	136.2 ± 18.1	141.9 ± 16.4
Diastolic BP (mmHg)	71.0 ± 5.9	73.5 ± 6.3	72.5 ± 7.8	78.0 ± 9.3	81.2 ± 8.6	79.4 ± 9.3	77.1 ± 7.9	80.1 ± 8.3	81.5 ± 7.9

All values are adjusted for gender, body mass index, chronic illness index and medication count.

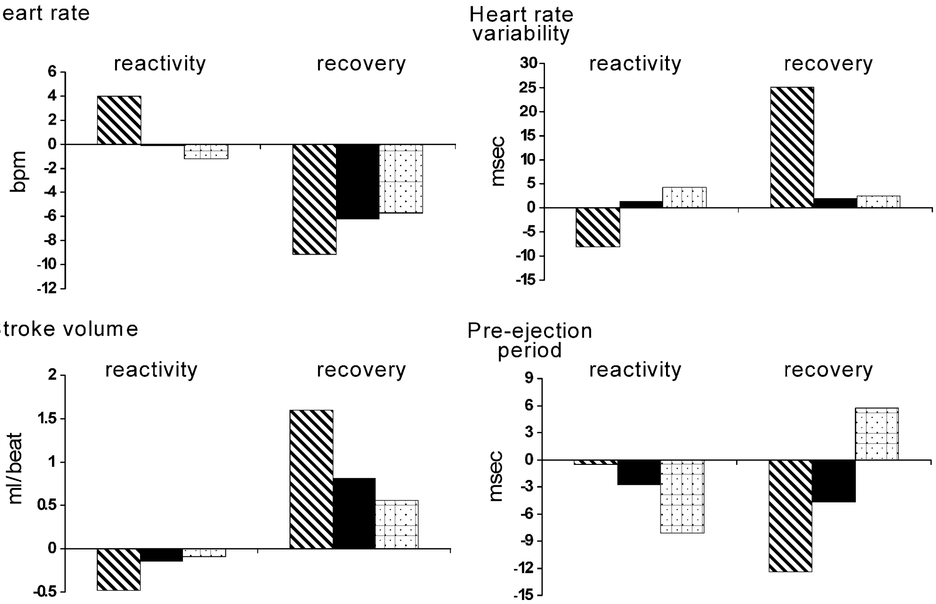

Fig. 1. Mean changes between baseline and task trials (reactivity) and between task trails and recovery (recovery) in heart rate, heart rate variability, stroke volume index and cardiac pre-ejection period in younger (hatched bars), older/higher education (solid bars) and older/lower education (stippled bars) groups. Values are adjusted for gender, BMI, chronic illness and medication.

heart rate responses to tasks varied across groups, $F(2,120) = 8.94$, p for linear effect $<.001$. Heart rate increased significantly during tasks in the younger group ($p = .005$), and fell significantly in the older/lower education group ($p = .008$). There was no change in the older/higher education group (Fig. 1). Thus, as postulated, older age was associated with diminished heart rate responsivity, and this effect was attenuated in more educated older participants after adjustment for gender, BMI, the index of chronic illness and medication count. The heart rate decrease post-tasks also varied with group, being largest in the younger participants and smallest in the older/low education group, $F(2,118) = 4.55$, p for linear effect = .006. The quadratic effect was not significant ($p = .11$), suggesting that the older/higher education group was intermediate between the other two.

The repeated measures analysis of heart rate variability showed a near significant main effect of group, $F(2,105) = 2.91$, $p = .059$, a significant trial effect, $F(2,210) = 7.50$, $p < .001$, together with a group by trial quadratic interaction, $F(2,210) = 2.99$, $p = .023$. Heart rate variability tended to be lower across the study in the older participants. It also decreased during task trials in the younger, but not in either of the older groups (Fig. 1). Analysis of post-task recovery revealed a quadratic effect for group, $F(2,104) = 6.29$, $p = .014$. Heart rate variability increased post-tasks in the younger group, but remained unchanged in older participants. Thus, heart rate variability reactions and recovery were attenuated with age, and there was no evidence that SES in old age influenced responses.

