Psychological Medicine, 2006, **36**, 375–385. © 2006 Cambridge University Press
doi:10.1017/S0033291705006616 First published online 5 January 2006. Printed in the United Kingdom

The heritability of perceived stress

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ABSTRACT

Background. Exploration of the degree to which perceived chronic stress is heritable is important as these self-reports have been linked to stress-related health outcomes. The aims of this study were to estimate whether perceived stress is a heritable condition and to assess whether heritability estimates vary between subjective stress reactivity and stress related to external demands.

Method. A sample of 103 monozygotic and 77 dizygotic twin pairs completed three questionnaires designed to measure perceived stress: the Perceived Stress Scale (PSS), the Measure for the Assessment of Stress Susceptibility (MESA) and the Trier Inventory for the Assessment of Chronic Stress (TICS). The TICS assesses the frequency of stressful experiences on six scales, the MESA assesses subjective stress reactivity, and the PSS takes both factors into account.

Results. A multivariate model-fitting procedure revealed that a model with common additive genetic and shared environmental factors best fit the eight scales (PSS, MESA, six TICS scales). Heritabilities for the best-fitting model varied between 5% and 45%, depending on the scale.

Conclusions. The present data suggest that perceived stress is in part heritable, that nearly half of the covariance between stress scales is due to genetic factors, and that heritability estimates vary considerably, depending on the questionnaire. Beyond methodological considerations that pertain to the validity of the questionnaires, these data suggest that studies assessing the heritability of perceived chronic stress should take the specific questionnaire focus into account.

INTRODUCTION

Behavioral genetic studies have revealed evidence for genetic influences on variables that had previously been considered to have a greater environmental influence (Plomin & Bergeman, 1991; Plomin, 1994). For instance, twin studies suggest that genetic factors contribute to the variance in religiosity (Waller *et al.* 1990; Bouchard *et al.* 1999), divorce (McGue & Lykken, 1992), and sports participation (Beunen & Thomis, 1999). Regarding self-reported variables in general, heritability estimates average at about 40% (Loehlin, 1992).

Although perceived stress has not yet been studied with regard to heritability estimates, some studies have investigated related topics. Plomin *et al.* (1990) showed that 40% of the variability in self-reported major life events during the second half of the life span was attributable to genetic differences between individuals. Higher heritability estimates were detected for controllable events (43%) compared to events that were not under the control of the subject (18%). A more recent report (Saudino *et al.* 1997) suggests significant heritabilities for controllable, desirable and undesirable life events in women. Kendler *et al.* (1993) found that life events affecting

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individuals in the respondents' social network seemed to be uninfluenced by genetic factors, while personal events directly affecting the respondent were under significant genetic load (14–39%). In a comparable but longitudinal study (Foley *et al*. 1996), 65% of the variance in 'personal events' were attributable to genetic factors when only enduring life event influences were assessed. A recent study (Sobolewski *et al*. 2001) revealed substantial heritabilities for subject-dependent life changes, with slightly higher heritability estimates for stressors evaluated as negative (74%) than for stressors evaluated as challenging (64%). Life changes that occur independently of the subject's actions were explicable by shared (11%) and unique (89%) environmental factors. In sum, research on the heritability of life events suggests an impact of genetic factors on the individual variability of event exposure, especially when the events are 'personal events' and are under the control of the subject.

However, there are important differences between the objective occurrence of life events and the perception of the stressfulness of these events. Besides detrimental effects on productivity and well-being, perceived stress has important consequences for the onset, progression and treatment of several diseases through physiological and behavioral pathways (Cohen *et al*. 1995; Dougall & Baum, 2001). For example, self-reported stressful life events have been linked to various mental and physical conditions (Brown & Harris, 1989) and decreases in immune system activity (Herbert & Cohen, 1993). Additionally, perceived stress has been shown to predict susceptibility to viral infection (Cohen *et al*. 1998), speed of wound healing (Ebrecht *et al*. 2004), and rate of cellular aging (Epel *et al*. 2004).

In human stress theories, it is assumed that stress is a common experience that arises from person–environment interactions (e.g. Lazarus & Launier, 1978; McEwen & Stellar, 1993). Thus, in addition to situational factors that represent stressful demands, stress reactions are assumed to be influenced by personality factors (Matthews & Deary, 1998). Based on this distinction and on the preliminary data obtained in life event research, the aim of the present study was to examine heritability coefficients for three different measures of perceived stress that vary in the focus they set on the stress process. The Trier Inventory for the Assessment of Chronic Stress (TICS; Schulz & Schlotz, 1999) focuses on the frequency of stressful experiences arising from environmental and internal demands (i.e. stressors) in several domains in a defined time-frame. While four scales of the TICS (work overload, work discontent, social stress, lack of social recognition) assess stressful experiences directly related to environmental demands, the remaining two scales (intrusive memories, worrying) reflect the frequency of internal demands, that is stressful experiences related to cognitive activity directed towards past and future events. The Perceived Stress Scale (PSS; Cohen *et al*. 1983) also assesses stressful experiences in a defined time-frame, but focuses on subjective reactions to demands. The Measure for the Assessment of Stress Susceptibility (MESA; Schulz *et al*. 2005), by contrast, assesses typical subjective emotional and physiological reactions in different stressful situations; that is, stress reactivity. Those scales that focus more on the frequency of recent stress events are expected to reflect a stronger unique environmental component and thus lower clustering of scores within families.

In summary, the aims of the present study were (1) to investigate to what extent perceived stress is heritable and (2) to assess whether the influence of heritability and unique environmental factors on perceived stress scores varies systematically across questionnaires.

