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PERSONALITY AND AFFECT—

A PSYCHOPHYSIOLOGICAL APPROACH

DOCTORAL THESIS

BY

MICHAEL HERMES

SUPERVISORS:

PD DR. DIRK HAGEMANN (UNIVERSITÄT HEIDELBERG & TRIER)

PROF. DR. KARL-FRIEDRICH WENDER (UNIVERSITÄT TRIER)

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INTRODUCTION AND OUTLINE OF THE THESIS

CHAPTER I

1.1 INTRODUCTION

When people talk about emotions, they usually refer to their subjective component, the "feelings" or "affects". These are often classified as being "good" (e.g., happiness and joy) or "bad" (e.g., anger and hate) based on their hedonic tone. Most people experience affects as dependent on situational conditions like being happy when receiving a nice present or being angry when a good friend forgets an important appointment. In addition, almost everyone is aware of interindividual differences in the experience of affects: some persons tend to be happier than others, i.e. on average they experience more feelings of happiness—independent of the situation and stable over a longer period of time. In other words: there seems to be a trait component in the experience of affects, which is characterized by transsituational consistency and temporal stability.

In the last three decades, a large amount of studies investigated the trait characteristics of self-reported affects (see Chapter II). These studies yielded mainly converging results and consistently drew two conclusions: first, *there are* temporally stable and transsituationally consistent individual differences in affective experiences. Second, these individual differences can be described by a two-dimensional structure, which is composed of two broad factors that were termed *positive affect* and *negative affect*[1] (for an alternative model, see Russell & Barrett, 1999). This structure is based on the observation that persons who experience above-average levels of one kind of positive affect also tend to experience above-average levels of other positive affects (the same patterns were observed for negative affects as well as for below-average levels of affects). That is, a person who often experiences feelings of enthusiasm is also likely to frequently experience feelings of pride. Taken together, remarkable evidence exists for stable individual differences in affective experiences.

[1] It should be noted that the terms "positive affect" and "negative affect" not only comprise "basic" emotions such as happiness, fear, or sadness, but also include affective states associated with moods.

But how can this stability in affective experiences be explained? One factor crucial in maintaining consistent levels of affective experiences over time is the role of personality processes (Diener & Lucas, 1999). Consistent with this view, a considerable amount of studies showed a strong association between levels of affect and personality traits, specifically extraversion/introversion—which will be termed extraversion for short—and neuroticism (e.g., Watson & Clark, 1992). In particular, extraverts are characterized by high levels of positive affect whereas introverts experience only low levels of positive affect. In addition, neurotic subjects are characterized by high levels of negative affect whereas emotionally stable subjects experience only low levels of negative affect. There is, however, no consensus about the exact mechanisms underlying the association between personality and affective traits.

A further unknown issue about the relation between personality and trait affect concerns its biological basis. Considering the consistent associations between extraversion and positive affect, and between neuroticism and negative affect, it seems reasonable to ask whether there is a common neural basis of these relationships. For example, are extraversion and positive affect associated with the same brain structures? And if yes, does the knowledge about the function of these common brain structures help to understand why personality and affect are so strongly related?

Thus, investigating the neural basis of this relationship may not only yield insights into the functioning of the human brain but may also provide important implications for the understanding of personality-affect relationships.

1.2. OUTLINE OF THE THESIS

The work presented in this manuscript was aimed at investigating the neural basis of personality and affective traits. For this examination, a developing and promising imaging technique—continuous arterial spin labeling (CASL)—was used, which allows the non-invasive measurement of baseline cerebral blood

flow (CBF)[2]. This technique employs arterial blood water as an endogenous contrast agent and thus renders unnecessary the injection of exogenous tracers. However, some methodological aspects of the CBF measurement had to be evaluated before CASL could be used to investigate the neural basis of personality and affective traits. One aspect concerns the validity and reproducibility of the CASL measurements. Neuroimaging techniques such as CASL only measure hemodynamic changes associated with neural processes and do not allow for a direct measurement of neural activation. It was therefore important to show that CASL indeed measures the basal level of brain activation.

To evaluate whether valid conclusions about the neural activation can be drawn from CASL baseline CBF measurements, a study was conducted that compared baseline CBF at two resting states: eyes closed and eyes open. Because of the increased visual stimulation, subjects should yield an increased level of neural activation in the primary and secondary visual areas in the eyes-open compared to the eyes-closed condition. Therefore, if baseline CBF—as measured with CASL—is a valid marker of tonic neural activation, CBF in these visual areas should be greater in the eyes-open than in the eyes-closed state. Moreover, since the physiological effects of a visual stimulation should be stable over time, the area-specific CBF difference should be observed at different measurement occasions, even over longer time periods. Thus, the effects on baseline CBF should be reproducible. In Chapter III, a study is described, which examined these hypotheses with an emphasis on the reproducibility of CASL measurements. In addition to the reproducibility analysis on the effects of visual stimulation, the ability of CASL measurements to consistently detect differences between brain areas, hemispheres, and groups was analyzed as well. The study in Chapter III has also been published in Hermes et al. (2007).

A second methodological issue that had to be evaluated was the trait characteristics of baseline CBF measurements. If baseline CBF mainly reflects situational fluctuations rather than a stable and consistent characteristic of the

[2] In addition, CASL is also suitable for measuring phasic changes in CBF, which extends its application to activation studies.

organism, then it may not be a sound target for the investigation of the neural basis of personality and affective traits, which is the main goal of the present work. Therefore, the second study investigated the trait characteristics of baseline CBF measurements within the methodological framework of the latent state-trait (LST) theory. This study is presented in Chapter IV.

After the examination of these methodological issues, Chapter V describes the study that examines the neural basis of personality and affective traits. As outlined in the introductory section, it may be interesting to examine whether positive affect and extraversion, for example, are associated with the same brain structures and whether these analyses help to understand why personality and affect are so strongly related. In addition, this study also examined whether positive affect forms the core of extraversion as proposed by Watson and Clark (1997) or whether extraversion forms the core of positive affect. It should be noted that all empirical studies (Chapters III-V) are presented as autonomous (published or publishable) manuscripts, which implicates some overlap in the methods sections across chapters.

Finally, Chapter VI presents a general discussion of the findings. Before proceeding to the first methodological study in Chapter III, Chapter II will give a more detailed overview of the psychological findings on the relationship between personality and affect. In the first subchapter, a review of studies will be given that examined the correlational relations between personality and affective traits. The second subchapter presents different theories about the causal relations between personality and affective traits.

PERSONALITY AND AFFECT

CHAPTER II

2.1 STUDIES ON THE RELATION BETWEEN PERSONALITY AND AFFECTIVE TRAITS

Although a broad range of personality traits were studied in relation to affective traits (e.g., Watson & Clark, 1992), most of the studies focused on extraversion and neuroticism. For example, Bradburn (1969) found that sociability, a trait included in almost all models of extraversion (Depue & Collins, 1999), was associated with pleasant affect, but not with negative affect. This result was extended by Costa and McCrae (1980), who found extraversion to be correlated with pleasant affect (but not with unpleasant affect) and neuroticism to be correlated to with unpleasant affect (but not with pleasant affect). This pattern was maintained even when the affect measures were taken 10 years after the personality tests. Subsequent studies yielded similar results and replicated the pattern found by Costa and McCrae (Emmons, 1985; Larsen & Diener, 1992; Larsen & Ketelaar, 1989; Librán, 2006; Lucas & Fujita, 2000; Meyer & Shack, 1989; O'Malley & Gillett, 1984; Tellegen, 1985; Warr, Barter, & Brownbridge, 1983; Watson & Clark, 1984, 1992; Watson, Wiese, Vaidya, & Tellegen, 1999; Williams, 1981).

The initial studies only found moderately high correlations between personality and affect variables (between .20 and .40), which may be due to the shorter time frame for the affect ratings. In particular, subjects had to report how they had felt during the day or during the last week. These ratings may be more influenced by situational factors than those presented in later studies, which used trait affect questionnaires (in which subjects had to report how they *generally* felt). For example, Meyer and Shack (1989) found correlations of .66 between extraversion and positive affect, and of .63 between neuroticism and negative affect (N = 231). In contrast, extraversion only correlated -.22 with negative affect and neuroticism only correlated -.17 with positive affect. Similarly strong associations were observed by Watson et al. (1999), who examined these relationships in 12 samples with an overall sample size of 4.457.

Thus, there is conclusive evidence for systematic relations between personality and affective traits.

2.2 PROCESSES UNDERLYING THE RELATION BETWEEN PERSONALITY AND AFFECTIVE TRAITS

Although there are strong correlations between personality and affective traits as reported above, these findings do not imply *why* personality and affective traits are so strongly related. This issue, which also concerns the causal relationships between traits and the underlying processes, was investigated in another line of research (Elliot & Thrash, 2002; Fossum & Barrett, 2000; Gross, Sutton, & Ketelaar, 1998; Lucas & Baird, 2004; Lucas & Diener, 2001; Lucas, Diener, Grob, Suh, & Shao, 2000; Lucas & Fujita, 2000; Pavot, Diener, & Fujita, 1990; Rusting & Larsen, 1997; Watson, Clark, McIntyre, & Hamaker, 1992).

There are different explanatory models on the relation between personality and affective traits, which include indirect-effects models and temperament models (Lucas & Fujita, 2000; McCrae & Costa, 1991). These models will be reviewed and discussed in the next sections. The focus in this section will be on the relation between positive affect and extraversion because this association also constitutes the core of the empirical study in Chapter V.

