Stress responsivity and socioeconomic status

A mechanism for increased cardiovascular disease risk?

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Aims Low socioeconomic status is associated with increased cardiovascular disease risk. We hypothesized that psychobiological pathways, specifically slow recovery in blood pressure and heart rate variability following mental stress, partly mediate social inequalities in risk.

Methods and Results Participants were 123 men and 105 women in good health aged 47–58 years drawn from the Whitehall II cohort of British civil servants. Grade of employment was the indicator of socioeconomic status. Cardiovascular measures were monitored during performance of two behavioural tasks, and for 45 min following stress. Post-stress return of blood pressure and heart rate variability to resting levels was less complete after 45 min in the medium and low than in the high grade of employment groups. The odds of failure to return to baseline by 45 min in the low relative to the high grade of employment groups were 2·60 (95% CI 1·20–5·65) and 3·85 (1·48–10·0) for systolic and diastolic pressure, respectively, and 5·19 (1·88–18·6) for heart rate variability, adjusted for sex, age, baseline levels and reactions to tasks. Subjective ratings of task difficulty, involvement and stress did not differ by socioeconomic status.

Conclusions Lower socioeconomic status is associated with delayed recovery in cardiovascular function after mental stress. Impaired recovery may reflect heightened allostatic load, and constitute a mechanism through which low socioeconomic status enhances cardiovascular disease risk.
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Introduction

Research relating socioeconomic status with cardiovascular disease risk has evolved from describing the association to investigating the mediating pathways. Unfavourable profiles of health behaviour contribute to the higher incidence of premature coronary heart disease in lower socioeconomic status groups[1,2]. However, the gradient is reduced but not eliminated after taking health behaviour into account, indicating that other pathways are also involved[3,4]. It has been proposed that the experience of low social position elicits sustained activation of autonomic, neuroendocrine and immunological responses that in turn promote atherogenesis[5,6].

One of the best established methods of investigating psychobiological processes is to assess cardiovascular responsivity to standardized mental stressors[7]. Differences in stress responsivity may emerge both in the magnitude of acute reactions and in the rate of post-stress recovery. The concept of allostasis implies that chronic stress leads to impairment of restitutional processes, manifest in delayed return to baseline following mental stress[8]. We therefore hypothesized that low socioeconomic status would be associated with impairment of cardiovascular recovery following mental stress. Cardiovascular stress responsivity was indexed by changes in blood pressure, heart rate, and heart rate variability. The magnitude of acute blood pressure stress reactions has been found to predict future hypertension[9], left ventricular mass[10] and progression of carotid atherosclerosis[11]. Impaired post-stress recovery is associated with heightened cardiovascular disease risk[12,13], and with mortality in patients with existing coronary heart disease[14]. Low heart rate variability is indicative of disturbed cardiac autonomic tone, and predicts prognosis after myocardial infarction[15]. The

Table 1   Characteristics of participants in the three employment grades

Employment grade	High (n=85)		Medium (n=78)		Low (n=65)	
	Men	Women	Men	Women	Men	Women
n (%)	47 (55·3%)	38 (44·7%)	43 (55·1%)	35 (44·9%)	33 (50·8%)	32 (49·2%)
Age	52·4 ± 2·6	50·9 ± 2·2	52·0 ± 2·4	52·3 ± 2·9	53·9 ± 2·7	52·3 ± 2·8
BMI	25·4 ± 3·0	25·9 ± 4·3	26·0 ± 4·1	24·9 ± 3·9	25·8 ± 3·2	25·6 ± 4·2
Waist (cm)	90·1 ± 9·4	79·2 ± 11·4	88·8 ± 12·8	77·7 ± 11·5	89·3 ± 11·2	78·9 ± 10·5
Waist/hip	0·91 ± 0·07	0·80 ± 0·10	0·89 ± 0·07	0·81 ± 0·13	0·91 ± 0·07	0·79 ± 0·06
Hormone replacement therapy		11 (28·9%)		11 (31·4%)		8 (26·7%)
Cigarette smokers	1 (2·1%)	2 (5·3%)	5 (11·9%)	3 (8·6%)	5 (15·2%)	2 (6·5%)
Systolic pressure (mmHg)						
Manual	120·1 ± 9·7	111·0 ± 13·3	122·5 ± 14·9	114·4 ± 14·5	122·1 ± 12·2	116·3 ± 14·5
Portapres baseline	118·9 ± 10·1	111·9 ± 12·9	118·2 ± 13·9	109·0 ± 14·2	119·1 ± 11·9	113·2 ± 13·2
Diastolic pressure (mmHg)						
Manual	73·8 ± 6·7	70·6 ± 10·3	75·1 ± 10·1	71·9 ± 10·5	75·2 ± 9·4	72·7 ± 8·8
Portapres baseline	72·1 ± 7·1	68·6 ± 10·4	72·2 ± 10·5	68·4 ± 11·6	72·0 ± 10·2	69·3 ± 9·2
Heart rate (bpm)						
Manual	61·4 ± 10·0	66.2 ± 7.8	61·5 ± 9.3	65·6 ± 7.6	63·7 ± 11.2	64.7 ± 9.1
Portapres baseline	65·6 ± 9·6	68·9 ± 9·1	64·6 ± 10·0	67·9 ± 7·1	67·1 ± 11·3	66·1 ± 6·6
Heart rate variability (RMSSD in ms)	32·7 ± 17·6	27·1 ± 10·9	29·4 ± 16·3	33·2 ± 16·7	25·2 ± 10·8	30·6 ± 9·4