METHOD

Subjects and general procedure

In three independent studies participants were recruited by mail. Addresses of potential twin pairs (pairs of individuals with corresponding dates of birth, birth places and family names) were supplied by the residents' registration office (DIZ) of Rheinland-Pfalz, Germany (studies 1 and 3) or the city registration office of Trier, Germany (study 2). In studies 2 and 3, additional twin pairs were recruited through newspaper advertisements and emails to all students at the University of Trier, Germany. The complete sample consists of 180 twin pairs [45 monozygotic females (MZF), 58 monozygotic males (MZM), 30 dizygotic females (DZF), 32 dizygotic males (DZM), and 15

dizygotic opposite sex (DZO)] with a mean age of 24·9 years (S.D. = 7·7, range 16–64). Written informed consent was obtained from all subjects.

In studies 1 and 2, subjects received questionnaires and instructions by mail. They were asked to fill out the questionnaires independently of the sibling and to send them back to the laboratory. In study 3, questionnaires were filled out in our laboratory. All subjects received detailed information about their results and general information about twin research. When zygosity was questionable, a blood sample was taken for subsequent DNA fingerprinting in studies 1 and 3. In study 2, zygosity was determined by a questionnaire (see below).

Psychological assessment

Participants filled out a German version of the PSS (Cohen *et al.* 1983). This 14-item scale assesses the frequency of experiencing a situation as unpredictable, uncontrollable, or overloading. Participants indicate on a five-point scale (0 = never to 4 = very often) how often they experienced subjective affective and cognitive stress reactions, subjective effectiveness of and confidence about coping efforts, and subjective controllability of potential stressors during the past month (see Appendix for item examples). The PSS is perhaps the most widely used questionnaire in studies on stress and health, and numerous studies on, for example, cortisol, bodily symptoms and illness indicate its validity (Cohen *et al.* 1983, 1999; Edwards *et al.* 2003; Vedhara *et al.* 2003). The PSS, unlike the TICS (see below), is an instrument designed to provide a global measure of stress. Internal consistency ranges between 0·84 and 0·86.

The 36-item MESA has recently been shortened and renamed the Stress Reactivity Scale (SRS; Schulz *et al.* 2005). This questionnaire measures typical reactions to different stressors. Each item consists of two parts: the first part describes a typical stressful situation and the second part provides three possible reactions (see Appendix for item examples). Items are scored on a three-point scale (scoring range 1–3). The questionnaire reveals good psychometric properties (internal consistency $\alpha = 0{\cdot}91$) and has proved to be an effective instrument in stress studies. Correlations with measures of personality, bodily symptoms and sleep-related variables, as well as enhanced scores in a group of patients with atopic dermatitis, indicate the validity of the questionnaire (Buske-Kirschbaum *et al.* 2004; Schulz *et al.* 2005).

The TICS (Schulz & Schlotz, 1999) is a 39-item self-report instrument measuring six dimensions of perceived chronic stress, namely work overload (number of items, 8), worries (6), social stress (6), lack of social recognition (8), work discontent (5), and intrusive memories (6). For each item, the frequency of a stressful experience in the past year had to be indicated on a five-point scale from 1 = never to 5 = very often (see Appendix for item examples). Correlations with cortisol measures, measures of perceived stress and self-reported stress related variables (e.g. bodily symptoms), as well as specific profiles of different occupational groups, indicate the validity of the TICS (e.g. Schulz & Schlotz, 1999; Wüst *et al.* 2000; Pruessner *et al.* 2003; Schlotz *et al.* 2004). Internal consistency ranges between 0·76 and 0·91, depending on the dimension assessed.

Determination of zygosity

If no clear evidence for zygosity was apparent in studies 2 and 3 (opposite sex, discordant eye and/or hair color), zygosity was determined by DNA fingerprinting (study 2 used the DNA-Profiler-Kit, and study 3 the AmpFISTR Profiler PCR Amplification Kit, both from Applied Biosystems, Weiterstadt, Germany and Foster City, CA, USA). The probability of an incorrect identification of zygosity with both techniques is less than 0·1%.

Zygosity estimates in study 1 relied on the Questionnaire of Twins Physical Resemblance (Oniszczenko & Rogucka, 1996), a self-report instrument assessing indices of physical similarities and twin confusion by parents, relatives and strangers. Previous research suggests an agreement of approximately 93% between zygosity determination by questionnaire and DNA genotyping (Oniszczenko *et al.* 1993; Rietveld *et al.* 2000).

Statistical analyses

After randomly selecting one partner of each twin pair, univariate analyses of variance (ANOVAs) were used to test for zygosity and gender differences, and linear regressions were used to test for effects of age on the means of all

questionnaire scales. Correlations between questionnaire scales are Pearson correlations. Twin- and cross-correlations are also reported.

Genetic model fitting

Genetic model fitting of twin data allows for separation of the observed phenotypic variance into genetic and environmental components. Additive genetic variance (A) is the variance that results from the additive effects of alleles at each contributing genetic locus, shared environmental variance (C) results from environmental events common to both members of a twin pair, and non-shared environmental variance (E) results from environmental effects that are not shared by members of a twin pair. Estimates of E also include the measurement error. For a summary of the twin method, the various assumptions and the plausibility of these assumptions see, for example, Neale & Cardon (1992).

Structural equation modeling

The structural equation modeling procedure is based on a χ^2 test. An ACE model was fitted and compared with alternative models by subtracting the two-times log-likelihood (-2 LL) of the reduced model from that of the full model. If no significant difference in χ^2 was observed, the more parsimonious model was preferred, and ultimately, the most parsimonious model was chosen as an alternative model to ACE.