Indirect-effects models

Indirect-effects models propose no direct association between extraversion and positive affect but a mediation of this relation by the interaction with social situations and the subtrait of sociability. More specifically, these models suggest a mediation of the extraversion-positive affect relation by the amount of time people spend in social situations, differences in social skills, or the person-situation fit (Argyle & Lu, 1990a; Diener, Larsen, & Emmons, 1984; Emmons, Diener, & Larsen, 1986; Pavot et al., 1990). In addition, other indirect-effects

models suggest that extraversion and positive affect may be associated due to differences in the frequency of positive life events (Headey & Wearing, 1989).

For example, one model proposes that extraverts engage more frequently in social interactions than introverts and that social interaction is associated with positive affect, regardless of whether a person is extraverted or introverted. Hence, according to this model extraverts experience more positive affect than introverts only due to the indirect effect of more social contacts. The model thus implies that extraverts and introverts should experience similar amounts of positive affect in social situations, that they should also experience similar amounts of positive affect in nonsocial situations, and that they only differ in the frequency of social interactions.

In support of this model, there is evidence that social activity is generally associated with increased levels of pleasant affect (Clark & Watson, 1988; Watson, 1988a). In addition, Pavot et al. (1990) found that both extraverts and introverts report more pleasant affect in social than in nonsocial situations. Furthermore, Argyle and Lu (1990b) observed that extraverts engage in more social situations than introverts (but see also Pavot et al., 1990). But despite this supporting evidence, there are other findings that are not compatible with such indirect-effects models. For example, Pavot et al. (1990) also found that extraverts reported more pleasant affect than introverts even when they were alone. This suggests that extraverts experience more pleasant affect than introverts, whether a situation is social or not.

This finding is not in line with congruence models either, which posit that extraverts experience more positive affect due to a better person-situation fit (Diener et al., 1984; Emmons et al., 1986). According to these models, people experience high positive affect only when the situation fits with their personality. Extraverts may enjoy social situations more than introverts because social situations fit better to the personality trait of extraversion than to introversion. Since extraverts and introverts may be similarly forced to engage in social situations by the demands of society, greater positive affect may result in extraverts because of their greater enjoyment when facing these demands

(Diener & Lucas, 1999). In addition to these environmental pressures, extraverts may also choose to engage in social interactions more frequently because these situations have been associated with pleasant affect in the past (due to a better person-situation fit). Although there is some evidence in support of these congruence models (Diener & Lucas, 1999), other findings are not in agreement with the view that a better person-situation fit explains the relation between extraversion and positive affect[3]. As described above, congruence models are not compatible with the finding that extraverts report more pleasant affect than introverts even when they are alone (Pavot et al., 1990). In addition, Diener et al. (1984) found that extraverts reported more pleasant affect whether they lived alone or with others, and whether they worked in social or in non-social occupations. Moreover, Lucas and Diener (2001) observed that extraverts rated pleasurable situations more favorably than introverts, irrespective of whether the situation was social or not.

Taken together, there is mixed support of indirect-effects models. Although several studies suggest that social interaction is a significant mediator of the extraversion-positive affect relation, there is also some evidence that social interaction cannot completely account for this association. In addition, there are findings, which suggest the need for a stronger differentiation of social situations. For example, Emmons et al. (1986) found that the correlation between extraversion and positive affect in social situations strongly depended on whether the situation was chosen by or whether it was imposed on the person. Furthermore, Lucas et al. (2000) suggested that it may be necessary to differentiate between sociability, i.e. "the tendency to enjoy social situations simply because they provide the opportunity for social interaction" (p. 466), and affiliation, i.e. the enjoyment of close interpersonal bonds. In addition, it should also be noted that there are also problematic and unpleasant social situations (Clark & Watson, 1988), which may not be crucial for the association between extraversion and positive affect. Finally, the causal direction between extraver-

[3] At least if it is presumed that social situations fit better to the trait of extraversion and being alone fits better to the trait of introversion—an assumption that seems plausible with regard to the defining characteristics of extraversion and introversion (McCrae & Costa, 1987).

sion, positive affect, and social interaction may also be reversed: high levels of state positive affect may also be associated with enhanced affiliative feelings and an increased motivation for social activities (Cunningham, 1988). Thus, positive affect may not only be the outcome of social interactions but may also serve as a motivating force to engage in social interactions.

Temperament models

In contrast to indirect-effects models, temperament models do not propose that the key mechanism that underlies the association between extraversion and positive affect is the interaction with social situations and the subtrait of sociability. Instead, these models suggest that extraverts have a temperamental susceptibility to experience greater positive affect, which is associated with their greater reward sensitivity (Elliot & Thrash, 2002; Gray, 1981; Lucas & Diener, 2001; Lucas & Fujita, 2000), i.e. their greater tendency to experience "an incentive motivational state that facilitates and guides approach behavior to a goal" (Depue & Collins, 1999, p. 495). Thus, according to temperament models, extraverts have an increased preference for social situations not because extraverts are more sociable. They prefer social situations because these situations are, on average, more rewarding and extraverts are more sensitive to these rewarding situations. This in turn implies that extraverts only have a preference for those social situations that are associated with reward and not for social situations per se. Furthermore, extraverts may also experience more positive affect in non-social situations because rewarding situations are not necessarily social situations.

It is apparent that the findings, which are compatible with indirect-effects models, are also consistent with temperament models. Extraverts and introverts may both report more pleasant affect in social than in nonsocial situations (Pavot et al., 1990) since social situations are, on average, more rewarding than non-social situations (Baumeister & Leary, 1995; Clark & Watson, 1988). Furthermore, extraverts may engage more frequently in social situations than

introverts (Argyle & Lu, 1990b) due to their greater sensitivity to rewards associated with social situations.

In addition, temperament models are also compatible with findings that are not in line with indirect-effects models. Extraverts may report more positive affect than introverts even when they are alone (Pavot et al., 1990) because they are more sensitive to rewards in non-social situations, as well. Finally, the correlations between extraversion and positive affect may not be consistent across different types of social situations (Emmons et al., 1986) because social situations are not necessarily associated with rewards. Also consistent with temperament models is the finding that reward sensitivity predicts positive affect but is unrelated to negative affect (Zelenski & Larsen, 1999). In sum, temperament models posit a greater sensitivity to rewards in extraverts than in introverts and are compatible with a large amount of findings concerning the relation between extraversion and positive affect.

After this introduction to explanatory models of the personality-affect relationship, the following chapter presents an empirical study that investigates the reproducibility of continuous arterial spin labeling, a technique that may be used for investigating the biological basis of personality and affect.

REPRODUCIBILITY OF CONTINUOUS ARTERIAL SPIN LABELING PERFUSION MRI AFTER SEVEN WEEKS

CHAPTER III

ABSTRACT

Continuous arterial spin labeling (CASL) is a non-invasive technique for the measurement of cerebral blood flow (CBF). The aim of the present study was to examine the reproducibility of CASL measurements and its suitability to consistently detect differences between groups, regions, and resting states. 38 healthy subjects (19 female) were examined at 1.5 T on two measurement occasions that were seven weeks apart. Baseline CBF was measured with eyes open and eyes closed. In different regions of interest (ROIs) the repeatability estimates varied between 9 and 19 ml/100g/min. There were no significant mean differences between occasions in all ROIs ($p > .05$). Greater CBF in the eyes-open than in the eyes-closed state was consistently present in the primary and secondary visual areas. Furthermore, CBF was consistently greater in the right than in the left hemisphere ($p < .05$) and differed between lobes and between arterial territories ($p < .001$). Finally, we consistently observed greater CBF in women than in men ($p < .001$). This study demonstrates the suitability of CASL to consistently detect differences between groups, regions, and baseline states even after seven weeks. This emphasizes its usefulness for longitudinal designs.

3.1 INTRODUCTION

Cerebral blood flow (CBF) is an important physiological parameter for the diagnosis and evaluation of neurological disorders as well as for the examination of brain function (Kessler, 2003; Wintermark et al., 2005). Several methods that either use exogenous or endogenous tracers are currently available for the measurement of CBF. For example, positron emission tomography (PET) uses exogenous tracers that are injected or inhaled. Unfortunately, this method has several disadvantages that may limit its use as a diagnostic tool. First, it requires the expensive production of the tracer. Second, the time span between repeated measurements is limited due to the half-life of the tracer. Third, the subject is exposed to ionizing radiation. Fourth, quantification of physiological units depends on arterial blood sampling and thus is invasive.

Another method for the measurement of CBF is *arterial spin labeling* (ASL), which uses magnetically labeled arterial blood water as an endogenous tracer and is based on magnetic resonance imaging (MRI) (Detre, Leigh, Williams, & Koretsky, 1992; Golay, Hendrikse, & Lim, 2004). There are several ASL techniques, which are commonly classified as continuous (CASL; Detre et al., 1992; Williams, Detre, Leigh, & Koretsky, 1992) and pulsed ASL (PASL; Edelman et al., 1994; Kim, 1995). In ASL, a perfusion weighted image is generated by subtracting an image with magnetic labeling (*label image*) from an image without this labeling (*control image*). Because this allows the non-invasive quantification of CBF without the use of ionizing radiation, most of the disadvantages of PET (high cost, invasive, ionizing radiation, limited repetition of acquisitions) do not apply to ASL measurements. Furthermore, due to the short decay rate of the endogenous tracer (the label relaxes with T_1 of arterial blood), ASL measurements may be repeated many times and in short intervals. Similar to PET, ASL allows the quantification of CBF in physiological units (ml of blood/100g of tissue/min)—both at rest as well as during activation.

Applications of ASL techniques include the diagnosis and evaluation of pathologic disorders in adults (e.g., stroke, tumor, Alzheimer's disease; Chalela et al., 2000; Johnson et al., 2005; Warmuth, Gunther, & Zimmer, 2003) and children (Oguz et al., 2003; Wang & Licht, 2006) as well as the functional imaging of CBF changes as an indicator of altered neural activity (Aguirre, Detre, & Wang, 2005; Detre & Wang, 2002; Silva & Kim, 2003). Furthermore, ASL measurements are well suitable for the evaluation of slowly developing processes and longitudinal studies (Kim et al., 2006; Olson et al., 2006; Rao, Wang, Tang, Pan, & Detre, 2006; Wang et al., 2003a). Validation studies which have been performed with PET and dynamic susceptibility contrast imaging (DSCI) show that ASL measurements are in good agreement with these standard methods (Weber et al., 2003; Ye et al., 2000).