Table 2   Subjective ratings during the stress session

Employment grade	Colour/word task			Mirror tracing task		
	High	Medium	Low	High	Medium	Low
Task difficulty	5·76 (1·1)	5·21 (1·5)	5·32 (1·6)	5·83 (1·5)	5·73 (1·6)	5·83 (1·3)
Task involvement	5·41 (1·4)	5·16 (1·6)	5·75 (1·3)	6·10 (1·1)	5·88 (1·4)	6·14 (1·2)
Control over task	2·38 (1·2)	2·55 (1·2)	2·59 (1·4)	3·10 (1·8)	2·89 (1·8)	2·68 (1·5)
Performance estimate	2·30 (1·1)	2·23 (1·1)	2·39 (1·4)	2·57 (1·7)	2·40 (1·7)	2·31 (1·3)
Stress rating	4·08 ± 1·5	3·66 (1·5)	3·89 (1·6)	4·31 (1·7)	3·90 (1·8)	3·98 (1·8)

All ratings on 7-point scales from 1=low to 7=high.

study was carried out with participants in the Whitehall II study, a prospective cohort of British civil servants in which differences in rates of cardiovascular disease across grades of employment have been established[16]. Grade of employment was the indicator of socioeconomic status in this study.

Method

Participants

Participants were 228 volunteers drawn from the Whitehall II cohort (123 men and 105 women). The Whitehall II cohort consists of 10 308 London-based civil servants, recruited in 1985–1988 to investigate demographic, psychosocial and biological risk factors for coronary heart disease. Participants in this substudy were recruited on the following criteria: aged 45–59 years, still based in the London area, not planning to retire for at least 3 years, no history of coronary heart disease, no previous diagnosis or treatment for hypertension, and willingness to take part in ambulatory blood pressure monitoring (not described here) as well

as the laboratory session. Participants were drawn equally from high (administrative and professional), medium (senior executive officers), and low (executive officers, clerical, office support) employment grades. The study was restricted to participants of white Caucasian origin, since cardiovascular stress responsivity may vary with ethnic background, and it was difficult to identify sufficiently large minority groups in all grades of employment. The response rate was 55%, and was greater in higher than lower status participants. Invitations were based on employment status 5 years earlier, and by the time of the study the position of some participants had altered due to promotion and job changes. The final sample consisted of 85 high (47 men, 38 women), 78 medium (43 men, 35 women), and 65 low (33 men, 32 women) employment grade participants. Employment grade in the British civil service correlates highly with income and educational attainment.
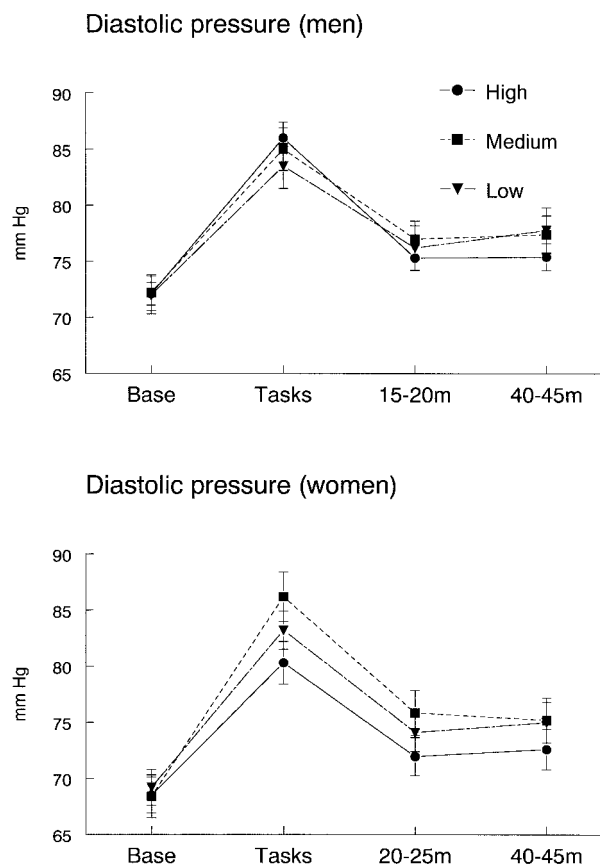
Equipment and behavioural tasks