The stroke volume index analysis showed a significant group by trial interaction, $F(4,180) = 4.57$ $p = .012$, and no interaction with gender. Stroke volume index did not differ between groups at baseline. There was a significant quadratic effect in stroke volume responses to tasks, $F(2,91) = 11.1$, $p = .006$. Stroke volume decreased in all groups (all $p < .01$), but the reduction was greater in the younger compared with the two older groups. Stroke volume task responses did not differ between the older groups. In the recovery phase, stroke volume increased again. The linear effect across groups was significant, $F(2,89) = 4.22$, $p = .005$, but not the quadratic effect. As can be seen in Fig. 1, the largest increase was found in the younger group, an intermediate increase in the older/higher education group, and the smallest change in the older/lower education group.

In the repeated measures analysis of pre-ejection period, there was a significant group by trial quadratic effect, $F(2,116) = 3.40$, $p = .037$, and no interaction with gender. Pre-ejection period did not change significantly in response to tasks in the younger or in the older/higher education group, but did shorten in the older/lower education group ($p = .016$). The three groups also differed during recovery, $F(2,115) = 3.86$, p for linear effect = .009. As can be seen in Fig. 1, pre-ejection period shortened in younger participants between tasks and recovery trials. By contrast, the older/lower education group showed an increase in pre-ejection period, while the recovery effects in the older/higher education group were intermediate. None of these effects related to cardiac responses varied with gender.

3.3. Blood pressure responses

There were significant effects for group in the analysis of both systolic and diastolic pressure, $F(1,148) = 20.7$ and 13.5, respectively, $p < .001$. Blood pressure levels were higher throughout the study in the two older groups compared with the younger group (Table 2). The main effect for gender was also significant for both variables since blood pressure was higher in men than women, $F(1,148) = 15.8$ and 6.41, respectively, $p < .01$, but gender did not interact with group status. There were also main effects of trial in both analyses, $F(2,296) = 6.54$ and 14.9, respectively, $p < .002$. The group by trial interaction was significant for systolic but not diastolic pressure, $F(4, 296) = 2.89$, $p = .025$. When task responses were assessed as changes from baseline, there was no significant difference between the groups ($p = .46$), with all showing a small systolic pressure increase. By contrast, systolic pressure recovery showed a linear difference between groups, $F(2, 147) = 2.26$, $p = .036$. As can be seen in Fig. 2, there was little change in systolic pressure between tasks and recovery in the younger group. The older/lower education group showed a large increase systolic pressure between task and recovery trials, with an intermediate pattern in the older/higher education group.

The cardiovascular analyses were repeated after excluding participants taking antihypertensive medication, but this did not alter the pattern of results.

3.4. Cortisol responses

There was no difference in baseline cortisol values between groups, or between men and women in this study. In the repeated measures analysis, there was a significant group by trial interaction, $F(2,127) = 3.85$, $p = .024$, with no effects involving gender. The interaction is summarized in Fig. 3. It can be seen that the two older groups showed greater