All eight scales (PSS, MESA, six TICS scales) were included in a multivariate model to test for the presence of underlying sets of genetic and environmental influences and for the presence of test-specific genetic and environmental influences. Compared to a univariate approach, this results in an increase in power (Schmitz *et al*. 1998). The multivariate model fitting was started with a Cholesky decomposition for all variance components. This approach allows the decomposition of the variance of each scale and the covariance between scales at the same time into additive genetic (A), shared environmental (C) and non-shared environmental (E) sources. This model was then used as a reference model to compare the fit of more restrictive models. To this end, the influence of genetic and shared environmental factors was reduced to a common factor (A and C), representing one underlying set of genes or shared environmental factors influencing all scales. Finally, non-shared environmental influences were reduced to be test-specific only, because this variance component includes, at least in part, measurement error. All genetic model fitting and structural equation modeling procedures were performed with Mx (Neale *et al*. 1999).

Table 1. *Descriptive statistics for all questionnaire scales*

	Sample			Reference values[a]		
Scale	Mean	S.D.	Range	Mean	S.D.	Range
PSS	24·61	7·23	7–50	23·18–25·00[b]	7·31–8·00[b]	0–56
MESA	69·65	11·76	38–107	71·76	12·55	36–108
WO	21·10	5·88	8–38	21·00	5·33	8–40
WOR	16·04	4·60	7–30	16·70	4·69	6–30
SO	14·99	3·52	6–30	14·90	3·19	6–30
LS	17·92	4·17	9–34	16·90	4·09	8–40
WD	12·83	3·47	6–24	12·70	3·30	5–25
IM	15·28	4·80	6–30	16·10	4·40	6–30

PSS, Perceived Stress Scale; MESA, Measure for the Assessment of Stress Susceptibility; TICS, Trier Inventory for the Assessment of Chronic Stress; WO, work overload; WOR, worries; SO, social stress; LS, lack of social recognition; WD, work discontent; IM, intrusive memories.

[a] Reference values for the PSS are from Cohen *et al*. (1983), for the MESA from Schulz (unpublished data, cf. Schulz *et al*. 2005) and those for the TICS are from Schulz & Schlotz (1999).

[b] Reference values vary depending on the reported reference sample.

RESULTS

The TICS was available in 178 twin pairs (1 MZM and 1 DZF missing) and the PSS in 176 twin pairs (2 MZF, 1 MZM and 1 DZF missing). The MESA was completed by a subsample of 159 twin pairs (5 MZF, 5 DZF, 2 DZM and 10 DZO missing).

All questionnaire scales were normally distributed. Means, standard deviations and ranges were comparable to the respective reference values (Cohen *et al*. 1983; Schulz & Schlotz, 1999; Schulz *et al*. 2005; Table 1).

Univariate ANOVAs with one randomly selected partner of each pair revealed no significant differences between MZ and DZ siblings in the mean values of all scales (all $F<2{\cdot}05$, N.S.). Similarly, linear regression revealed no significant effect of age on any of the scales (all $t<1{\cdot}80$, N.S.). However, significant differences were found between male and female subjects for the PSS [$F(1, 176)=4{\cdot}58$, $p<0{\cdot}05$]

and MESA [$F(1, 161) = 13{\cdot}95$, $p < 0{\cdot}001$], with women reporting higher levels of stress. We therefore decided to include gender as a definition variable in the model-fitting procedure. All questionnaire scales were significantly intercorrelated ($r = 0{\cdot}31$–$0{\cdot}73$, all $p < 0{\cdot}01$) and could thus be included in one multivariate analysis.

All MZ twin correlations were higher than the respective DZ twin correlations, suggesting genetic influences for all scales assessed (range MZ: $r = 0{\cdot}24$–$0{\cdot}53$; DZ: $r = 0{\cdot}10$–$0{\cdot}30$; Table 2 diagonal). Because of large confidence intervals (CIs), most MZ twin correlations were within the range of the DZ 95% CI and vice versa. This indicates a relatively small difference between MZ and DZ correlations, suggesting influences of shared environment for these scales as well. This was not the case for the PSS, the MESA and the TICS scale 'lack of social recognition', providing preliminary evidence for a higher influence of additive genetic factors for these scales.

With one exception (comparison of 'intrusive memories' with 'work discontent'), all MZ cross-correlations ($r = 0{\cdot}12$–$0{\cdot}41$) were higher than the respective DZ cross-correlations ($r = 0{\cdot}02$–$0{\cdot}26$), suggesting that the covariance between the scales is primarily influenced by genetic factors (Table 2 off-diagonal).

The multivariate model-fitting procedure (Table 3) was started with a Cholesky decomposition for all variance components (model 1: ACE). We then tested whether a model with A as a common factor and C as a Cholesky (model 2: comA) and a model with C as a common factor and A as a Cholesky (model 3: comC) would result in a better fit of the data. Both models were not significantly different from the full model ACE (both $p = 0{\cdot}99$). Next, a model with a subtest-specific E was tested, where A and C were a Cholesky (model 4: specE); however, this model was significantly different from ACE ($p < 0{\cdot}05$). Finally, all variance components were modeled in an ideal way, as suggested by the previous analyses (models 2–4). This model with common A and C components and a Cholesky structure for E (model 5: comAC_cholE) provided the best fit of the data ($p = 0{\cdot}77$).