Blood pressure and heart rate were monitored continuously from the finger using a Portapres-2, a portable

Systolic Pressure (men)

Diastolic pressure (men)

Systolic pressure (women)
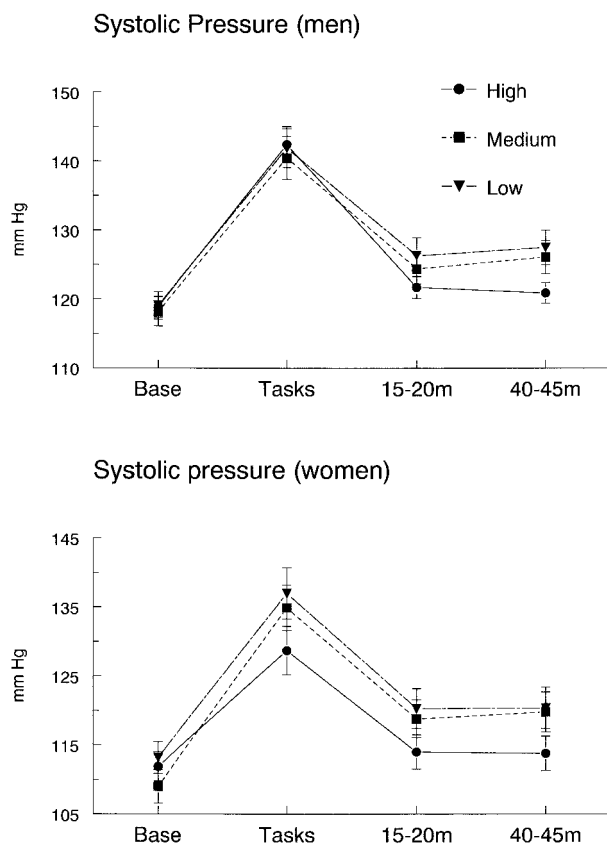
Figure 1 **Mean levels of systolic pressure in mmHg in men (upper panel) and women (lower panel) during the baseline (base), behavioural tasks, and recovery periods 1 and 2, in relation to grade of employment. Error bars are SEM.**

Diastolic pressure (women)

Figure 2 **Mean levels of diastolic pressure in mmHg in men (upper panel) and women (lower panel) during the baseline (base), behavioural tasks, and recovery periods 1 and 2, in relation to grade of employment. Error bars are SEM.**

version of the Finapres device that shows good reproducibility and accuracy in a range of settings[17,18]. Heart rate variability was assessed as the root mean square of successive differences in R-R intervals (RMSSD) obtained from a three-lead electrocardiogram in 159 participants using an ambulatory cardiac impedance device (VU-AMS, Free University, Amsterdam, NL)[19]. Mental stress was induced by two behavioural tasks. The first was a computerized colour-word interference task previously used in cardiovascular research[20]. This involved the successive presentation of target colour words (e.g. green, yellow), printed in another colour. At the bottom of the computer screen were four names of colours, again printed in incongruous colours. The task was to press a computer key that corresponded to the position at the bottom of the screen of the name of the colour in which the target word was printed. The rate of presentation of stimuli was adjusted to the performance of the participant, to ensure sustained demands. The second task was mirror tracing, involving the tracing of a star with a metal stylus which could only be seen in mirror image[21]. Each time the stylus came off the star a mistake was registered and a loud beep was emitted by the apparatus (Lafayette Instruments Corp, Lafayette, IN, U.S.A.). Participants were told that the average

person completed five circuits of the star in the time available, and were asked to give accuracy priority over speed on both tasks.