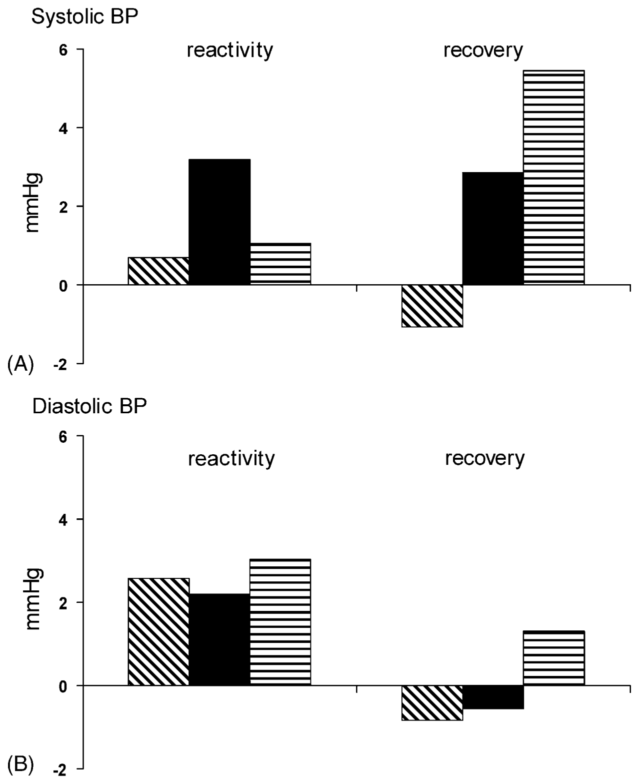

Fig. 2. Mean changes between baseline and task trials (reactivity) and between task trails and recovery (recovery) in systolic blood pressure (panel A) and diastolic blood pressure (panel B) in younger (hatched bars), older / higher education (solid bars) and older/lower education (stippled bars) groups. Values are adjusted for gender, BMI, chronic illness and medication.

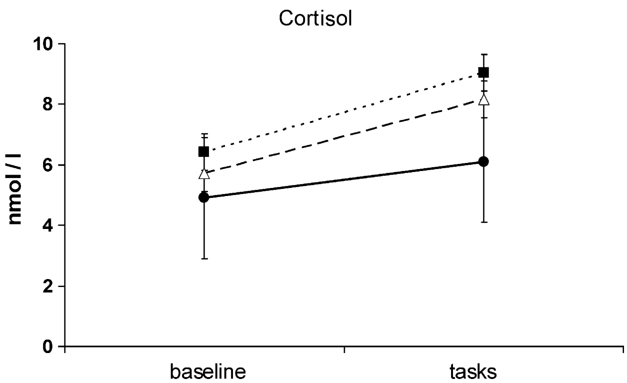

Fig. 3. Mean levels of saliva cortisol in baseline and task periods in younger (solid line, ●), older/higher education (dashed line, △) and older/lower education (dotted line, ■) groups. Values are adjusted for gender, BMI, chronic illness, medication, and time of day of testing. Error bars are standard errors of the mean.

task-induced increases in cortisol than younger participants, after adjusting for time of day, BMI, chronic illness and medication. The absolute cortisol task values also differed between groups, $F(2, 123) = 1.96, p = .05$. However, cortisol values in the two older groups did not differ at any point. Thus, cortisol task reactivity was greater in older than younger participants, but was not influenced by SES in the older groups. Additional analyses based on the subjective SES ladder showed no differences in cortisol reactivity in the older participants.

4. Discussion

This study was based on the hypothesis that higher SES might protect against age-related changes in cardiovascular and cortisol dysregulation during cognitive performance. Lower SES is associated with premature development of serious illnesses such as coronary heart disease, hypertension and diabetes, so protective factors might be expected to operate in elderly higher SES individuals. Lower SES groups adopt older age identities than more affluent groups, and old age is perceived as commencing at a younger age (Mirowsky and Ross, 2003). This may be due in part to earlier timing of life stages such as marriage, having children, and retiring, but the presence of more health problems at younger ages is also relevant (Barrett, 2003).

The results partly support the hypothesis that higher SES in old age is associated with a pattern of cardiovascular responsivity and recovery that more closely resembles the younger profile than does that of lower SES older individuals. All the psychophysiological responses in this study were small in comparison with those typically seen in studies of mental stress testing, because of the unstressful nature of the tasks. Heart rate responses were greatest in the younger group, which also showed the largest post-task recovery. The pattern in the older/higher education group was intermediate between the younger and older/lower education groups (Fig. 1). The heart rate results are consistent with a recent study involving men aged 35–50 years, in which we found that recovery post-stress was inversely associated with SES (Brydon et al., 2004). Differences in systolic blood pressure recovery were also as predicted, with the older/higher education group falling between the younger and older/lower education groups (Fig. 2). It should be noted, however, that blood pressure was recorded after rather than during task trials, and responses often subside very rapidly after the termination of challenges. The stroke volume and pre-ejection period recovery profiles in the older/higher education group were also intermediate between those of the younger participants and the older/lower education group. By contrast, we found no evidence for heart rate variability reactions or recovery differing in the two older age groups. Fluctuations in heart rate variability were markedly blunted in the older compared with younger participants. It may be that changes in heart rate variability are more indicative of physiological ageing (Hrushesky et al., 1984), and are less influenced by psychosocial factors. The stroke volume data are consistent with the prediction that the age-related changes in systolic pressure were mediated in part through differences in myocardial contractility.