The percentages of scale-specific variances (diagonal) and the between-scale covariances (off-diagonal) explained by additive genetic, shared environmental and non-shared

Table 2. *Twin- and cross-correlations. Twin-correlations are on the diagonal (upper value, MZ; lower value, DZ); cross-correlations are off-diagonal (above diagonal, MZ; below diagonal, DZ)*

		Twin 1							
	PSS	MESA	WO	WOR	SO	LS	WD	IM
Twin 2								
PSS	**0·40 (0·23–0·55)**[a] **0·18 (0·02–0·37)**	0·34 (0·20–0·48)	0·32 (0·18–0·45)	0·39 (0·25–0·52)	0·22 (0·08–0·36)	0·31 (0·17–0·44)	0·19 (0·04–0·33)	0·30 (0·16–0·42)
MESA	0·15 (−0·01 to 0·32)	**0·53 (0·38–0·67)** **0·23 (0·04–0·44)**	0·36 (0·23–0·49)	0·41 (0·27–0·54)	0·17 (0·02–0·31)	0·17 (0·01–0·31)	0·17 (0·02–0·31)	0·27 (0·13–0·41)
WO	0·04 (−0·11 to 0·21)	0·10 (−0·07 to 0·27)	**0·41 (0·25–0·56)** **0·29 (0·08–0·48)**	0·36 (0·22–0·49)	0·25 (0·11–0·38)	0·17 (0·02–0·31)	0·24 (0·10–0·38)	0·28 (0·14–0·41)
WOR	0·18 (0·02–0·35)	0·19 (0·02–0·36)	0·17 (−0·01 to 0·35)	**0·49 (0·33–0·63)** **0·30 (0·10–0·49)**	0·22 (0·07–0·36)	0·21 (0·06–0·36)	0·15 (0·00–0·30)	0·35 (0·20–0·48)
SO	0·04 (−0·07 to 0·18)	0·09 (−0·04 to 0·23)	0·15 (0·01–0·30)	0·13 (0·00–0·29)	**0·24 (0·08–0·41)** **0·10 (0·01–0·26)**	0·21 (0·07–0·36)	0·12 (−0·02 to 0·26)	0·23 (0·09–0·37)
LS	0·12 (−0·02 to 0·28)	0·02 (−0·12 to 0·19)	0·04 (−0·12 to 0·20)	0·16 (0·00–0·33)	0·03 (−0·08 to 0·18)	**0·48 (0·32–0·62)** **0·21 (0·04–0·39)**	0·24 (0·10–0·38)	0·20 (0·06–0·35)
WD	0·11 (−0·04 to 0·27)	0·06 (−0·11 to 0·23)	0·04 (−0·13 to 0·20)	0·14 (−0·03 to 0·30)	0·06 (−0·07 to 0·21)	0·18 (0·02–0·34)	**0·39 (0·22–0·54)** **0·26 (0·05–0·45)**	0·08 (−0·06 to 0·22)
IM	0·13 (−0·02 to 0·29)	0·15 (−0·01 to 0·32)	0·13 (−0·04 to 0·29)	0·26 (0·08–0·43)	0·12 (0·00–0·29)	0·14 (−0·01 to 0·31)	0·15 (−0·01 to 0·32)	**0·30 (0·15–0·46)** **0·26 (0·07–0·45)**

For abbreviations refer to Table 1. [a] Values in parentheses reflect 95% confidence intervals.

Table 3. *Model fitting results*

Model	−2 LL	df	c.t.m.	χ^2	Δdf	*p*
1. ACE	15684·228	2680				
2. comA	15691·654	2708	1	7·42	28	0·99
3. comC	15689·642	2708	1	5·35	28	0·99
4. specE	16016·862	2708	1	332·63	28	<0·05
5. comAC_cholE	**15731·925**	**2736**	**1**	**47·69**	**56**	**0·77**

c.t.m., Compared to model; ACE, full Cholesky ACE model; comA, A reduced to a common factor; comC, C reduced to a common factor; specE, E modeled subtest specific; comAC_cholE, A and C reduced to a common factor, E is a Cholesky.

The best-fitting model is in bold.

environmental factors for the best-fitting model (comAC_cholE) are presented in Table 4. The influence of genetic factors varied between 5% and 45% and the influence of shared environment between 0% and 22%, depending on the scale. Highest influences of genetic factors were detected for variation in the TICS scale 'lack of social recognition' (45%), the PSS (30%) and the TICS scale 'worries' (23%). The highest impact of shared environment was observed for the TICS scales 'work overload' and 'worries' (both 22%) and the MESA (20%).

All covariance components are depicted in Table 4 off-diagonal. Overall, the overlap between the distinct scales is mostly accounted for by genetic and non-shared environmental factors. Genetic factors explain 12–73% and non-shared environmental factors 30–87% of the covariance between scales. The influence of shared environment on the covariance is low for most scales.

DISCUSSION

The aims of the present study were to estimate the heritability of perceived stress and to investigate whether genetic, shared and unique environmental influences vary depending on the focus of the questionnaire. Three questionnaires were assessed and revealed varying results. To the best of our knowledge, this is the first study documenting a contribution of genetic factors to variability in perceived stress, as measured by self-report questionnaires. In general, heritability coefficients obtained for perceived stress measures in this study are lower than those observed for measures of distress not directly related to stressful events, such as depressive, anxiety and somatic symptoms (Kendler *et al.* 1994; Gillespie *et al.* 2003; Rijsdijk *et al.* 2003).

Highest heritability estimates were found for the TICS scale 'lack of social recognition' (45%) and the PSS (30%). For both scales, the contribution of shared environmental factors was low (0% for lack of social recognition; 5% for PSS). Somewhat lower heritabilities were found for the TICS scale 'worries' (23%); however, for this scale an additional moderate influence of shared environmental factors (22%) was observed. Lower heritabilities were observed for the remaining scales (5–16%), although in two of these scales a moderate influence of shared environmental factors could be observed (work overload: 22%, MESA: 20%). The complementary amounts of variance due to unique environmental factors thus were highest in the TICS scales 'social stress', 'work discontent', 'intrusive memories' and 'work overload' (72–87%) and considerably lower for the PSS (65%), the MESA (67%), and the TICS scales 'worries' (55%) and lack of social recognition (55%)'. Thus, although not totally in accordance with our prediction, clearly differing contributions of genetic and/or shared environmental factors were observed depending on the focus these instruments set regarding the person–environment interaction in the stress process.