Procedure

Participants were tested in either the morning or afternoon in a light and temperature controlled laboratory. Participants were instructed not to have drunk tea, coffee, or caffeinated beverages, or to have smoked for at least 2 h prior to the study, and not to have consumed alcohol or exercised on the evening before or the day of testing. The study was approved by the UCL/UCLH Committee on the Ethics of Human Research.

Body weight, height, waist and hip circumference were measured using standardized methods. Information concerning smoking, alcohol consumption, physical exercise and hormone replacement treatment was collected by questionnaire. Following instrumentation and the insertion of a venous cannula for the periodic collection of blood samples (not described here), the participant rested for 30 min. Blood pressure and heart rate were recorded for the last 5 min, and heart rate variability for

Heart rate

Heart rate variability
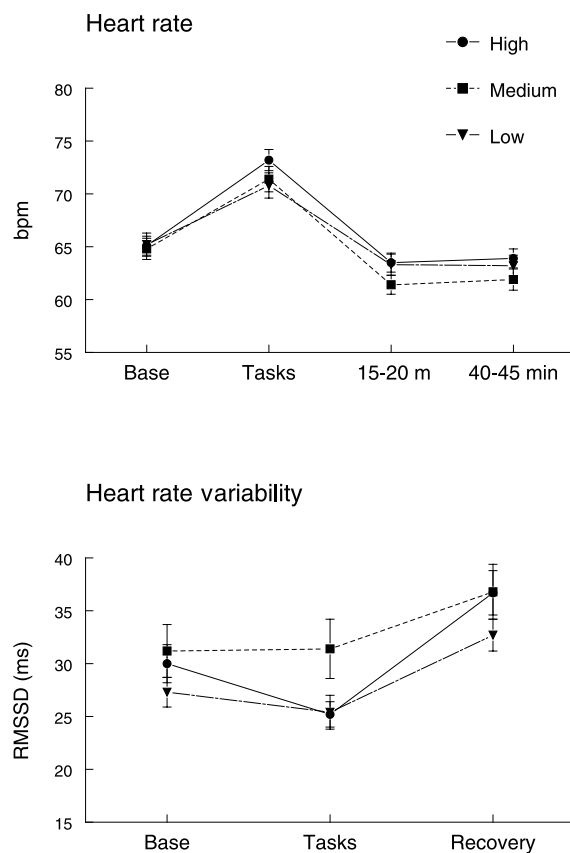
Figure 3 **Mean levels of heart rate in bpm (upper panel) and heart rate variability expressed as RMSSD in ms (lower panel) during the baseline (base), behavioural tasks, and recovery, in relation to grade of employment. Error bars are SEM.**

the last 10 min this period (baseline trial). Two measures using a standard arm cuff (A&D UA779) were also obtained. The two tasks were then administered in random order. Each lasted for 5 min, during which blood pressure and heart rate were recorded continuously. Following each task, the participant rated task difficulty, involvement, perceived performance, degree of control and feelings of stress on a series of 7–point scales from 1=*low* to 7=*high.* The post-stress recovery period was assessed with 5 min recordings of blood pressure and heart rate made 15–20 and 40–45 min after tasks, and a 10 min recording of heart rate variability made 30–40 min after tasks. Participants rested quietly during the recovery period.

Statistical analysis

Systolic pressure, diastolic pressure and heart rate were averaged into 5-min means for baseline, the two tasks and two recovery periods. Measures obtained during tasks were averaged to produce a mean task value. Heart rate variability data were analysed for baseline, the two task periods combined, and a single recovery period, with mean RMSSD for each period being computed.

Data were analysed using repeated measures analysis of variance with sex and employment grade as between-subject factors, and trial as the within-subject factor. Cardiovascular reactions to tasks were assessed by analysing changes between baseline and task levels, and post-task recovery by computing changes between baseline and the second recovery period. Incomplete post-stress recovery was defined by failure of cardiovascular measures to return to baseline by the 40–45 min for blood pressure and heart rate, and 30–40 min for heart rate variability. Factors associated with incomplete recovery were analysed using logistic regression.

