

BDNF Serum Concentrations in Healthy Volunteers are Associated with Depression-Related Personality Traits

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The issue of neurotrophins is recognized as a new lead in the quest for a deeper understanding of mood disorders. This hypothesis has emerged from experimental evidence suggesting that antidepressant drugs might work by a neuroprotective effect through the stimulation of the neurotrophin expression in distinct regions of the CNS. Endogenous levels of BDNF protein were measured in the serum samples of 118 healthy unrelated volunteers (64 male, 54 female, age: 42.1 ± 13.0 years), and the NEO-FFI has been performed in all subjects. BDNF serum values amounted to 16.3 ± 7.3 ng/ml. BDNF concentration correlated significantly with age ($r = 0.182$, $p = 0.048$), but showed no gender differences (male 16.1 ± 7.2 , female 16.5 ± 7.4 ng/ml). A negative correlation between the BDNF serum concentration and the depression-related factor neuroticism ($r = -0.212$, $p = 0.022$) has been found. Low BDNF levels in healthy humans with depressive personality traits might constitute a risk marker, reflecting a personality profile that is linked to vulnerability to mood disorders. These results provide further support for the hypothesis that BDNF may be central to the development of depressive mood states.

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INTRODUCTION

The NEO-five factor inventory (NEO-FFI) is a psychometrically sound and widely used instrument, which assesses five global personality domains and one of them constitutes neuroticism (Costa and McCrae, 1992). Neuroticism is a strong marker for vulnerability to depression (Duggan *et al*, 1995) and a personality trait accompanied by anxiety, low mood, and hostility. New experimental evidence suggests that mood disorders, which have traditionally been conceptualized as neurochemical disorders, are also associated with impairments of structural plasticity and cellular resilience (Manji *et al*, 2003). Based on clinical and animal studies, it has been suggested that mood disorders are associated with neuronal atrophy and neuronal cell loss (Duman *et al*, 2000), especially in the hippocampus (Sheline, 2000) and cerebral cortex (Rajkowska, 2000). Therefore, the issue of neuroprotection and neurotrophins is recognized as an important new lead in the quest for a deeper understanding of mood disorders and the mechan-

isms of action of antidepressants and mood stabilizers (Duman *et al*, 1997; Altar, 1999). This hypothesis has emerged especially from recent experimental evidence suggesting that antidepressant drugs and electroconvulsive treatment might work by a neuroprotective effect through the enhancement of the neurotrophin expression in distinct regions of the CNS (Duman *et al*, 1997; Altar, 1999; Siuciak *et al*, 1997). Previous animal studies have shown that hippocampal BDNF mRNA levels are significantly increased after physical exercise (Russo-Neustadt *et al*, 2000), administered antidepressant medications, and electroconvulsive therapy (Duman *et al*, 2000, 1997; Altar, 1999; Russo-Neustadt *et al*, 2000, 2001; Duman and Vaidya, 1998; Nibuya *et al*, 1995; Russo-Neustadt, 2003). According to this hypothesis, the infusion of BDNF into the midbrain of depression-model rats has been followed by recovery of behavioral deficits (Siuciak *et al*, 1997; Shirayama *et al*, 2002). In humans, increased BDNF expression was found in dentate gyrus, hilus, and supragranular regions in subjects treated with antidepressant medications at the time of death, compared with antidepressant-untreated subjects (Chen *et al*, 2001). In humans, decreased serum BDNF levels were reported recently in major depressed patients (Karege *et al*, 2002a) and increasing BDNF concentrations have been observed after antidepressant treatment (Shimizu *et al*, 2003). These data suggest BDNF concentrations to be a trait connected with depressed mood, which is also in line with the recent finding that a BDNF coding variant is associated

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with a depression-related personality trait in the NEO-FFI (Sen *et al*, 2003). The question as to whether this depression-related trait is also correlated to BDNF protein serum concentrations in healthy never-treated human volunteers has been addressed in this study.

SUBJECTS AND METHODS

Subjects

A total of 118 healthy unrelated volunteers (64 male, 54 female, age: 42.1 ± 13.0 years) were recruited for this study in the Charité Medicine Berlin by newspaper advertisement. The study was approved by the ethics committee. The Mini-International Neuropsychiatric Interview (Sheehan *et al*, 1998) was applied. Axis-I or axis-II disorders, axis-I diagnosis of first degree relatives, and psychotropic drug intake led to the exclusion of the study as detailed elsewhere (Gallinat *et al*, 2002). The NEO-FFI (Costa and McCrae, 1992) has been performed in all subjects, all of whom were unrelated individuals of German descent (Caucasians). The participants completed the German version of the NEO-FFI, which consists of 60 items and allows reliable and valid assessment of personality along the dimensions *neuroticism*, *extraversion*, *openness to experiences*, *agreeableness*, and *conscientiousness* (Borkenau and Ostendorf, 1993). After a complete description of the study to the subjects, written informed consent was obtained.