The additive genetic component (A) explains a considerable amount of variance in the scales, as well as covariance between the scales, and is due to the statistical model restriction, common to all scales. Besides a set of genes that may exert a common influence on the self-reported amount of stress in these scales, there may also be influences through a common third variable. As the personality trait neuroticism can influence emotional responses as well as exposure to stressful events (Bolger & Zuckerman, 1995), and is under significant genetic load (Loehlin, 1992; Bouchard, 1994), while no influence of shared environmental factors on familial resemblance was found (Lake *et al.* 2000), this personality trait is a prime candidate to explain the common additive genetic influence on the eight self-report stress scales.

While four of the TICS scales met our expectations of being highly attributable to unique environmental factors, the scales 'worries' and 'lack of social recognition' revealed high

Table 4. *Parameter estimates*: *percentages of the total variance* (*diagonal*, *bold type*) *and the covariance* (*off-diagonal*) *for the best-fitting model comAC_cholE*

		PSS	MESA	WO	WOR	SO	LS	WD	IM
A	PSS	**0·30 (0·14–0·44)**[a]	0·38 (0·08–0·61)	0·31 (0·00–0·60)	0·42 (0·14–0·63)	0·30 (0·03–0·56)	0·73 (0·46–0·87)	0·50 (0·14–0·80)	0·40 (0·12–0·63)
	MESA		**0·14 (0·01–0·30)**	0·21 (0·00–0·47)	0·29 (0·05–0·52)	0·24 (0·02–0·49)	0·64 (0·17–0·89)	0·55 (0·10–0·88)	0·28 (0·04–0·51)
	WO			**0·06 (0·00–0·19)**	0·18 (0·00–0·38)	0·12 (0·00–0·33)	0·48 (0·00–0·86)	0·27 (0·00–0·67)	0·19 (0·00–0·42)
	WOR				**0·23 (0·05–0·41)**	0·20 (0·01–0·40)	0·59 (0·26–0·79)	0·47 (0·13–0·77)	0·24 (0·05–0·43)
	SO					**0·05 (0·00–0·16)**	0·29 (0·03–0·53)	0·24 (0·02–0·55)	0·13 (0·01–0·31)
	LS						**0·45 (0·28–0·59)**	0·54 (0·15–0·82)	0·44 (0·16–0·65)
	WD							**0·16 (0·01–0·36)**	0·39 (0·10–0·69)
	IM								**0·13 (0·02–0·27)**
C	PSS	**0·05 (0·00–0·17)**	0·18 (0·03–0·41)	0·24 (0·05–0·50)	0·16 (0·02–0·39)	0·15 (0·03–0·34)	0·00 (0·00–0·17)	0·04 (0·00–0·23)	0·15 (0·02–0·37)
	MESA		**0·20 (0·07–0·35)**	0·49 (0·23–0·74)	0·35 (0·15–0·56)	0·37 (0·15–0·60)	0·00 (0·00–0·31)	0·12 (0·00–0·50)	0·32 (0·15–0·55)
	WO			**0·22 (0·07–0·37)**	0·35 (0·19–0·54)	0·29 (0·09–0·50)	0·00 (0·00–0·35)	0·10 (0·00–0·46)	0·36 (0·19–0·58)
	WOR				**0·22 (0·07–0·39)**	0·24 (0·11–0·41)	0·00 (0·00–0·25)	0·08 (0·00–0·39)	0·22 (0·08–0·41)
	SO					**0·08 (0·02–0·18)**	0·00 (0·00–0·15)	0·06 (0·00–0·27)	0·17 (0·06–0·31)
	LS						**0·00 (0·00–0·05)**	0·00 (0·00–0·11)	0·00 (0·00–0·18)
	WD							**0·01 (0·00–0·09)**	0·07 (0·00–0·33)
	IM								**0·12 (0·04–0·25)**
E	PSS	**0·65 (0·52–0·81)**	0·44 (0·24–0·69)	0·45 (0·18–0·76)	0·42 (0·25–0·64)	0·55 (0·29–0·83)	0·27 (0·13–0·52)	0·46 (0·18–0·82)	0·45 (0·25–0·70)
	MESA		**0·67 (0·51–0·84)**	0·30 (0·05–0·65)	0·36 (0·20–0·57)	0·39 (0·18–0·72)	0·36 (0·11–0·74)	0·33 (0·09–0·85)	0·40 (0·19–0·63)
	WO			**0·72 (0·56–0·90)**	0·47 (0·29–0·70)	0·59 (0·33–0·86)	0·52 (0·14–0·99)	0·63 (0·25–0·98)	0·45 (0·21–0·72)
	WOR				**0·55 (0·42–0·73)**	0·56 (0·36–0·79)	0·41 (0·21–0·65)	0·45 (0·15–0·83)	0·54 (0·37–0·74)
	SO					**0·87 (0·73–0·97)**	0·71 (0·47–0·97)	0·70 (0·40–0·96)	0·70 (0·51–0·88)
	LS						**0·55 (0·41–0·72)**	0·46 (0·18–0·85)	0·56 (0·35–0·81)
	WD							**0·84 (0·64–0·98)**	0·54 (0·25–0·87)
	IM								**0·74 (0·60–0·89)**

For abbreviations refer to Table 1.