Despite these promising findings, current ASL techniques have still not reached the capability to replace the standard invasive CBF measurement methods. One reason for this is the relatively low signal-to-noise ratio (SNR) in ASL measurements and hence, its low sensitivity. The low SNR mainly results from the low difference signal in the perfusion images, which could be as low as 1 % of the static tissue signal (Wong, Buxton, & Frank, 1999). This is particularly crucial in functional studies. In baseline CBF measurements the SNR can be increased by averaging over consecutive trials. Nevertheless, it is important to examine the reproducibility of ASL measurements over different periods of time and its suitability to consistently detect differences between groups, regions, or resting states. Recently, Parkes, Rashid, Chard, and Tofts (2004) and Floyd, Ratcliffe, Wang, Resch, and Detre (2003) using CASL and Jahng et al. (2005) and Yen et al. (2002) using PASL investigated the reproducibility of baseline CBF measurements. These studies mainly focused on interscan intervals of one week and shorter, with the exception of five subjects in the Parkes et al. (2004) study who were rescanned after several months and twelve subjects in the Yen et al. (2002) study who were rescanned after 1-4 weeks. All studies found that the reproducibility was comparable to other CBF imaging techniques such as PET or single photon emission computed tomography (SPECT). The aim of the present

study is to replicate and extend these findings with a focus on the long-term reproducibility of baseline CBF measurements. We measured baseline CBF in 38 subjects on two occasions seven weeks apart. The first issue of the study was to determine how reproducible the CASL measurements are after this period of time. We examined the reproducibility of raw CBF data for several regions of interest (ROIs): whole brain, gray and white matter, the cerebral lobes and the major arterial territories. The second issue was to investigate whether differences in CBF between groups (men and women), regions (lobes, arterial territories), and resting states (eyes open and eyes closed) that are seen in one occasion can be replicated in the second occasion seven weeks later.

3.2 METHODS

Subjects and MR acquisition

Thirty-eight right-handed subjects (19 female and 19 male, mean age = 24.5 years, *SD* = 2.3 years, range = 20-29 years) were scanned twice. The time interval was seven weeks for all participants. Before the first CASL measurement, all subjects underwent a screening interview to determine if they were suitable for MR imaging. Informed consent was obtained for all subjects. Exclusion criteria included cerebrovascular diseases, psychiatric disorders, regular medication (besides contraceptives) as well as any chronic diseases. The study was approved by the local ethics committee.

Imaging was performed on a clinical 1.5 T scanner (Intera, Philips Medical Systems, Best, The Netherlands) with a send/receive coil provided by the manufacturer. Interleaved label and control images were acquired using a single-shot spin echo EPI sequence. Thirteen slices covering the whole brain were acquired from inferior to superior (field of view [FOV] = 230 mm, matrix = 64 × 63, slice thickness = 8 mm with a 1 mm gap, bandwidth = 78.4 kHz, flip angle = 90°, TR/TE = 4125 ms/42 ms) and reconstructed to a 128 × 128 matrix. The labeling plane was placed 60 mm beneath the center of the imaging slices

(labeling duration = 2.2 s, labeling amplitude = 35 mG, labeling gradient = 0.25 G/cm). The postlabeling delay (Alsop & Detre, 1996) varied from 0.8 s to 1.8 s because each slice was acquired at a slightly different time. In order to control for magnetization transfer effects, an amplitude-modulated version of the CASL technique was used (Alsop & Detre, 1998).

In both measurement occasions baseline CBF was measured in four consecutive baselines in a scanning room which was well-lit. Each baseline consisted of 40 CASL acquisitions (scan duration: 5 min 42 s) and was acquired while the subjects kept their eyes open or closed. All subjects were randomly assigned to one of two counterbalanced orders of the eyes-open (O) and eyes-closed (C) condition (OCCO and COOC). After each baseline, there was a short break which lasted about 10 s. Before the first baseline and during the breaks, each subject was instructed by microphone to open or close his eyes, respectively.

Prior to the CASL measurement a high-resolution T_1-weighted sequence was acquired (fast field echo, 160 slices, field of view [FOV] = 256 × 192 mm, matrix = 256 × 256, slice thickness = 1 mm, TR/TE = 11.9 ms/3.3 ms, scan duration: 13 min 22 s). After the CASL measurement a T_2-weighted image was acquired in order to control for neurological abnormalities (scan duration: 2 min 43 s). The same imaging protocol was performed at both examinations except that the T_2-weighted sequence was not acquired at the second time.

Data processing

Offline data processing of CASL and T_1 images was performed with the Statistical Parametric Mapping Software (SPM2, Wellcome Department of Imaging Neuroscience, London UK, implemented in MATLAB 7, The MathWorks Inc., Natick, MA). First, we checked the data for gross artifacts. Since the lowest slice showed heavy low-intensity artifacts in all subjects, all voxels in this slice were set to zero and thereby excluded from CBF quantification. In a next step the label and control images were motion corrected using a six-parameter, rigid-body, least squares realignment routine (Friston et al., 1995a), then reoriented and coregistered to the T_1 image. It should be noted that during these

steps no interpolation was applied to the data. Instead, only a set of parameters was estimated, which was applied later on. Next, the parameters for normalization were estimated based on the T_1 image (with the default bounding box of SPM2) and transferred to the label and control images. The template for normalization was the MNI 152 subjects average brain (Montréal Neurological Institute; Mazziotta, Toga, Evans, Fox, & Lancaster, 1995). Then, the T_1 image as well as the label and control images were resampled using a 4th degree B-spline interpolation (Thévenaz, Blu, & Unser, 2000), which applied the parameters derived from realignment, reorientation, coregistration, and normalization. The CASL images were resampled to a voxel size of 1.8 × 1.8 × 9 mm and the T_1 images to 1 × 1 × 1 mm.

After these image registration steps we separately averaged over 80 label and control images, which resulted in one pair of label and control images for the eyes-open condition and one pair for the eyes-closed condition for each occasion. These mean CASL data were subsequently quantified using the following formula (Alsop & Detre, 1996):

$$CBF = \frac{(M_C - M_L)\cdot\lambda}{2M_0\cdot\alpha\cdot T_{1t}\cdot\exp\left(-\frac{\delta}{T_{1a}}\right)\left[\exp\left(\frac{\min(\delta-w,0)}{T_{1t}}\right)-\exp\left(-\frac{w}{T_{1t}}\right)\left(1-\frac{T_{1t,RF}}{T_{1t}}\right)\right]}$$

where CBF is the cerebral blood flow in ml/100g/min; M_C is the tissue magnetization in the control experiment; M_L is the tissue magnetization in the label experiment; λ is the brain-blood partition coefficient of water which was set to 0.98 for gray matter and 0.82 for white matter (Herscovitch & Raichle, 1985; Roberts, Rizi, Lenkinski, & Leigh, 1996); M_0 is the equilibrium magnetization; α is the labeling efficiency (α = .71) (Alsop & Detre, 1998); T_{1t} is the T_1 of brain tissue which was set to 1 s for gray matter and 0.6 s for white matter; δ is the assumed arterial transit time from the labeling plane to the imaged slice (δ = 1.2 s); T_{1a} is the T_1 of arterial blood (T_{1a} = 1.4 s); w is the post-labeling delay (Alsop & Detre, 1996) which varies from 0.8 s to 1.8 s because each slice is acquired at a slightly different time; $T_{1t,RF}$ is the T_1 of brain tissue in the presence of the labeling pulse which was set to 0.75 s for gray matter (Oguz et al., 2003) and

0.45 s for white matter. Since we did not measure M_0 in our subjects we used M_C instead of M_0 in order to normalize the CBF equation. To compensate for the inaccuracy that results from this procedure we calculated a correction factor which was introduced to the quantification formula. This correction factor was derived as follows: First, we collected CASL data from one subject in a separate session (80 acquisitions). In addition, we collected a further set of data from that subject with the same imaging parameters as in the CASL sequence (same TR, TE, etc.) except that labeling was completely turned off. This second data set was acquired immediately after the first acquisition and also consisted of 80 acquisitions. Since no labeling was applied and TR was set to 4.1 s this sequence should be a sufficient approximation to M_0. In a next step the CASL data as well as the M_0 data from this subject were realigned and averaged. The correction factor was then derived from the ratio of the mean brain signal in the CASL control experiment (M_C) divided by the mean brain signal in the M_0 experiment. The value for the correction factor was 0.8181.

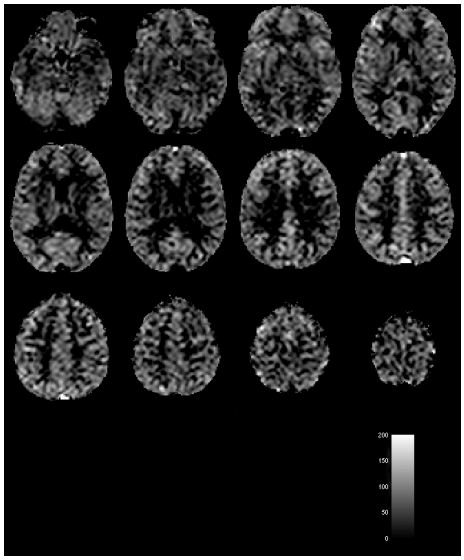

Figure 1. A quantitative CBF map of a healthy subject acquired at 1.5 T. Note: The signal in the sagittal sinus appears artificially high. However, these voxels were classified as liquor in the segmentation process and therefore removed from further analyses.