Measurement of BDNF Levels

Endogenous levels of BDNF were measured in the rethawed serum samples using commercial ELISA kits in principle according to the manufacturer's instructions (Promega Inc., Mannheim, Germany), but adapted to the fluorometric technique used also for nerve growth factor determination (Hellweg *et al*, 2003), and described in detail previously (Hellweg *et al*, 1989). The BDNF content was expressed as equivalents of recombinant human BDNF. The detection limit of the assay was 1 pg/ml. Determinations of recovery, specific, and unspecific neurotrophin binding (the latter against mouse IgG₁ obtained from MOPC 21) involved quadruplicate fluorescence determinations for each serum sample (Hellweg *et al*, 2003).

Data Analysis

The Kolmogorov–Smirnov test was employed to evaluate whether BDNF level is a normally distributed trait. Gender effects were tested using *T*-test for independent samples, and age effects were determined with Pearson's correlation test. BDNF was correlated with NEO scores using partial correlation test. The results are presented as means \pm 1 SD. Analyses were carried out using statistical software (SPSS 11.0[®]). A *p*-value of $p < 0.05$ was considered significant, while $p < 0.10$ was accepted in order to detect trends.

RESULTS

BDNF serum values in the healthy human population amounted to 16.3 ± 7.3 ng/ml, and the median amounted to 14.7 ng/ml. The Kolmogorov–Smirnov test ($D = 1.29$,

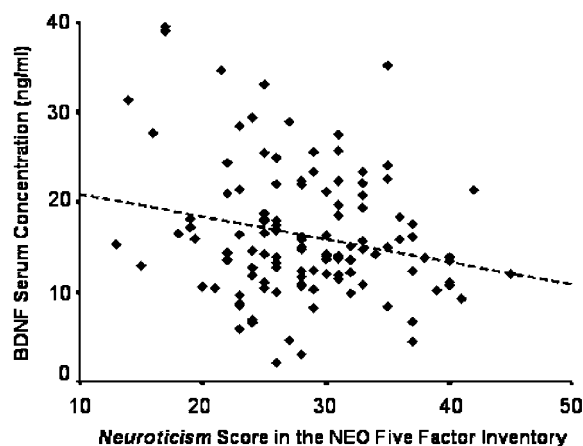


Figure 1 Correlation between brain-derived neurotrophic factor serum concentration (ng/ml) and *neuroticism* score in the NEO-FFI in healthy volunteers ($r = -0.212$, $N = 118$, $p = 0.022$).

$p = 0.07$) showed that the BDNF serum concentrations in our sample were normally distributed. BDNF concentration correlated significantly with age ($r = 0.182$, $p = 0.048$), but showed no gender differences (male 16.1 ± 7.2 , female 16.5 ± 7.4 ng/ml; $T = -0.343$, $df = 116$, $p = 0.732$; *T*-test).

Significant age effects were found for the NEO factors *neuroticism* ($r = -0.218$, $p = 0.018$) and *conscientiousness* ($r = -0.246$, $p = 0.007$), but not for *extraversion* ($r = 0.102$, $p = 0.273$), *openness for experiences* ($r = 0.006$, $p = 0.950$), and *agreeableness* ($r = 0.125$, $p = 0.179$). The effects of gender were observed in the factor *neuroticism* (male 26.9 ± 5.9 , female 30.2 ± 6.3 ; $T = -2.927$, $df = 116$, $p = 0.004$) and *agreeableness* (male 42.5 ± 5.5 , female 44.4 ± 4.6 ; $T = -2.039$, $df = 116$, $p = 0.044$), but not for *extraversion* (male 40.8 ± 5.0 , female 40.9 ± 6.4 ; $T = -0.155$, $df = 116$, $p = 0.877$), *openness for experiences* (male 42.3 ± 6.0 , female 43.5 ± 5.8 ; $T = -1.105$, $df = 116$, $p = 0.272$), and *conscientiousness* (male 46.4 ± 4.8 , female 46.0 ± 5.5 ; $T = 0.381$, $df = 116$, $p = 0.704$).

Partial correlation test with the covariate *age* showed a significant negative correlation between the BDNF concentration and the factor *neuroticism* ($r = -0.212$, $p = 0.022$; see Figure 1) and a positive correlation with the factor *conscientiousness* ($r = 0.225$, $p = 0.015$).