The cortisol results do not support the notion that higher SES protects against age-related changes in responses to tasks. We found that cortisol responses were greater in older than younger participants, supporting the observations made in some (Gotthardt et al., 1995) but not other (Nicolson et al., 1997; Rohleder et al., 2002) previous work (Fig. 3). However, educational background had no impact on cortisol responses in the older sample, so the hypothesis that higher SES might be protective was not confirmed. There was no indication of greater cortisol responses in older women than men as described by Seeman et al. (2001). This difference may be task-specific, since higher cortisol responsivity in older age men than women has been demonstrated in some studies (Traustadottir et al., 2003). It should be noted that the magnitude of cortisol responses was small in comparison with those found in many mental stress testing studies, and differences between groups might have emerged with more vigorous challenges to the hypothalamic–pituitary–adrenocortical axis. Additionally, the time course of the study prevented cortisol recovery from being evaluated, and it may be that this component rather than the magnitude of reactions is more significant as far as ageing is concerned (Seeman and Robbins, 1994).

Educational attainment was used as a marker of SES in older participants. The measurement of SES in old age is complicated, since current occupation cannot be used, and incomes may not reflect lifetime differentials. Assessment based on education has two advantages for research on older populations (Krieger et al., 1997). First, it is applicable to people who are not and may never have been in the workforce. Second, it is stable over the lifespan regardless of health status, while income and wealth may decline in people with chronic illnesses. In addition, education may have favorable effects over and above wealth or occupation by providing people with skills in learning to cope more effectively with environmental challenges (Mirowsky and Ross, 2003). A number of studies have shown more consistent associations between health and SES based on education than other criteria, and education-related differentials in mortality persist in old age (Crimmins and Saito, 2001). The assessment of education in terms of qualifications rather than years of schooling has been recommended, since educational credentials have concrete effects on employment opportunities (Krieger et al., 1997). We did not collect income data in this study, but it is encouraging that subjective ratings of social position were in line with the categorisation based on education (Table 1).

The results of this study need to be interpreted in the light of the unusual setting for cognitive testing. Instead of carrying out testing in a laboratory, data were collected in the patients' own primary health care centres. The reason for this was to reduce obstacles to participation among elderly volunteers. Invitations to take part were sent by family physicians, and travel to an unfamiliar laboratory in central London might have discouraged participation. The cognitive tasks were administered with their standard instructions in a low stress context without criticism or ego threat, so cardiovascular and cortisol responses were small compared with those elicited with more challenging stress procedures. These factors limit the comparisons that can be made with other studies that tested older volunteers under laboratory conditions with more conventional mental stressors.

The cognitive challenges administered in this study involved memory and reasoning tasks. It might be argued that memory tasks were not appropriate, since task appraisal and performance might have been influenced by the stereotypical threat associated with negative cultural beliefs about the impact of age on memory performance (Hess et al., 2003). Performance of the memory tasks was indeed superior in the younger group. But against this interpretation is the observation that younger and older participants rated the memory tasks as equally stressful, and there were no group differences in task appraisal either.

The higher and lower SES older participants differed in important ways. Body weight and BMI were greater in the lower education group, while the higher education group engaged in more regular physical activity. These differences were expected, since lower SES has been associated with greater BMI and less leisure-time physical activity in other larger studies (Kubzansky et al., 1998; Stamler et al., 1992). It is possible that lifestyle factors contributed in part to the differences in cardiovascular reactivity and recovery, because both BMI and sedentary lifestyles have been associated with reactivity (Crews and Landers, 1987; Sung et al., 1997). However, BMI was included as a covariate in the analyses, so the differences described in the results are independent of body mass. Additional adjustment for frequency of sport activity did not alter the pattern of results or statistical significance of effects described here (data not shown).