Results

The three employment grades did not differ significantly in body mass, waist circumference, waist/hip ratio, proportion of women taking hormone replacement therapy, or in baseline blood pressure and heart rate (Table 1). Smoking was more common in lower than higher socioeconomic status men ($P<0.05$). Baseline heart rate variability was inversely associated with socioeconomic status in men but not women ($P<0.05$). Mean age was inversely associated with employment grade ($P<0.005$), while women were slightly younger than men ($P<0.01$). As expected, waist circumference, waist/hip ratio and resting blood pressure were greater in men than women ($P<0.01$), while resting heart rate was higher among women ($P<0.01$).

Appraisal of tasks

Participants appraised the tasks as difficult, engaging and moderately stressful, felt that they had limited control, and that their performance was poor (Table 2). The tasks were rated similarly by men and women, and by participants across the social gradient. On average, the mirror tracing task was perceived as more difficult and involving ($P<0.001$), while control was rated as lower during the colour/word task ($P<0.005$). The three grade of employment groups did not differ in the pattern of subjective stress responses across the session.

Cardiovascular responses and socioeconomic status

The tasks induced substantial blood pressure reactions, with average increases of 22.5 ± 13.4 mmHg systolic pressure and 13.6 ± 6.9 mmHg diastolic pressure (Figs 1 and 2). Employment grade influenced responses in systolic ($P<0.005$) and diastolic pressure ($P<0.025$). Systolic and diastolic pressure remained more elevated during recovery in medium and low grade participants than in the high grade group ($P<0.025$). Blood pressure during recovery trial two averaged $1.9/2.5$ mmHg above baseline in the high employment grade, compared with $8.6/6.0$ mmHg in the medium and low grade groups. In

Table 3 Post-stress recovery of blood pressure and heart rate variability in relation to grade of employment

Employment grade	Percentage showing incomplete recovery			Odds for employment grade, adjusted for sex, age, baseline value and reactions to tasks		
	Systolic pressure	Diastolic pressure	Heart rate variability	Systolic pressure	Diastolic pressure	Heart rate variability
High	58·3%	70·9%	9·4%	1	1	1
Medium	85·9%	83·3%	17·1%	4·10 (1·85 to 9·07)	1·90 (0·84 to 4·28)	2·13 (0·60 to 7·56)
Low	78·1%	87·7%	28·6%	2·60 (1·20 to 5·65)	3·85 (1·48 to 10·0)	5·91 (1·88 to 18·6)

Systolic and diastolic pressure recovery: differences between baseline and 40–45 min post-task.
Heart rate variability recovery: difference in RMSSD between baseline and 30–40 min post-task.

addition, systolic and diastolic pressure reactions to tasks were smaller in the high than low grade women ($P<0·005$), but did not differ with grade of employment in men.

Grade of employment was associated with the likelihood of complete blood pressure post-stress recovery. Complete systolic pressure recovery was shown by only 27% of participants overall, and complete diastolic pressure recovery by 20%. Incomplete recovery was more prevalent in lower socioeconomic status groups (Table 3). By comparison with the high employment grade, the odds of impaired systolic and diastolic pressure recovery were substantially elevated in the low grade participants, after adjustment for sex, age, body mass, baseline blood pressure and pressure reactions to tasks. The adjusted odds for the low grade group were 2·60 (95% CI 1·20 to 5·65) for systolic pressure, and 3·85 (1·48 to 10·0) for diastolic pressure. Further adjustment for smoking status did not alter this pattern.

Tasks elicited moderate increases in heart rate coupled with reductions in heart rate variability, indicative of a disturbance in autonomic balance (Fig. 3). Heart rate reactions to tasks were marginally greater in the high grade (mean $8·03 \pm 6·0$ bpm), compared with medium ($6·6 \pm 5·6$ bpm) and low grade groups ($5·56 \pm 6·3$ bpm, $P=0·059$), but there were no differences during the recovery period. Heart rate variability responses varied with grade of employment ($P<0·05$), with smaller reactions in the medium grade group. Complete recovery of heart rate variability to baseline levels or above was evident in the majority (82·5%) of participants. Nonetheless, incomplete recovery was associated with socioeconomic status. Compared with the high grade of employment group, the odds of incomplete recovery in RMSSD were 5·91 (1·88 to 18·6) in the low grade group, adjusted for age, sex, baseline heart rate variability and reactions to tasks (Table 3).