[a] Values in parentheses reflect 95% confidence intervals.

heritability estimates. Furthermore, a high percentage of the covariance between these two measures is attributable to genetic factors (59%). As worrying is a facet of neuroticism (Eysenck & Eysenck, 1985), it is likely that the scale 'worries' is more strongly influenced by this personality trait than the other TICS scales, thus resulting in a higher heritability estimate for this scale. In support of this argument, a high covariance attributable to additive genetic factors was observed in a study of the sources of covariance between neuroticism and generalized anxiety disorder, which is characterized by excessive chronic worry in multiple areas of life (Hettema *et al.* 2004). However, the reason for the unexpectedly high heritability estimate of the scale 'lack of social recognition' remains unclear. There may be a link through the personality trait self-esteem, which is highly correlated with lack of social recognition (Schlotz, unpublished data) and shows so little discriminate and incremental validity compared to neuroticism that these personality constructs may be seen as a marker of the same higher order concept (Judge *et al.* 2002).

Nearly half of the familial clustering in the scale 'worries' is attributable to shared environmental factors (C), and the percentage of variance accounted for by this factor is comparable to the variance due to shared environment for the MESA and the TICS scale 'work overload'. In a recent study familial clustering in burnout symptoms was found to be due to shared environmental factors (Middeldorp *et al.* 2005). Because burnout is a condition closely related to stress from the work environment, it may be that the experience of having too much to do and not enough time for rest and recreation (scale work overload), worrying about different future events, for example not being able to manage occupational demands (scale worries), and the experience of bodily and emotional stress reactions (MESA) have some origin in non-genetic factors such as education, and relate to specific states of strong distress such as burnout.

The covariance components explained by non-shared environmental factors (E) demonstrate that the consequences of stressful events may span different stress scales. For example, the observation that 71% of the covariance between 'social stress' and 'lack of social recognition' is attributable to non-shared environmental factors may be due to a feeling of rejection triggered by conflicts emerging from the social environment, thus eventually resulting in a perceived lack of social recognition. In addition, coping skills developed and refined in association with stressful interactions faced in the course of a lifetime may be more efficiently applicable in some stressful situations than others and thus explain part of the high amount of covariance between the stress scales attributable to non-shared environmental factors.

The present study is limited to some degree by the relatively small sample size. As the focus of all three studies used in this analysis was the assessment of endocrine parameters (reported elsewhere: Wüst *et al.* 2000, 2004, 2005; Federenko *et al.* 2004), the investigation of a larger number of subjects was not possible. We tried to address this issue by including all scales in one multivariate model-fitting procedure. Compared to univariate analyses, multivariate model fitting gives more reliable estimates of variance of covariance components, due to an increase of power. In addition to within-pair covariances, the multivariate model also takes cross-trait and within-person information into account, and facilitates the detection not only of c^2 but also of h^2 (Schmitz *et al.* 1998). However, the limited power is reflected by large 95% CIs that sometimes included the value '0'. Furthermore, in two of the three studies, twin pairs were allowed to fill out the questionnaires at home. We cannot exclude the possibility that members of a pair worked together on the questionnaires and that MZ pairs were more likely to do so. While this might result in increased heritabilities for each questionnaire, it should not have an impact on the differing heritabilities we found between the questionnaires. Finally, the inclusion of opposite-sex twin pairs could be associated with an underestimation of DZ pair similarities and thus with higher heritabilities. Because of the small sample size in general and the low number of opposite-sex twin pairs ($n=15$), a test for heterogeneity and sex differences in the strength of the genetic and environmental factors was not performed.

Taken together, the variance and covariance of self-reported stress was found to be

attributable to unique environmental factors and familial clustering to very different amounts in the eight stress scales. Common additive genetic factors explained most of the variance and covariance in familial clustering, while common shared environmental factors play a secondary role. Many of the observed heritability differences and complementary differences in unique environmental contributions can be explained by the different conceptual backgrounds of the questionnaires. Thus, this finding also corroborates the validity of the questionnaires. This study demonstrates that stress questionnaires yield different information, depending on the focus they set with regard to the person–environment interaction in the stress process. Decisions about self-reports to measure stress should therefore take the focus of the questionnaire into account.

ACKNOWLEDGMENTS

This study was supported by the German Research Foundation (DFG), grant FOR 255/2-1. We thank Professor Dr Christian Rittner and Professor Dr Peter Schneider, University of Mainz, Germany, for their invaluable support in zygosity testing.

DECLARATION OF INTEREST

None.

APPENDIX: Item examples

Item examples from the Perceived Stress Scale (PSS)

(1) In the last month, how often have you felt nervous and 'stressed'?
(2) In the last month, how often have you found that you could not cope with all the things that you had to do?
(3) In the last month, how often have you been able to control the way you spend your time?

Answers: 0 = never; 1 = almost never; 2 = sometimes; 3 = fairly often; 4 = very often.

Item examples from the Measure for the Assessment of Stress Susceptibility (MESA)

(1) If I have little time for my work …

Answers: 1 = I mostly stay calm; 2 = I mostly get uneasy; 3 = I mostly get quite hectic.

(2) When I argue with other people …

Answers: 1 = I mostly calm down fast; 2 = I mostly stay aroused for some time; 3 = It mostly takes a very long time until I calm down again.

(3) When I have to speak in front of other people …

Answers: 1 = I am mostly very nervous; 2 = I am mostly slightly nervous; 3 = I generally keep my balance.

Item examples from the Trier Inventory for the Assessment of Chronic Stress (TICS)

(1) I have too little time to perform my daily tasks (scale 'work overload')
(2) Times when worries overwhelm me (scale 'worries')
(3) Times when I get into conflict with other people (scale 'social stress')
(4) Feeling that I receive little recognition from other people (scale 'lack of social recognition')
(5) Times when I have to perform tasks that I am not at all willing to do (scale 'work discontent')
(6) Recurrent memories of past unpleasant experiences (scale 'intrusive memories')

Answers: How often experienced in the last year? 1 = never; 2 = rarely; 3 = sometimes; 4 = often; 5 = very often.