The strengths of this study include the recruitment of a population-based sample of older individuals, and the measurement and statistical control for chronic illness and medication. These factors might affect both the appraisal of experimental conditions and the physiological regulatory processes governing cardiovascular reactivity and recovery. The study also has several limitations. It is unlikely that the older participants were representative, since the study will have attracted volunteers who were actively interested in the issues surrounding health and ageing. The lower life expectancy of lower SES men and women inevitably means that those who survive into old age may have health advantages. These selection biases may have had the effect of reducing differences between SES groups, by involving better functioning lower SES individuals. A further limitation of the study is that the younger group were not recruited through health care centres in the same way as the older groups, and the study was limited to people of white European origin. We did not include a group of younger, lower education participants, which would have allowed a full comparison of the influence of age and SES on psychophysiological responses. The study involved cognitive tasks that were not very activating in terms of cardiovascular or neuroendocrine responses. It can be argued that such conditions are probably more relevant to the everyday lives of older adults than arbitrary laboratory stressors, but it cannot be assumed that the same profile of responses would emerge. Blood pressure was not measured continuously or during tasks, so responses were almost certainly underestimated. Nevertheless, the results suggest that SES differences in biological responses to behavioral challenges that have been observed in children, younger and middle-aged adults, persist in attenuated form in old age. Additionally, the pattern of differences suggests that some of the modifications in responsivity and recovery during cognitive challenges that take place with advancing age are ameliorated or postponed in higher SES men and women. The small responses observed here are not of course significant for health in themselves. But the data are consistent with the theory that SES confers health advantages in old age in part by maintenance of more effective cardiovascular regulatory processes and potentially by reduced allostatic load.

Acknowledgements

This study was supported by the Medical Research Council. We are grateful to Dr Steve Iliffe for assistance with patient selection and recruitment, and to Elizabeth Cort, Lindsey Emmerson, and Marlous Knol for their involvement with data collection, to Clemens Kirschbaum for analysing the cortisol samples, and to Oliver Foese for advice about cognitive testing.

References

Adler, N.E., Epel, E.S., Castellazzo, G., Ickovics, J.R., 2000. Relationship of subjective and objective social status with psychological and physiological functioning: preliminary data in healthy white women. Health Psychology 19, 586–592.

Barnes, R.F., Raskind, M., Gumbrecht, G., Halter, J.B., 1982. The effects of age on the plasma catecholamine response to mental stress in man. Journal of Clinical Endocrinology Metabolim 54, 64–69.

Barrett, A.E., 2003. Socioeconomic status and age identity: the role of dimensions of health in the subjective construction of age. Journals of Gerontology B Psychological Science and Social Science 58, S101–S109.

Benyamini, Y., Leventhal, H., Leventhal, E.A., 2004. Self-rated oral health as an independent predictor of self-rated general health, self-esteem and life satisfaction. Social Science and Medicine 59, 1109–1116.

Brydon, L., Edwards, S., Mohamed-Ali, V., Steptoe, A., 2004. Socioeconomic status and stress-induced increases in interleukin-6. Brain, Behavior and Immunity 18, 281–290.

Crews, D.J., Landers, D.M., 1987. A meta-analytic review of aerobic fitness and reactivity to psychosocial stressors. Medicine and Science in Sports and Exercise 19, S114–S120.

Crimmins, E.M., Saito, Y., 2001. Trends in healthy life expectancy in the United States, 1970–1990: gender, racial, and educational differences. Social Science and Medicine 52, 1629–1641.

Ditto, B., Miller, S., Maurice, S., 1987. Age differences in the consistency of cardiovascular response patterns in healthy women. Biological Psychology 25, 23–31.

Garwood, M., Engel, B.T., Capriotti, R., 1982. Autonomic nervous system function and aging: response specificity. Psychophysiology 19, 378–385.

Gotthardt, U., Schweiger, U., Fahrenberg, J., Lauer, C.J., Holsboer, F., Heuser, I., 1995. Cortisol, ACTH, and cardiovascular response to a cognitive challenge paradigm in aging and depression. American Journal of Physiology 268, R865–R873.

Hess, T.M., Auman, C., Colcombe, S.J., Rahhal, T.A., 2003. The impact of stereotype threat on age differences in memory performance. Journal of Gerontology B Psychological Science and Social Science 58, P3–P11.