It should be noted that the quantification was performed twice, in a first run with the parameters for gray matter and in a second run with the parameters for white matter. Figure 1 shows an example of an averaged CBF map.

After quantification, the T_1 images were segmented and the resulting tissue probability maps were converted into dichotomous masks. These masks were multiplied with the CBF images which resulted in CBF maps for gray matter. Then the cerebral lobes and the major arterial territories of each hemisphere (i.e. territories for the anterior [ACA], medial [MCA] and posterior cerebral arteries [PCA]) were defined as ROIs based on published templates (Tatu, Moulin, Bogousslavsky, & Duvernoy, 1998; Tzourio-Mazoyer et al., 2002). We will refer to the former as "lobe ROIs" and to latter as "territory ROIs". Only the neocortical regions of each arterial territory were used as an ROI. Finally, the ROI masks were multiplied with the gray matter CBF images and the mean CBF in each ROI was calculated. In addition to these ROI images, the images for the voxel-based analyzes were generated as follows: for the analysis of the eyes-open compared to eyes-closed condition the unsegmented CBF images were spatially smoothed with a 6 × 6 × 12 mm full width at half maximum (FWHM) kernel. For the analyses of the effects of sex and measurement occasion we averaged over all 160 acquisitions of each measurement occasion and applied the same smoothing kernel as above.

Statistical analysis

Reproducibility was assessed in three steps: In a first step, we analyzed the within-subject standard deviation (SD_w) and the repeatability according to Bland and Altman (1996) for the mean CBF values at the two measurement occasions. In a second step, we investigated the mean differences between occasions, groups, regions, and resting states with analyses of variance (ANOVAs). In a third step, we conducted voxel-based analyses in order to investigate the specific regional CBF differences between occasions, groups, and resting states.

The within-subject standard deviation (SD_w) was estimated by the formula $SD_w = (\Sigma(y_{i1}-y_{i2})^2/2n)^{0.5}$ (Bland & Altman, 1996), where n is the number of subjects and $y_{i1}-y_{i2}$ is the difference between occasion 1 and 2 for subject i. The repeatability coefficient, which is defined as the 95 % confidence limits for the

difference between repeated measurements, was estimated by the formula $CL = \sqrt{2}*1.96*SD_w$ (Bland & Altman, 1996).

The mean differences in CBF were assessed by performing overall (i.e., a factor measurement occasion was included) and occasion-specific ANOVAs. For the overall ANOVA we included measurement occasion (first, second), hemispheres (left, right), regions (cerebral lobes/arterial territories), eye conditions (eyes-open, eyes-closed), and sex (male, female) as factors with repeated measurement on the first four. In these analyses, only the main effect of measurement occasion and all interaction effects that included the factor measurement occasion were of interest because these effects would indicate significant mean differences in gray matter CBF between occasions. The occasion-specific ANOVAs were conducted in order to evaluate whether the results of occasion 1 may be replicated on occasion 2. Therefore, we performed a hemisphere × region × eye condition × sex ANOVA with repeated measurement on the first three factors for each occasion. All ANOVAs were separately performed for the lobe ROIs and the territory ROIs.

In all ANOVAs a Huynh-Feldt correction of the degrees of freedom was performed where appropriate. Significant effects (alpha = .05) were further decomposed using *t*-tests for repeated measurements. For all main effects (with only two levels) and all *t*-tests we computed the percent change in CBF (ΔCBF). In addition, we calculated Hays' ω^2 (Hays, 1974) as a further effect size measure since it has the advantage of not only considering the absolute differences between two variables but also the variation within conditions. For example, a CBF difference of 5 % between two conditions may be considered large if there is no variation within the two conditions but may be considered small if the variation within the two conditions is very large. In addition, this allows to estimate the effect size of main effects with more than two levels as well as the effect size of interaction effects. It may be noted that Hays' ω^2 is conceptually comparable to the coefficient of determination r^2 and quantifies the portion of variance of the dependent variable (e.g., CBF in the occipital cortex) that is explained by the variation of the independent variable (e.g., eyes open vs. eyes

closed). It varies between zero and one whereas a ω^2 of zero means that the variation of the independent variable explains zero percent of the variation observed on the dependent variable. Instead, a ω^2 of one means that the variation of the independent variable completely explains the variation observed on the dependent variable. All ANOVAs and *t*-tests were performed with SPSS for Windows (Version 12.0, SPSS Inc.).

The voxel-based analyses were performed within the framework of the general linear model (Friston et al., 1995b), which is employed in SPM2. The mean (unsegmented and smoothed) CBF images were employed in random effects models. We calculated statistical parametric maps (SPMs) for CBF increases in the eyes-open compared to eyes-closed condition separately for both measurement occasions (paired *t*-test). Furthermore, we calculated SPMs for CBF decreases in the eyes-open compared to eyes-closed condition separately for both measurement occasions. For the analyses of the effects of sex we conducted two-sample *t*-tests and for the effects of measurement occasion we conducted paired *t*-tests. To minimize the contribution of extracerebral voxels, we employed an absolute CBF threshold of 5 ml/100g/min (Parkes et al., 2004) in all analyses. The significance threshold was set to $p < .01$ (uncorrected) at the voxel level. Areas of significant activation were identified at the cluster level (Forman et al., 1995) for $p < .05$ (family-wise error corrected) and cluster sizes larger than 25 voxels. Anatomical labeling was performed with the automated anatomical labeling (AAL) software described by Tzourio-Mazoyer et al. (2002). The mean CBF change in each cluster was calculated with the SPM Marsbar toolbox (Brett, Anton, Valabregue, & Poline, 2002).

3.3 RESULTS

Table 1 shows the mean CBF for the first and the second measurement occasion, which were seven weeks apart. The CBF values for each occasion represent the average of 160 acquisitions, i.e. they are aggregated over the two resting conditions. The CBF for the whole gray matter (including cortical as well as subcortical gray matter) was 72.1 ± 12.9 and 71.4 ± 12.3 ml/100g/min for the first and the second occasion, respectively. The corresponding CBF values for white matter were 41.5 ± 7.4 and 40.9 ± 7.7 ml/100g/min. The mean differences between occasions were small in all ROIs, ranging from 0.1 to 1.8 ml/100g/min.

Table 1. Mean CBF ± one Standard Deviation in ml/100g/min for both Occasions (t1 and t2), the Within-Subject Standard Deviation, and the Repeatability (α = .05)

		t1 ($M \pm SD$)	t2 ($M \pm SD$)	SD_w (ml/100g/min)	Repeatability (ml/100g/min)
Whole brain[a]		59.9 ± 11.0	59.3 ± 10.7	4.49	12.46
Gray matter[b]		72.1 ± 12.9	71.4 ± 12.3	5.42	15.03
White matter		41.5 ± 7.4	40.9 ± 7.7	3.24	8.99
Frontal lobe	left	68.6 ± 12.6	67.6 ± 12.5	6.95	19.26
	right	70.4 ± 13.0	68.6 ± 12.2	6.89	19.09
Temporal lobe	left	74.2 ± 14.2	74.3 ± 13.1	6.01	16.66
	right	76.5 ± 14.4	74.7 ± 13.6	5.59	15.50
Parietal lobe	left	72.1 ± 14.2	72.4 ± 13.2	5.77	15.99
	right	74.1 ± 14.6	73.5 ± 14.0	6.11	16.94
Occipital lobe	left	77.6 ± 15.2	78.3 ± 14.6	5.96	16.52
	right	81.2 ± 14.6	80.5 ± 14.6	6.12	16.96
ACA	left	68.5 ± 12.6	68.3 ± 12.3	6.21	17.21
	right	71.9 ± 14.0	70.5 ± 12.5	6.48	17.97
MCA	left	71.7 ± 14.5	71.0 ± 13.9	6.56	18.19
	right	73.1 ± 14.1	71.5 ± 14.2	6.00	16.62
PCA	left	73.7 ± 14.5	74.6 ± 13.7	5.78	16.01
	right	77.7 ± 14.1	76.7 ± 14.0	6.19	17.14

Note. The mean CBF in each occasion (t1 and t2) represents the average over 160 acquisitions. The sum of the territory ROIs is not equivalent to the sum of the lobe ROIs since the insula and the cingulate cortex are not represented in the lobes. ACA = arterial territory of the anterior cerebral artery; MCA = arterial territory of the medial cerebral artery; PCA = arterial territory of the posterior cerebral artery. SD_w = within-subject standard deviation; N = 38; Δt = 7 weeks.

[a] This includes neocortical and subcortical gray matter as well as white matter.

[b] This includes neocortical and subcortical gray matter (in contrast to the lobe and territory ROIs which only include neocortical gray matter).

Within-subject standard deviation and repeatability

The within-subject standard deviation and repeatability estimates are also shown in Table 1. The within-subject standard deviation varied between 3.24 ml/100g/min in white matter and 6.95 ml/100g/min in the left frontal lobe. The repeatability estimates varied between 8.99 ml/100g/min and 19.26 ml/100g/min.

Mean differences in CBF between occasions

The results of the overall ANOVA are summarized in Table 2. There were no significant effects for the lobe ROIs as well as for the territory ROIs with one exception: the interaction between measurement occasion and hemisphere reached statistical significance in the territory ROIs. However, the small effect size of this interaction ($\omega^2 = .03$) indicates that the difference between occasions is only marginal.