REFERENCES

Beunen, G. & Thomis, M. (1999). Genetic determinants of sports participation and daily physical activity. *International Journal of Obesity and Related Metabolic Disorders* **23**, S55–S63.

Bolger, N. & Zuckerman, A. (1995). A framework for studying personality in the stress process. *Journal of Personality and Social Psychology* **69**, 890–902.

Bouchard, T. J. (1994). Genes, environment, and personality. *Science* **264**, 1700–1701.

Bouchard, T. J., Jr., McGue, M., Lykken, D. & Tellegen, A. (1999). Intrinsic and extrinsic religiousness: genetic and environmental influences and personality correlates. *Twin Research* **2**, 88–98.

Brown, G. W. & Harris, T. O. (eds) (1989). *Life Events and Illness*. Unwin Hyman: London.

Buske-Kirschbaum, A., Ebrecht, M., Kern, S., Höllig, H., Gierens, A. & Hellhammer, D. H. (2004). Personality characteristics and their association to biological stress responses in patients with atopic dermatitis. *Dermatology and Psychosomatics* **5**, 12–16.

Cohen, S., Doyle, W. J. & Skoner, D. P. (1999). Psychological stress, cytokine production, and severity of upper respiratory illness. *Psychosomatic Medicine* **61**, 175–180.

Cohen, S., Frank, E., Doyle, W. J., Skoner, D. P., Rabin, B. S. & Gwaltney, J. M. (1998). Types of stressors that increase susceptibility to the common cold in healthy adults. *Health Psychology* **17**, 214–223.

Cohen, S., Kamarck, T. & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior* **24**, 385–396.

Cohen, S., Kessler, R. C. & Gordon, L. U. (1995). Strategies for measuring stress in studies of psychiatric and physical disorders. In *Measuring Stress. A Guide for Health and Social Scientists* (ed. S. Cohen, R. C. Kessler and L. U. Gordon), pp. 3–26. Oxford University Press: New York.

Dougall, A. L. & Baum, A. (2001). Stress, health, and illness. In *Handbook of Health Psychology* (ed. A. Baum, T. A. Revenson and J. E. Singer), pp. 321–337. Erlbaum: Mahwah, NJ.

Ebrecht, M., Hextall, J., Kirtley, L.-G., Taylor, A., Dyson, M. & Weinman, J. (2004). Perceived stress and cortisol levels predict speed of wound healing in healthy male adults. *Psychoneuroendocrinology* **29**, 798–809.

Edwards, S., Hucklebridge, F., Clow, A. & Evans, P. (2003). Components of the diurnal cortisol cycle in relation to upper respiratory symptoms and perceived stress. *Psychosomatic Medicine* **65**, 320–327.

Epel, E. S., Blackburn, E. H., Lin, J., Dhabhar, F. S., Adler, N. E., Morrow, J. D. & Cawthon, R. M. (2004). Accelerated telomere shortening in response to life stress. *Proceedings of the National Academy of Sciences of the United States of America* **101**, 17312–17315.

Eysenck, H. J. & Eysenck, M. W. (1985). *Personality and Individual Differences: A Natural Science Approach*. Plenum: New York.

Federenko, I. S., Nagamine, M., Hellhammer, D. H., Wadhwa, P. D. & Wüst, S. (2004). The heritability of hypothalamus–pituitary–adrenal axis responses to psychosocial stress is context dependent. *Journal of Clinical Endocrinology and Metabolism* **89**, 6244–6250.

Foley, D. L., Neale, M. C. & Kendler, K. S. (1996). A longitudinal study of stressful life events assessed at interview with an epidemiological sample of adult twins: the basis of individual variation in event exposure. *Psychological Medicine* **26**, 1239–1252.

Gillespie, N. A., Zhu, G., Neale, M. C., Heath, A. C. & Martin, N. G. (2003). Direction of causation modeling between cross-sectional measures of parenting and psychological distress in female twins. *Behavior Genetics* **33**, 383–396.

Herbert, T. B. & Cohen, S. (1993). Stress and immunity in humans: a meta-analytic review. *Psychosomatic Medicine* **55**, 364–379.

Hettema, J. M., Prescott, C. A. & Kendler, K. S. (2004). Genetic and environmental sources of covariation between generalized anxiety disorder and neuroticism. *American Journal of Psychiatry* **161**, 1581–1587.

Judge, T. A., Erez, A., Bono, J. E. & Thoresen, C. J. (2002). Are measures of self-esteem, neuroticism, locus of control, and generalized self-efficacy indicators of a common core construct? *Journal of Personality and Social Psychology* **83**, 693–710.

Kendler, K. S., Neale, M., Kessler, R., Heath, A. & Eaves, L. (1993). A twin study of recent life events and difficulties. *Archives of General Psychiatry* **50**, 789–796.

Kendler, K. S., Walters, E. E., Truett, K. R., Heath, A. C., Neale, M. C., Martin, N. G. & Eaves, L. J. (1994). Sources of individual differences in depressive symptoms: analysis of two samples of twins and their families. *American Journal of Psychiatry* **151**, 1605–1614.

Lake, R. I., Eaves, L. J., Maes, H. H., Heath, A. C. & Martin, N. G. (2000). Further evidence against the environmental transmission of individual differences in neuroticism from a collaborative study of 45,850 twins and relatives on two continents. *Behavior Genetics* **30**, 223–233.

Lazarus, R. S. & Launier, R. (1978). Stress-related transactions between person and environment. In *Perspectives in Interactional Psychology* (ed. L. A. Pervin and M. Lewis), pp. 287–327. Plenum: New York.

Loehlin, J. C. (1992). *Genes and Environment in Personality Development*. Sage: Newbury Park, CA.