This correlation has also been observed when *age* as a covariate has been removed for *neuroticism* ($r = -0.252$, $p = 0.021$) as for *conscientiousness* ($r = 0.237$, $p = 0.030$).

No significant correlation between BDNF concentration and *extraversion*, *openness*, or *agreeableness* was observed ($r = 0.115$, $p = 0.217$; $r = 0.032$, $p = 0.728$; and $r = 0.109$, $p = 0.142$, respectively).

DISCUSSION

This is, to our knowledge, the first study showing a negative correlation of BDNF serum concentrations and neuroticism in healthy volunteers. Low BDNF levels in healthy humans with depressive personality traits might reflect a genetic profile, which is linked to vulnerability to depression and therefore BDNF serum concentrations could serve as a risk marker. This point of view would be in line with the recent

finding that also a BDNF coding variant is associated with the NEO personality inventory domain neuroticism (Sen *et al*, 2003). Also, BDNF gene association studies showed that the BDNF locus confers susceptibility to bipolar disorder (Neves-Pereira *et al*, 2002; Sklar *et al*, 2002). To verify this relationship, it also remains to be elucidated if serum BDNF levels are associated with the genetic polymorphisms examined. Higher BDNF serum values could therefore result from a genotype that might be protective against depression.

Another possibility to explain our results would be that BDNF serum concentrations are altered secondarily in a stress-dependent way. Stress can precipitate and exacerbate depression and may cause neuronal atrophy and death, especially in the hippocampus (McEwen, 2000; Sapolsky, 2000). Thus, a stress-induced BDNF reduction would inhibit the protective and trophic BDNF effects in the hippocampus. The reported antidepressant-induced neurogenesis in the hippocampus may be central to the antidepressive properties of antidepressant medications (Malberg *et al*, 2000), and this neurogenesis is possibly at least partly due to BDNF accumulation. Accordingly, a stress-induced reduction of hippocampal volumes (Sheline, 2000) and BDNF may be central to the development of depressive mood states (Rajkowska, 2000; Altar, 1999).

This hypothesis would be in line with data shown previously that physical exercise and antidepressant treatment increase the transcription of BDNF (Russo-Neustadt, 2003). Also, the infusion of BDNF into the midbrain of depression-model rats has been followed by recovery of behavioral deficits (Siuciak *et al*, 1997; Shirayama *et al*, 2002). In keeping with our current understanding of the cellular and molecular mechanisms of depression (Duman *et al*, 2000, 1997), monoaminergic neurotransmitter function may be an important component of these interventions. Accordingly, an augmentation of serotonergic activity within various brain areas following infusion of BDNF into the midbrain has been reported recently (Mossner *et al*, 2000). This serotonergic activity is due to the modulation of the serotonin transporter (Mossner *et al*, 2000).

One has to bear in mind, however, that BDNF serum changes in depressed subjects could be an epiphenomenon as the exact mechanisms of regulation of humoral BDNF levels are widely unknown. Platelets, brain neurons, and vascular endothelial cells are considered as candidate sources. A major source of the serum BDNF are platelets, which bind, store, and release BDNF upon activation and in response to coagulation stimuli (Yamamoto and Gurney, 1990; Fujimura *et al*, 2002). As platelets and neurons develop from a common embryonic precursor in the neural crest (Pearse, 1980), the peripheral BDNF concentration could possibly reflect the central neurotransmission state. A parallel BDNF brain and serum situation is underlined by the finding of Karege *et al* (2002b), who reported a positive correlation between the brain and serum BDNF levels in rats, which underwent similar changes during maturation and aging processes.

Previous studies on BDNF were mostly based on animal models, so an association of serum BDNF to the mood state in healthy human volunteers—as reported in this study—has not been shown yet. In contrast to previously reported observations (Chen *et al*, 2001; Karege *et al*,

2002a; Shimizu *et al*, 2003), an antidepressant drug-associated effect on BDNF could be ruled out in our sample of healthy human volunteers. These data suggest a causative relation between BDNF and mood states.

A decrease in serum BDNF levels might possibly influence the cascade relevant in the pathophysiology of depression also in the central nervous system, as it has been shown that neurotrophic factors from the blood stream can cross the blood–brain barrier under experimental conditions (Pan *et al*, 1998). However, there are also conflicting results showing that neurotrophins do not cross the blood–brain barrier (Pardridge, 2002). Therefore, it is premature to conclude that an upregulation of these factors in the blood will have beneficial effects in the brain. Whether such alterations are causatively associated with increased neural plasticity, improved cognitive function, and decreased depressive mood states remains to be elucidated in human studies.

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