Table 2. Mean Differences in CBF between Occasions

	Cerebral lobes					*Arterial territories*				
	df	*F*	ε	*p*	ω^2	*df*	*F*	ε	*p*	ω^2
Occ	1,36	0.21	—	.648	.00	1,36	0.25	—	.618	.00
Occ × hemi	1,36	3.78	—	.060	.02	1,36	6.24	—	.017**	.03
Occ × region	3,108	1.19	.72	.310	.00	2,72	0.89	.69	.384	.00
Occ × eye cond	1,36	0.22	—	.644	.00	1,36	0.32	—	.573	.00
Occ × sex	1,36	0.34	—	.561	.00	1,36	0.30	—	.590	.00
Occ × hemi × region	3,108	0.91	1.00	.440	.00	2,72	0.83	1.00	.440	.00
Occ × hemi × eye cond	1,36	0.37	—	.547	.00	1,36	0.00	—	.947	.00
Occ × hemi × sex	1,36	0.01	—	.945	.00	1,36	0.02	—	.905	.00
Occ × region × eye cond	3,108	1.97	.91	.130	.00	2,72	2.28	1.00	.109	.01
Occ × region × sex	3,108	0.17	.72	.844	.00	2,72	0.05	.69	.900	.00
Occ × eye cond × sex	1,36	0.52	—	.477	.00	1,36	0.35	—	.556	.00
Occ × hemi × region × eye cond	3,108	0.56	1.00	.640	.00	2,72	1.13	.86	.323	.00
Occ × hemi × region × sex	3,108	0.74	1.00	.532	.00	2,72	2.26	1.00	.112	.01
Occ × hemi × eye cond × sex	1,36	0.38	—	.543	.00	1,36	0.10	—	.753	.00
Occ × region × eye cond × sex	3,108	0.13	.91	.930	.00	2,72	0.76	1.00	.471	.00
Occ × hemi × region × eye cond × sex	3,108	1.96	1.00	.124	.00	2,72	0.15	.86	.826	.00

Note. *F*-value, degrees of freedom (*df*) effect/error, Huynh-Feldt epsilon values (ε), Huynh-Feldt corrected *p* level, and effect size ω^2. Occ = measurement occasion; hemi = hemisphere; eye cond = eye condition (eyes open/closed). $N = 38$.
** = $p < .05$.

In sum, the overall ANOVA suggests that there were no significant differences between the occasions with the exception of a gradual difference in the asymmetry effect.

Effects of hemisphere, region, eye condition, and sex on mean CBF (ROI analyses)

Table 3 and 4 show the results of the occasion-specific ANOVAs for the lobe ROIs and the territory ROIs. Only effect sizes larger than $\omega^2 = .01$ will be considered. For the lobe ROIs there were three significant main effects, which were present in both occasions: hemisphere, lobe (region), and sex. First, CBF was generally greater in the right than in the left hemisphere (see Figure 2). The size of this asymmetry effect, however, differed between occasions and was greater in the first ($\omega^2 = .19$, ΔCBF = 3.29 %) than in the second occasion ($\omega^2 = .04$, ΔCBF = 1.64 %).

Table 3. Effects of Hemisphere, Region (Cerebral Lobes), Eye Condition, and Sex on Mean CBF

		Occasion 1				*Occasion 2*			
	df	*F*	ε	*p*	ω^2	*F*	ε	*p*	ω^2
Hemi	1,36	19.11	—	.000**	.19	4.14	—	.049**	.04
Region	3,108	45.31	.78	.000**	.47	52.32	.65	.000**	.50
Eye cond	1,36	0.11	—	.742	.00	0.05	—	.817	.00
Sex	1,36	19.29	—	.000**	.32	30.83	—	.000**	.44
Hemi × region	3,108	2.31	1.00	.080	.01	2.51	.97	.064	.01
Hemi × eye cond	1,36	1.22	—	.277	.00	0.00	—	.991	.00
Hemi × sex	1,36	0.37	—	.548	.00	0.24	—	.625	.00
Region × eye cond	3,108	13.99	.89	.000**	.11	5.25	.90	.003**	.04
Region × sex	3,108	4.57	.78	.009**	.07	3.17	.65	.049**	.04
Eye cond × sex	1,36	2.11	—	.155	.02	0.34	—	.566	.00
Hemi × region × eye cond	3,108	0.16	1.00	.921	.00	1.17	1.00	.325	.00
Hemi × region × sex	3,108	1.97	1.00	.122	.01	0.46	.97	.704	.00
Hemi × eye cond × sex	1,36	0.10	—	.758	.00	1.52	—	.226	.00
Region × eye cond × sex	3,108	2.04	.89	.120	.01	0.86	.90	.443	.00
Hemi × region × eye cond × sex	3,108	1.09	1.00	.358	.00	3.27	1.00	.024**	.01

Note: *F*-value, degrees of freedom (*df*) effect/error, Huynh-Feldt epsilon values (ε), Huynh-Feldt corrected *p* level, and effect size ω^2. Hemi = hemisphere; eye cond = eye condition (eyes open/closed). $N = 38$.
** = $p < .05$.

Second, CBF was different between lobes with the greatest values in the occipital lobe and the lowest in the frontal lobe (see Figure 2). These differences were similar in both occasions (ω^2_{t1} = .47, ω^2_{t2} = .50) and were further analyzed with *t*-tests for repeated measurements. In the first occasion all differences between lobes were significant: CBF was greater in the occipital than in the temporal lobe, greater in the temporal than in the parietal lobe, and greater in the parietal than in the frontal lobe (all $t[37] \geq 2.70$, all $p < .05$, all $\omega^2 \geq .08$, all $\Delta CBF \geq 3.10$ %). The same pattern was present in the second occasion except that the difference between the temporal and parietal lobe was not significant ($t[37] = 1.91$, $p = .064$, $\omega^2 = .03$, $\Delta CBF = 2.09$ %).

Third, CBF was significantly greater in women than in men. This effect was slightly lower in the first ($\omega^2 = .32$, $\Delta CBF = 23.63$ %) than in the second ($\omega^2 = .44$, $\Delta CBF = 26.44$ %) occasion (see Figure 3).

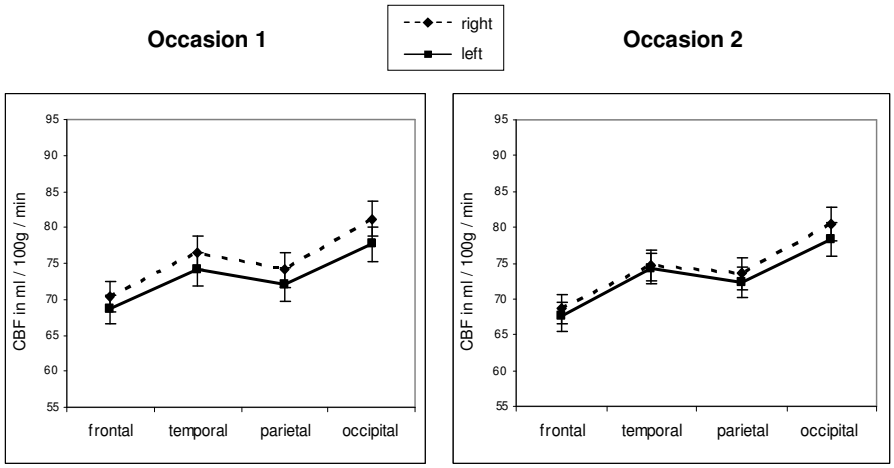

Figure 2. Hemispheric asymmetries in mean CBF for both occasions. CBF is significantly greater in the right than in the left hemisphere (occasion 1 and 2). Error bars represent ± one standard error (N = 38).

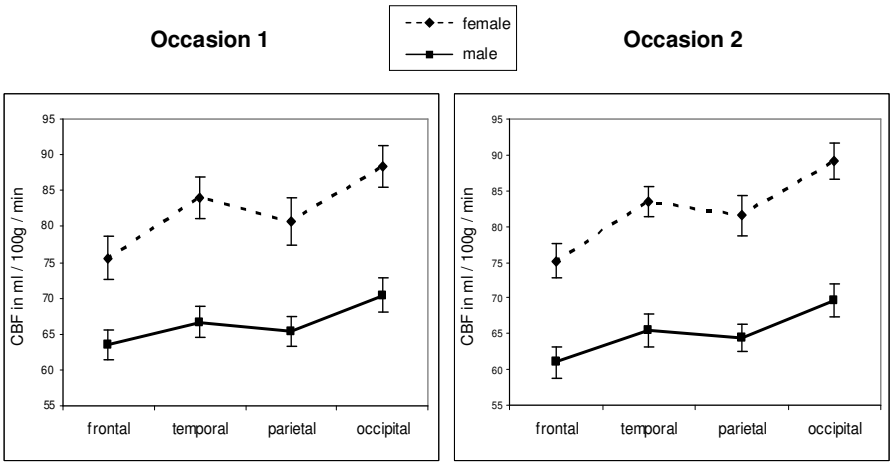

Figure 3. Mean CBF in women (n = 19) and men (n = 19) for both occasions. CBF is significantly greater in women than in men (occasion 1 and 2). Error bars represent ± one standard error.

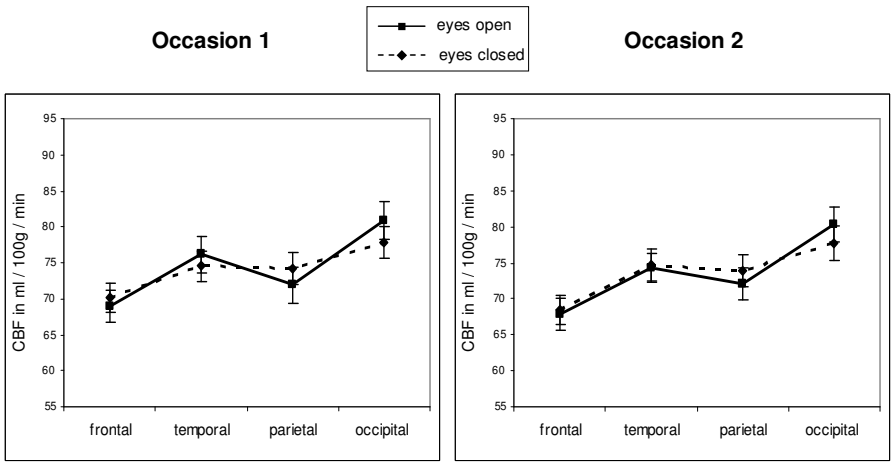

Figure 4. Mean CBF in the eyes-open compared to the eyes-closed condition for both occasions. Significant differences are present in the occipital lobe (occasion 1 and 2) and in the parietal lobe (occasion 1). Error bars represent ± one standard error (N = 38).