The relationships between cardiovascular stress responses and smoking, alcohol consumption and sedentary lifestyle were also analysed. However, blood pressure, heart rate and heart rate variability responses were not related to these aspects of lifestyle.

Discussion

Mental stress testing, involving the monitoring of physiological responses to acute challenges, is one of the principal methods used to investigate psychosocial influences on cardiovascular function, and elicits reproducible and reliable blood pressure and heart rate response patterns when administered in a standardized fashion[7]. McEwen[8] has argued that allostatic load, the wear and tear that physiological systems endure due to chronic strain elicited by psychosocial stressors or lifestyle factors such as smoking and sedentary habits, is manifest through failures of recovery mechanisms. We reasoned that low socioeconomic status might constitute a source of chronic strain leading to enhanced allostatic load, and should therefore be manifest in impaired post-stress recovery.

Rapid return to baseline following stress is characteristic of young, healthy individuals[13], and the low level of complete recovery in the present study may reflect the age of the sample. The relatively large blood pressure compared with heart rate responses are also typical of middle-aged compared with younger samples[22]. It is notable that neither systolic nor diastolic pressure showed any further return to baseline levels 40–45 min post-tasks than it did at 15–20 min. A consistent association in both men and women was found between incomplete post-stress recovery and lower socioeconomic status, with systolic and diastolic pressure remaining elevated in the medium and low compared with the high status group. In addition, the likelihood of effective recovery in blood pressure and heart rate variability was reduced in the medium and low socioeconomic status groups. Slow recovery can be a function of baseline levels, or of the magnitude of acute reactions; an individual who reacts to tasks with very large increases in cardiovascular activity might not return to reference levels so rapidly as a small reactor. Nevertheless, the association between socioeconomic status and incomplete recovery remained significant after adjustment for baseline levels and reactions to tasks. The phenomenon therefore reflects dysregulation of cardiovascular functioning.

Previous studies relating cardiovascular stress responsivity with socioeconomic status have been inconclusive[11,21,23,24]. Two substantial studies from the U.K. found that, contrary to expectations, higher social status was associated with greater rather than lesser blood pressure and heart rate reactions to behavioural tasks[23,24]. Neither of these studies measured post-stress recovery as in the present experiment. They also used

problem solving tasks — mental arithmetic and a modification of an intelligence test — to stimulate reactions. Such demands are more familiar to better educated and affluent participants, who may consequently have been more engaged by the situation, and will have strived to succeed to a greater extent. Task involvement is directly associated with the magnitude of acute cardiovascular reactions[25].

Comparisons of physiological stress responses require the selection of behavioural stimuli that are perceived as similarly challenging to people across the social gradient. In the present work, we piloted different tasks for their suitability for probing social status differences, and obtained ratings of involvement and task difficulty so as to assess subjective appraisal of stimuli. The tasks used were relatively 'status free', in that appraisals of difficulty and involvement did not vary with socioeconomic status. Under these conditions, no socioeconomic differences in blood pressure reactions were observed in men, while among women there was an inverse association between employment grade and reactivity (Figs 1 and 2). Previous studies that reported negative results were carried out with men, while a study involving women showed greater blood pressure reactivity in lower socioeconomic status participants[21]. There may therefore be important sex differences in the influence of socioeconomic status on acute reactivity.

A substantial number of civil servants declined to take part in this substudy, so the participants were a selected group. There were no associations between grade of employment and body mass or waist/hip ratio, although these are related to socioeconomic status in the main Whitehall cohort[16]. The gradient in smoking was also not as great as in the full cohort. The study may therefore have attracted relatively fit lower status participants. If this factor had an influence on results, it is likely to have reduced differences between socioeconomic groups, since the higher and lower grade participants were more similar in cardiovascular risk factors than is the case for the full cohort.

Altered cardiovascular stress recovery may be a significant mechanism through which social factors influence disease risk[6]. Lynch *et al.*[11] demonstrated that heightened systolic pressure reactivity coupled with low socioeconomic status was associated with accelerated increases in carotid atherosclerosis. Even short-term psychological stressors can lead to impairments of endothelial function[26] and increases in circulating inflammatory cytokine levels[27] that are sustained for several hours. These responses may be accentuated by delayed post-stress recovery, promoting favourable conditions for enhanced atherogenesis. The observation that post-stress recovery was less rapid among lower status individuals establishes a mechanism through which socioeconomic status may influence cardiovascular disease risk.

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