Hrushesky, W.J.M., Fador, D., Schmitt, O., Gilbertsen, V., 1984. The respiratory sinus arrhythmia: a measure of cardiac age. Science 224, 1001–1004.

Kamarck, T.W., 1992. Recent developments in the study of cardiovascular reactivity: contributions from psychometric theory and social psychology. Psychophysiology 29, 491–503.

Kaplan, G.A., Keil, J.E., 1993. Socioeconomic factors and cardiovascular disease: a review of the literature. Circulation 88, 1973–1998.

Kapuku, G.L., Treiber, F.A., Davis, H.C., 2002. Relationships among socioeconomic status, stress induced changes in cortisol, and blood pressure in African American males. Annals of Behavioral Medicine 24, 320–325.

Kaufman, A., Lichtenberger, E., 1999. Essentials of WAIS-III Assessment. John Wiley, Chichester.

Kingwell, B.A., Thompson, J.M., Kaye, D.M., McPherson, G.A., Jennings, G.L., Esler, M.D., 1994. Heart rate spectral analysis, cardiac norepinephrine spillover, and muscle sympathetic nerve activity during human sympathetic nervous activation and failure. Circulation 90, 234–240.

Krieger, N., Williams, D.R., Moss, N.E., 1997. Measuring social class in US public health research: concepts, methodologies, and guidelines. Annual Review of Public Health 18, 341–378.

Kristenson, M., Kucinskiene, Z., Bergdahl, B., Ort-Gomer, K., 2001. Risk factors for coronary heart disease in different socioeconomic groups of Lithuania and Sweden—the LiVicordia Study. Scandinavian Journal of Public Health 29, 140–150.

Kubzansky, L.D., Berkman, L.F., Glass, T.A., Seeman, T.E., 1998. Is educational attainment associated with shared determinants of health in the elderly? Findings from the MacArthur Studies of Successful Aging. Psychosomatic Medicine 60, 578–585.

Kudielka, B.M., Schmidt-Reinwald, A.K., Hellhammer, D.H., Kirschbaum, C., 1999. Psychological and endocrine responses to psychosocial stress and dexamethasone/corticotropin-releasing hormone in healthy postmenopausal women and young controls: the impact of age and a two-week estradiol treatment. Neuroendocrinology 70, 422–430.

Kunz-Ebrecht, S.R., Mohamed-Ali, V., Feldman, P.J., Kirschbaum, K., Steptoe, A., 2003. Cortisol responses to mild psychological stress are inversely associated with proinflammatory cytokines. Brain Behavior and Immunity 17, 373–383.

Lynch, J.W., Kaplan, G.A., Cohen, R.D., Tuomilehto, J., Salonen, J., 1996. Do cardiovascular risk factors explain the relation between socio-economic status, risk of all-cause mortality, cardiovascular mortality, and acute myocardial infarction? American Journal of Epidemiology 144, 934–942.

Lynch, J.W., Kaplan, G.A., Salonen, R., Cohen, R.D., Salonen, J., 1995. Socioeconomic status and carotid atherosclerosis. Circulation 92, 1786–1792.

Manton, K.G., Stallard, E., Corder, L., 1997. Education-specific estimates of life expectancy and age-specific disability in the U.S. elderly population: 1982 to 1991. Journal of Aging and Health 9, 419–450.

Marmot, M., Bartley, M., 2002. Social class and coronary heart disease. In: Stansfeld, S., Marmot, M. (Eds.), Stress and the Heart. BMJ Books, London, pp. 5–19.

Marmot, M.G., Shipley, M.J., 1996. Do socioeconomic differences in mortality persist after retirement? 25 year follow up of civil servants from the first Whitehall study. British Medical Journal 313, 1177–1180.

McEwen, B.S., Seeman, T., 1999. Protective and damaging effects of mediators of stress: elaborating and testing the concepts of allostasis and allostatic load. Annals of the New York Academy of Sciences 896, 30–47.

Mirowsky, R., Ross, C.E., 2003. Education, Social Status and Health. Aldine De Gruyter, New York.

Nicolson, N., Storms, C., Ponds, R., Sulon, J., 1997. Salivary cortisol levels and stress reactivity in human aging. Journals of Gerontology A 52, M68–M75.