Furthermore, two interaction effects reached statistical significance in both occasions. First, there was a significant interaction between lobes and eye conditions (see Figure 4). Subsequent *t*-tests for both occasions showed that there was no significant difference between the eyes-open and eyes-closed state in the frontal and temporal lobes (all $t[37] \leq 1.77$, all $p \geq .085$, all $\omega^2 \leq .03$, all $\Delta CBF \leq 2.10$ %). For the parietal lobe the effect of eye condition was slightly different between occasions. In the first occasion there was a significantly greater CBF in the eyes-closed than in the eyes-open condition ($t[37] = 2.53$, $p = .016$, $\omega^2 = .07$, $\Delta CBF = 3.19$ %) whereas this effect was only descriptively present in the second occasion ($t[37] = 1.79$, $p = .082$, $\omega^2 = .03$, $\Delta CBF = 2.50$ %). For the occipital lobe there was a significantly greater CBF in the eyes-open than in the eyes-closed condition. This effect was present in both occasions but was more pronounced in the first ($t[37] = 3.10$, $p = .004$, $\omega^2 = .10$, $\Delta CBF = 3.83$ %) than in the second ($t[37] = 2.25$, $p = .031$, $\omega^2 = .05$, $\Delta CBF = 3.47$ %).

Second, there was a significant interaction between lobes and sex. Subsequent *t*-tests for both occasions showed that in women CBF was significantly greater in the temporal than in the parietal lobe in the first occasion ($t[18] = 2.74$, $p = .013$, $\omega^2 = .15$, $\Delta CBF = 4.00$ %) and descriptively greater in the second occasion ($t[18] = 1.77$, $p = .093$, $\omega^2 = .05$, $\Delta CBF = 2.54$ %). However, no such differences were present in men (all $t[18] \leq 1.10$, all $p \geq .287$, all $\omega^2 \leq .01$, all $\Delta CBF \leq 2.00$ %). Taken together, the analyses for the lobe ROIs show that the effects of hemisphere, region, eye condition, and sex on CBF are reproducible after a period of seven weeks. In addition, it was shown that the size of these effects may differ between occasions.

The effects for the territory ROIs (Table 4) were similar to the effects of the lobe ROIs. The same main effects reached statistical significance: hemisphere, sex, and region. As in the lobe ROIs, CBF was generally greater in the right than in the left hemisphere and generally greater in women than in men. Furthermore, all differences between regions were significant in both occasions (all $t[37] \geq 3.20$, all $p \leq .003$, all $\omega^2 \geq .11$, all $\Delta CBF \geq 2.74$ %). CBF was greater in the

posterior than in the medial territory and greater in the medial than in the anterior territory (see Figure 5).

Table 4. Effects of Hemisphere, Region (Arterial Territories), Eye Condition, and Sex on Mean CBF

		Occasion 1				*Occasion 2*			
	df	*F*	ε	*p*	ω^2	*F*	ε	*p*	ω^2
Hemi	1,36	30.21	—	.000**	.28	9.41	—	.004**	.10
Region	2,72	20.34	.67	.000**	.25	27.61	.65	.000**	.32
Eye cond	1,36	0.23	—	.638	.00	0.05	—	.821	.00
Sex	1,36	19.63	—	.000**	.33	30.13	—	.000**	.43
Hemi × region	2,72	8.15	.96	.001**	.06	2.86	1.00	.064	.02
Hemi × eye cond	1,36	0.90	—	.349	.00	1.22	—	.277	.00
Hemi × sex	1,36	0.06	—	.810	.00	0.13	—	.717	.00
Region × eye cond	2,72	19.13	1.00	.000**	.14	4.16	.84	.026**	.03
Region × sex	2,72	2.35	.67	.123	.02	2.05	.65	.155	.02
Eye cond × sex	1,36	2.40	—	.130	.02	0.53	—	.470	.00
Hemi × region × eye cond	2,72	0.47	.82	.590	.00	1.33	1.00	.272	.00
Hemi × region × sex	2,72	4.06	.96	.023**	.03	0.10	1.00	.908	.00
Hemi × eye cond × sex	1,36	0.03	—	.872	.00	0.12	—	.730	.00
Region × eye cond × sex	2,72	7.46	1.00	.001**	.05	1.84	.84	.173	.01
Hemi × region × eye cond × sex	2,72	3.71	.82	.038**	.01	1.20	1.00	.308	.00

Note. *F*-value, degrees of freedom (*df*) effect/error, Huynh-Feldt epsilon values (ε), Huynh-Feldt corrected *p* level, and effect size ω^2. Hemi = hemisphere; eye cond = eye condition (open/closed). $N = 38$.
** = $p < .05$.

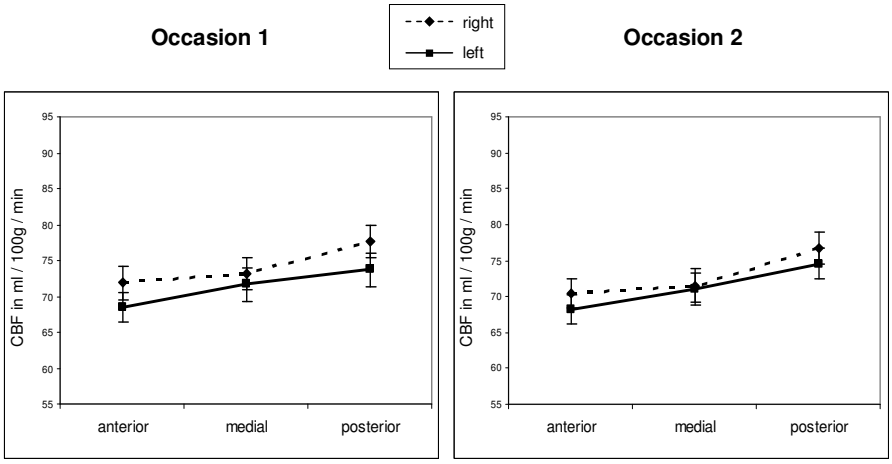

Figure 5. Mean CBF in the major arterial territories for both occasions. CBF is significantly greater in the posterior than in the medial territory and significantly greater in the medial than in the anterior territory (occasion 1 and 2). Error bars represent ± one standard error ($N = 38$).

The interaction effects partially differed from the interaction effects that were present in the lobe ROIs. First, there was a significant interaction between hemisphere and region, which only reached statistical significance in the first occasion. Subsequent *t*-tests showed that a significantly greater CBF in the posterior than in the medial territory was only present in the right hemisphere ($t[37] = 4.40$, $p < .001$, $\omega^2 = .19$, $\Delta CBF = 6.27$ %) but not in the left ($t[37] = 1.78$, $p = .084$, $\omega^2 = .03$, $\Delta CBF = 2.83$ %). Furthermore, the asymmetry effect (right greater than left) was present in all territories (all $t[37] \geq 2.07$, all $p \leq .045$, all $\omega^2 \geq .04$, all $\Delta CBF \geq 1.94$ %) aside from the medial territory in the second occasion ($t[37] = 0.59$, $p = .558$, $\omega^2 = .00$, $\Delta CBF = 0.69$ %).

Second, there was a significant interaction between region and eye condition that was present in both occasions. However, the effect size was greater in the first than in the second occasion ($\omega^2_{t1} = .14$, $\omega^2_{t2} = .03$). Subsequent *t*-tests showed that the only significant difference between the eyes-open and eyes-closed condition was in the posterior territory of the first occasion ($t[37] = 3.55$, $p = .001$, $\omega^2 = .13$, $\Delta CBF = 3.96$ %). In this region CBF was significantly greater in the eyes-open than in the eyes-closed condition.

Third, there was a significant interaction between hemisphere, region, and sex in the first occasion. Subsequent *t*-tests showed that a significantly greater CBF in the right than in the left posterior territory was only present in men ($t[18] = 2.50$, $p = .022$, $\omega^2 = .12$, $\Delta CBF = 7.39$ %) but not in women ($t[18] = 1.69$, $p = .108$, $\omega^2 = .05$, $\Delta CBF = 3.75$ %).

Fourth, there was a significant interaction between region, eye condition, and sex in the first occasion. Subsequent *t*-tests showed that a significantly greater CBF in the eyes-open than in the eyes-closed condition in the posterior territory was only present in women ($t[18] = 3.33$, $p = .004$, $\omega^2 = .21$, $\Delta CBF = 3.87$ %). In should be noted, however, that this effect was descriptively present in men, too ($t[18] = 1.94$, $p = .068$, $\omega^2 = .07$, $\Delta CBF = 4.07$ %). Taken together, most effects were reproducible for the territory ROIs. However, those effects with a smaller ω^2 effect size were only present in the first occasion.

Voxel-based analyses

Figure 6 and Table 5 show the results for the eye conditions. In both occasions there were significant CBF increases in the primary and secondary visual areas (BA 17,18) in the eyes-open compared to the eyes-closed condition. Areas of decreased CBF were only present in the first occasion and were located at the left insula and the left inferior frontal gyrus. For the effects of sex there was one large cluster in each occasion that expanded over the whole brain volume (occasion 1: k = 20083 voxels, occasion 2: k = 24425 voxels). Women showed greater CBF than men in the whole brain whereas men showed no significant CBF increase compared to women. For the effect of measurement occasion there were no significant CBF changes (neither for the t1 > t2 contrast nor for the t2 > t1 contrast).