Matthews, G. & Deary, J. (1998). *Personality Traits*. Cambridge University Press: Cambridge.

McEwen, B. S. & Stellar, E. (1993). Stress and the individual. Mechanisms leading to disease. *Archives of Internal Medicine* **153**, 2093–2101.

McGue, M. & Lykken, D. T. (1992). Genetic influence on risk of divorce. *Psychological Science* **3**, 368–373.

Middeldorp, C. M., Stubbe, J. H., Cath, D. C. & Boomsma, D. I. (2005). Familial clustering in burnout: a twin-family study. *Psychological Medicine* **35**, 113–120.

Neale, M. C., Boker, S. M., Xie, G. & Maes, H. H. (1999). *Mx: Statistical Modeling*. Department of Psychiatry: Box 126 MCV, Richmond, VA 23298.

Neale, M. C. & Cardon, L. R. (eds) (1992). *Methodology for Genetic Studies of Twins and Families*. NATO ASI Series, Series D: Behavioral and Social Sciences. Kluwer: Dordrecht.

Oniszczenko, W., Angleitner, A., Strelau, J. & Angert, T. (1993). *The Questionnaire of Twins' Physical Resemblance*. Unpublished report, University of Warsaw, Department of Psychology.

Oniszczenko, W. & Rogucka, E. (1996). [Diagnosis of twin zygosity on the basis of the questionnaire of the twins physical resemblance.] *Przeglad Psychologiczny* **39**, 161–175.

Plomin, R. (1994). *Genetics and Experience: The Interplay Between Nature and Nurture*. Sage: Thousand Oaks, CA.

Plomin, R. & Bergeman, C. S. (1991). The nature of nurture: genetic influence on 'environmental' measures. *Behavioral and Brain Sciences* **14**, 373–427.

Plomin, R., Lichtenstein, P., Pedersen, N. L., McClearn, G. E. & Nesselroade, J. R. (1990). Genetic influence on life events during the last half of the life span. *Psychology and Aging* **5**, 25–30.

Pruessner, M., Hellhammer, D. H., Pruessner, J. C. & Lupien, S. J. (2003). Self-reported depressive symptoms and stress levels in healthy young men: associations with the cortisol response to awakening. *Psychosomatic Medicine* **65**, 92–99.

Rietveld, M. J., van Der Valk, J. C., Bongers, I. L., Stroet, T. M., Slagboom, P. E. & Boomsma, D. I. (2000). Zygosity diagnosis in young twins by parental report. *Twin Research* **3**, 134–141.

Rijsdijk, F. V., Snieder, H., Ormel, J., Sham, P., Goldberg, D. P. & Spector, T. D. (2003). Genetic and environmental influences on psychological distress in the population: General Health Questionnaire analyses in UK twins. *Psychological Medicine* **33**, 793–801.

Saudino, K. J., Pedersen, N. L., Lichtenstein, P., McClearn, G. E. & Plomin, R. (1997). Can personality explain genetic influences on life events? *Journal of Personality and Social Psychology* **72**, 196–206.

Schlotz, W., Hellhammer, J., Schulz, P. & Stone, A. A. (2004). Perceived work overload and chronic worrying predict weekend–weekday differences in the cortisol awakening response. *Psychosomatic Medicine* **66**, 207–214.

Schmitz, S., Cherny, S. S. & Fulker, D. W. (1998). Increase in power through multivariate analyses. *Behavior Genetics* **28**, 357–363.

Schulz, P., Jansen, L. J. & Schlotz, W. (2005). Stressreaktivität: Theoretisches Konzept und Messung [Stress reactivity: theoretical concept and measurement]. *Diagnostica* **51**, 124–133.

Schulz, P. & Schlotz, W. (1999). Das Trierer Inventar zur Erfassung von chronischem Streß (TICS): Skalenkonstruktion, teststatistische Überprüfung und Validierung der Skala Arbeitsüberlastung [The Trier Inventory for the Assessment of Chronic Stress (TICS): scale construction, statistical testing, and validation of the scale work overload]. *Diagnostica* **45**, 8–19.

Sobolewski, A., Strelau, J. & Zawadzki, B. (2001). The temperamental determinants of stressors as life changes. *European Psychologist* **6**, 287–295.

Vedhara, K., Miles, J., Bennett, P., Plummer, S., Tallon, D., Brooks, E., Gale, L., Munnoch, K., Schreiber-Kounine, C., Fowler, C., Lightman, S. L., Sammon, A., Rayter, Z. & Farndon, J. (2003). An investigation into the relationship between salivary cortisol, stress, anxiety and depression. *Biological Psychology* **62**, 89–96.

Waller, N. G., Kojetin, B. A., Bouchard Jr., T. J., Lykken, D. T. & Tellegen, A. (1990). Genetic and environmental influences on religious interest, attitudes, and values: a study of twins reared apart and together. *Psychological Science* **1**, 138–142.

Wüst, S., Federenko, I., Hellhammer, D. H. & Kirschbaum, C. (2000). Genetic factors, perceived chronic stress, and the free cortisol response to awakening. *Psychoneuroendocrinology* **25**, 707–720.

Wüst, S., Federenko, I. S., van Rossum, E. F., Koper, J. W. & Hellhammer, D. H. (2005). Habituation of cortisol responses to repeated psychosocial stress – further characterization and impact of genetic factors. *Psychoneuroendocrinology* **30**, 199–211.

Wüst, S., Van Rossum, E. F., Federenko, I. S., Koper, J. W., Kumsta, R. & Hellhammer, D. H. (2004). Common polymorphisms in the glucocorticoid receptor gene are associated with adrenocortical responses to psychosocial stress. *Journal of Clinical Endocrinology and Metabolism* **89**, 565–573.