Rohleder, N., Kudielka, B.M., Hellhammer, D.H., Wolf, J.M., Kirschbaum, C., 2002. Age and sex steroid-related changes in glucocorticoid sensitivity of pro-inflammatory cytokine production after psychosocial stress. Journal of Neuroimmunology 126, 69–77.

Seeman, T.E., Crimmins, E.M., Huang, M.H., Singer, B., Bucur, A., Grunewald, T., Berkman, L.F., Reuben, D.B., 2004a. Cumulative biological risk and socio-economic differences in mortality: MacArthur studies of successful aging. Social Science and Medicine 58, 1985–1997.

Seeman, T.E., Robbins, R.J., 1994. Aging and hypothalamic-pituitary-adrenal response to challenge in humans. Endocrine Reviews 15, 233–260.

Seeman, T.E., Singer, B., Wilkinson, C.W., McEwen, B., 2001. Gender differences in age-related changes in HPA axis reactivity. Psychoneuroendocrinology 26, 225–240.

Seeman, T.E., Crimmins, E., Huang, M.H., Singer, B., Bucur, A., Gruenewald, T., Berkman, L.F., Reuben, D.B., 2004b. Cumulative biological risk and socio-economic differences in mortality: MacArthur Studies of Successful Aging. Social Science and Medicine 58, 1985–1997.

Stamler, R., Shipley, M., Elliott, P., Dyer, A., Sans, S., Stamler, J., 1992. Higher blood pressure in adults with less education. Some explanations from INTERSALT. Hypertension 19, 237–241.

Steenland, K., Henley, J., Thun, M., 2002. All-cause and cause-specific death rates by educational status for two million people in two American Cancer Society cohorts, 1959–1996. American Journal of Epidemiology 156, 11–21.

Steptoe, A., Feldman, P.M., Kunz, S., Owen, N., Willemsen, G., Marmot, M., 2002. Stress responsivity and socioeconomic status: A mechanism for increased cardiovascular disease risk? European Heart Journal 23, 1757–1763.

Steptoe, A., Fieldman, G., Evans, O., Perry, L., 1996. Cardiovascular risk and responsivity to mental stress: the influence of age, gender and risk factors. Journal of Cardiovascular Risk 3, 83–93.

Steptoe, A., Marmot, M., 2002. The role of psychobiological pathways in socio-economic inequalities in cardiovascular disease risk. European Heart Journal 23, 13–25.

Steptoe, A., Moses, J., Edwards, S., 1990. Age-related differences in cardiovascular reactions to mental stress tests in women. Health Psychology 9, 18–34.

Stratton, J.R., Cerqueira, M.D., Schwartz, R.S., Levy, W.C., Veith, R.C., Kahn, S.E., Abrass, I.B., 1992. Differences in cardiovascular responses to isoproterenol in relation to age and exercise training in healthy men. Circulation 86, 504–512.

Stratton, J.R., Levy, W.C., Caldwell, J.H., Jacobson, A., May, J., Matsuoka, D., Madden, K., 2003. Effects of aging on cardiovascular responses to parasympathetic withdrawal. Journal of the American College of Cardiology 41, 2077–2083.

Sung, B.H., Wilson, M.F., Izzo Jr., J.L., Ramirez, L., Dandona, P., 1997. Moderately obese, insulin-resistant women exhibit abnormal vascular reactivity to stress. Hypertension 30, 848–853.

Traustadottir, T., Bosch, P.R., Matt, K.S., 2003. Gender differences in cardiovascular and hypothalamic-pituitary-adrenal axis responses to psychological stress in healthy older adult men and women. Stress 6, 133–140.

Van Cauter, E., Leproult, R., Kupfer, D.J., 1996. Effects of gender and age on the levels and circadian rhythmicity of plasma cortisol. Journal of Clinical Endocrinology and Metabolism 81, 2468–2473.

Willemsen, G.H., De Geus, E.J., Klaver, C.H., Van Doornen, L.J., Carroll, D., 1996. Ambulatory monitoring of the impedance cardiogram. Psychophysiology 33, 184–193.