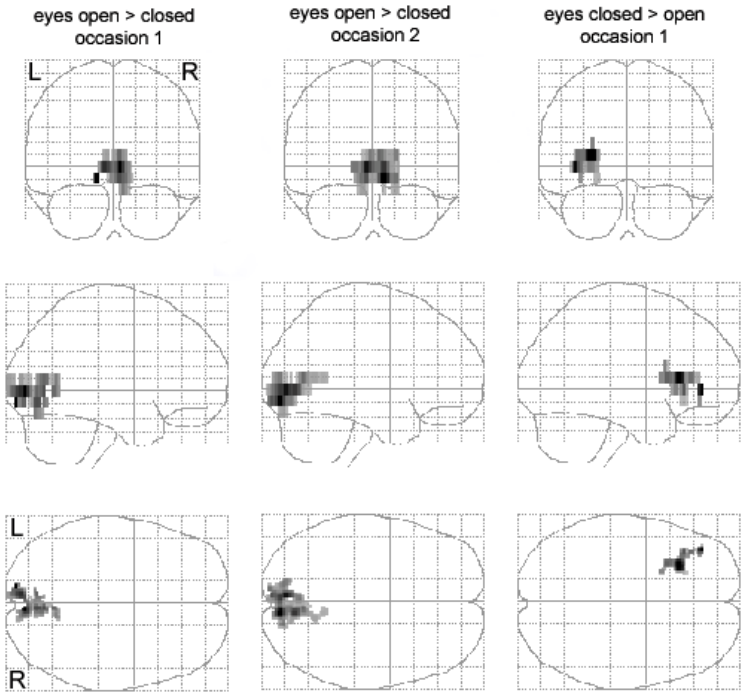

Figure 6. Regions of significant CBF increases and decreases in the eyes-open vs. eyes-closed condition (p < .01, cluster size > 25 voxels, N = 38). In the second occasion there were no significant CBF decreases in the eyes-open compared to the eyes-closed condition.

Table 5. Clusters of Significant CBF Changes in the Eyes-Open Compared to the Eyes-Closed Condition

Anatomical region	BA	Cluster size	MNI coordinates			*Z* value	% CBF change	Δ CBF (abs.)
			x	*y*	*z*			
Activations								
Occasion 1								
Bilateral lingual gyrus, bilateral calcarine fissure and surrounding cortex	17,18	168	5	-85	0	5.01	12.8	11.0
			-13	-92	-9	4.82		
			-7	-88	0	4.35		
Occasion 2								
Bilateral lingual gyrus, bilateral calcarine fissure and surrounding cortex	17,18	343	9	-85	-9	4.68	10.8	9.1
			-5	-81	0	4.30		
			9	-74	0	4.03		
Deactivations								
Occasion 1								
Left insula, left inferior frontal gyrus (triangular part)	47,48	101	-29	25	9	3.82	-9.6	-5.9
			-40	43	0	3.67		
			-38	29	0	3.12		
Occasion 2		—						

Note. Anatomical labels of each cluster are given according to Tzourio-Mazoyer et al. (Tzourio-Mazoyer et al., 2002). MNI coordinates and *Z* values are reported of (maximum 3) local maxima that were at least 8 mm apart. The mean CBF change within each cluster is shown in relative (%) as well as absolute units (ml/100g/min). BA = Brodmann area.

3.4 DISCUSSION

Arterial spin labeling is a promising technique for the non-invasive measurement of CBF. One major limitation, however, is its relatively low SNR and hence its low sensitivity. The aim of the present study was to examine the reproducibility of baseline CBF measurements over a period of seven weeks and its suitability to consistently detect differences between groups, regions, and resting states.

An initial analysis indicated that the CBF data for gray matter were well in accordance with the CBF data published in other CASL studies (Alsop & Detre, 1998; Ye et al., 2000). CBF in white matter was higher compared to these CASL studies but was still in the upper range of other CASL studies (Calamante, Thomas, Pell, Wiersma, & Turner, 1999). Although the standard deviation in

white matter is smaller than in gray matter the coefficients of variation (CV = *SD*/mean) are similar, which indicates that the variability between subjects was comparable in gray and white matter. It should be noted that the correction factor, which we applied in the CBF quantification was derived from the mean brain signal and thus does not capture differences between gray and white matter. Therefore, it may be expected that CBF in gray matter will be slightly underestimated and that CBF in white matter will be slightly overestimated. Furthermore, since the CBF formula used is only valid if the difference between the labeling duration and the transit time is much greater than $T_{1t,RF}$—which is not fully satisfied in our implementation—the calculated CBF values are biased. The quality of the mean CBF images (see Figure 1) was also comparable with other CASL studies at 1.5 T (Alsop & Detre, 1996; Ye et al., 2000).

Within-subject standard deviation and repeatability

To examine the reproducibility of the CASL measurements we calculated the within-subject standard deviation and the repeatability. These analyses indicate that even after seven weeks we can be 95 % confident that the difference between repeated measurements of whole brain CBF will be 12 ml/100g/min or smaller. Our results are thus well comparable with the reproducibility analysis of Floyd et al. (2003). In particular, our repeatability estimates are similar to their estimates based on a one hour interval and are even slightly smaller than their estimates based on a one week interval. This suggests that the reproducibility of CASL measurements after seven weeks is not diminished compared to shorter time intervals but is well comparable with repeated measurements after one week or shorter. The reproducibility results of the Parkes et al. (2004) study cannot be directly compared with our results since Parkes et al. used relative CBF changes in contrast to absolute CBF changes. In ten subjects who were rescanned after 20 minutes they found repeatability estimates of 7.6 % in whole brain, 7.1 % in gray matter and 9.6 % in white matter.

Effects of measurement occasion, hemisphere, region, eye condition, and sex

We further assessed the reproducibility of CASL measurements by investigating the effects of measurement occasion and the suitability to consistently detect differences in CBF between hemispheres, regions, eye conditions, and sex. The overall ANOVAs and the voxel-based analyses for the effects of measurement occasion indicated that there were no significant CBF differences between occasions (with the exception of a small difference in the asymmetry effect). These results support the repeatability analysis and further demonstrate the good reproducibility of the CASL measurements.

Our occasion-specific ANOVAs revealed an increased CBF in the right compared to the left hemisphere. Although the size of this asymmetry was significantly different between occasions as indicated by the overall ANOVA, the effect was present in both occasions. Previous PET (Perlmutter, Powers, Herscovitch, Fox, & Raichle, 1987) and SPECT (Catafau et al., 1996; Hagstadius & Risberg, 1989; Van Laere et al., 2001) studies also observed this global asymmetry whereas it was not present in some CASL studies (Floyd et al., 2003; Parkes et al., 2004). Whether these asymmetries in CBF reflect anatomical, cytoarchitectonic, or functional asymmetries and how they are related to variables such as age or mental functions is still a matter of research (Van Laere et al., 2001; Wager, Phan, Liberzon, & Taylor, 2003).

We further observed greater CBF in posterior than in anterior neocortical regions. This effect was almost identical in both occasions as indicated by the similar ω^2 effect sizes. Moreover, the effect was present in both hemispheres and was similar in men and women. Previous baseline CBF studies partially support this observation. While some studies also found greater CBF in anterior than in posterior regions (Devous, Stokely, Chehabi, & Bonte, 1986; Hendrikse, van der Grond, Lu, van Zijl, & Golay, 2004; Van Laere et al., 2001) other studies found greater CBF in anterior than in posterior regions (Floyd et al., 2003; Matthew et al., 1993; Parkes et al., 2004) or found no difference (Leenders et al., 1990). One explanation for greater CBF in posterior than in anterior regions in our study

could be differences in blood transit times between these regions. If this was the case, then we would expect larger transit times in frontal compared to posterior regions. Unfortunately, the transit time values reported in the literature are not consistent. While some studies found greater transit times in posterior than in anterior regions (Figueiredo, Clare, & Jezzard, 2005; Wong, Buxton, & Frank, 1997), another study found the opposite pattern (Wang et al., 2003b). Since we did not measure the transit times in our study, it cannot be finally assessed whether the greater CBF in posterior compared to anterior regions is due to different blood transit times.

Our analyses of variance also revealed that there was a consistently greater CBF in the eyes-open compared to the eyes-closed state, which was only present in the occipital lobe. In addition, the voxel-based analyses showed that the significant foci in the occipital lobe are located in the primary and secondary visual areas. This effect may be expected since the visual stimulation that was present in the eyes-open compared to the eyes-closed state should yield an increased neural activity and hence an increased CBF in these visual areas. In addition, these results are consistent with studies using functional MRI (Marx et al., 2004) and pulsed ASL (Uludag et al., 2004). In the posterior arterial territory, however, this effect was not reproducible. This instability may be due to a lower specificity of the posterior territory for the primary and secondary visual areas (Tatu et al., 1998) and is thus more prone to influences that are not related to visual stimulation.

Furthermore, we found a greater CBF in the eyes-closed than in the eyes-open condition in the parietal lobe. This effect was present in both occasions; however, in the second occasion it was not significant due to the smaller effect size. The voxel-based analyses revealed one significant cluster in the left insula and left inferior frontal gyrus that was specific for the first occasion. The greater activation in the eyes-closed compared to the eyes-open condition may be attributable to different mental states during these conditions. As suggested by Marx et al. (2003) the eyes-closed state may be associated with an “interoceptive” state that is characterized by imagination and multisensory activity whereas

the eyes-open state may be associated with an "exteroceptive" state that is characterized by attention and ocular motor activity. Marx et al. (2003) found greater activation in the visual (aside from the primary visual area), somatosensory, vestibular, and auditory cortical areas as well as in the medial frontal gyri when subjects were examined in a darkened room with their eyes closed compared to having their eyes open. This line of reasoning suggests that the greater activation that we found in the eyes-closed condition may be attributable to the "interoceptive" compared to the "exteroceptive" state.

Finally we observed an increased CBF in women compared to men, which was independent of the region and hemisphere (as indicated by the occasion-specific ANOVAs and the voxel-based analyses). This sex effect was present in both occasions and was also reported in previous CASL studies (Floyd et al., 2003; Parkes et al., 2004). Although other CBF imaging techniques (Devous et al., 1986; Gur et al., 1982; Rodriguez, Warkentin, Risberg, & Rosadini, 1988) support this observation—which suggests that it is not a technical artifact of the CASL technique—it cannot be excluded that the sex effect may be partly due to different T_1 parameter in men and women. Independent of the measurement technique, factors such as differences in brain volume or influences of different estrogen levels may contribute to the sex difference in CBF as well (Rodriguez et al., 1988).

In summary the effects of hemisphere, region, eye condition, and sex on baseline CBF could be replicated even after seven weeks. Together with the results of the repeatability analysis this indicates a good reproducibility of baseline CBF measurements at 1.5 T. This extends the results from previous studies that also found a good reproducibility of CASL and PASL measurements but mainly focused on interscan intervals of one week and shorter (Floyd et al., 2003; Jahng et al., 2005; Parkes et al., 2004; Yen et al., 2002). In addition, the present study not only demonstrates a good reproducibility of CASL measurements in different areas but also demonstrates a good reproducibility of differences between regions, groups, and resting states.

Together with the non-invasiveness of the measurement, the ability for absolute quantification, and the absence of baseline drifts (Aguirre, Detre, Zarahn, & Alsop, 2002) CASL baseline CBF measurements may be a suitable method for the comparison of different groups (such as clinical vs. control groups). Moreover our results underline the usefulness of CASL for longitudinal studies. This makes CASL appealing for the study of disease progression, for the monitoring of clinical interventions, or for the examination of slowly developing processes such as some learning processes (Olson et al., 2006).

THE LATENT STATE-TRAIT STRUCTURE OF CEREBRAL BLOOD FLOW IN A RESTING STATE

CHAPTER IV

ABSTRACT

Cerebral blood flow (CBF) is an important physiological parameter for the examination of brain functions. The aim of the present paper is to examine whether CBF in a resting state reflects a stable latent trait and is thus a sound target for the investigation of the biological basis of personality. Continuous arterial spin labeling was used to measure baseline CBF in 38 healthy subjects on two measurement occasions that were seven weeks apart. Data were analyzed within the methodological framework of latent state-trait theory, which allows the decomposition of the measured variables into temporally stable differences, occasion-specific fluctuations, and measurement errors. For most of the regions of interest, about 70 % of the observed variance was determined by individual differences on a latent trait whereas about 20 % of the variance was due to situational influences. This suggests that baseline CBF measurements predominately reflect a stable latent trait that is superimposed by occasion-specific fluctuations and by measurement errors. Baseline CBF measurements are thus suited to examine the biological basis of personality traits.

4.1 INTRODUCTION

In 1937, Gordon W. Allport conceptualized personality traits as "generalized neuropsychic systems". According to Allport, traits can be considered as "cortical, subcortical, or postural dispositions having the capacity to gate or guide specific phasic reactions" (Allport, 1966, p. 3). Since these pioneering conceptualizations, several lines of research have investigated the biological basis of personality traits. Studies have been conducted that link the effects of brain damage (Berlin, Rolls, & Kischka, 2004; Chow, 2000), individual differences in gene polymorphisms (Ebstein, 2006; Munafo et al., 2003), or indicators of tonic brain activity (Coan & Allen, 2004; Matthews & Gilliland, 1999) to personality traits or personality changes. For example, in his prominent psychophysiological theory of personality Eysenck (1967) proposed that extraverts are characterized by a tonic hypoactivity or hyposensitivity of the reticulo-thalamo-cortical pathways whereas introverts are characterized by a tonic hyperactivity or hypersensitivity of this neural system. This theory stimulated extensive research but the pattern of results appears inconsistent (Matthews & Gilliland, 1999). The reasons for these inconsistencies may be manifold (Eysenck, 1994), however, one critical aspect in psychophysiological studies of personality is the trait property of the indicator of tonic brain activity. In particular, if a neurophysiological measure mainly reflects situational fluctuations rather than a stable and consistent characteristic of the organism, then it may not be a sound target for the investigation of the biological basis of personality traits. Thus, an analysis of the trait property of these measures is helpful in interpreting and planning psychophysiological studies of personality.

Baseline cerebral blood flow and personality

In the last 25 years, one promising neurophysiological measure of brain activity, i.e. cerebral blood flow (CBF) in a resting state, was used in several

studies to investigate the biological basis of personality traits. Table 6 gives an overview over these studies (it should be noted that clinical studies are not included in this list; for reviews of clinical studies, see Kennedy, Javanmard, & Vaccarino, 1997; Mathew & Wilson, 1990). The personality traits that were most often examined were extraversion/introversion and neuroticism. As can be seen in Table 6, although there is some convergence among studies, there are also some inconsistencies in the results, which need for an explanation. In particular, while one study found a relation between extraversion/introversion and global baseline CBF in the dorsolateral cortex (Mathew, Weinman, & Barr, 1984), others found associations for specific areas that were not consistent among studies (Ebmeier et al., 1994; Johnson et al., 1999; O'Gorman et al., 2006; Stenberg, Risberg, Warkentin, & Rosén, 1990; Stenberg, Wendt, & Risberg, 1993). Furthermore, no association was found between baseline CBF and neuroticism (Ebmeier et al., 1994; Mathew et al., 1984; O'Gorman et al., 2006; Stenberg et al., 1990). The missing or inconsistent findings of these studies could be more clearly understood if we knew to what extent baseline CBF reflects a trait of the person and to what extent it is influenced by situational effects—such as phasic changes in the hormonal status, partial pressure of carbon dioxide (P_aCO_2), cardiac and respiratory rates, or neuronal activity (Ito, Kanno, & Fukuda, 2005; Krause, Duckles, & Pelligrino, 2006). In particular, if baseline CBF only poorly reflects a trait and strongly varies between situations, then the same subject would provide different CBF measurements in different studies although the personality traits of this subject would be fairly stable (Roberts, Caspi, & Moffitt, 2001; Vaidya, Gray, Haig, & Watson, 2006). The relation between baseline CBF and personality traits would thus depend on the specific situational conditions that are present in a particular study and inconsistent findings among studies would be expected.

Table 6. Overview of Studies on Baseline CBF and Personality Traits

Authors	Participants	Personality trait	Personality trait measure	Imaging technique	Regions analyzed	Significant associations found
Carlsson et al. (2000)	24 men (M = 23 y)	Anxiety (A) Creativity (C)	STAI CFT	133-xenon	Frontal, temporal, parietal, and occipital areas (mean relCBF), hemispheres (mean CBF)	A: no significant association to hemispheric CBF and prefrontal relCBF C: greater hemispheric (left and right) CBF in highly vs. low creative subjects
Ebmeier et al. (1994)	12 men, 21 women (M = 54 y)	Extraversion/ Introversion (E/I) Neuroticism (N) Psychoticism (P)	EPQ	SPECT	Frontal, temporal, and parietal areas, basal ganglia, thalamus, ACC (mean relCBF acquired on 2 slices)	E/I: ACC N: no significant associations P: no significant associations
Johnson et al. (1999)	10 men, 8 women (M = 29 y)	Extraversion/ Introversion (E/I)	NEO-FFI	PET	Whole brain (voxel-based analysis)	E: temporal lobes, ACC, posterior thalamus, right posterior insula, left amygdala I: frontal areas, right anterior temporal cortex, anterior thalamus, left hippocampus, right anterior insula/ putamen, left MCC
Mathew et al. (1984)	51 women (M = 32 y)	Extraversion/ Introversion (E/I) Neuroticism (N)	EPI	133-xenon	Frontal, temporal, parietal, and occipital areas, hemispheres (mean CBF)	E/I: all areas N: no significant associations
O'Gorman et al. (2006)	15 men, 15 women (M = 28 y)	Extraversion/ Introversion (E/I) Neuroticism (N) Psychoticism (P) Novelty seeking (NS) Harm avoidance (HA) Persistence (PS)	EPQ-R TCI	CASL	Whole brain (voxel-based analysis)	E/I: basal ganglia, thalamus, inferior frontal gyrus, cerebellum, cuneus N: no significant associations P: right thalamus, right basal ganglia NS: cerebellum, left thalamus, cuneus HA: cerebellum, cuneus, medial frontal gyrus PS: basal ganglia
Stenberg et al. (1990)	19 men, 18 women (M = 34 y)	Extraversion/ Introversion (E/I) Neuroticism (N)	EPI	133-xenon	Frontal, temporal, parietal, and occipital areas (mean relCBF), global CBF (mean CBF)	E/I: greater temporal relCBF for I than for E; greater relCBF for E than for I in left area of Broca N: no significant associations
Stenberg et al. (1993)	8 men, 9 women (M = 29 y)	Extraversion/ Introversion (E/I) Anxiety (Anx) Impulsivity (IM)	EPI KSP	133-xenon	Frontal, temporal, parietal, and occipital areas (mean relCBF), global CBF (mean CBF)	E/I: greater temporal relCBF for I than for E; significant association between I and global CBF in women Anx: significant association between temporal relCBF and anxiety IM: no significant associations

Table 6. (continued)

Authors	Participants	Personality trait	Personality trait measure	Imaging technique	Regions analyzed	Significant associations found
Sugiura et al. (2000)	13 men, 17 women (range 26-62 y)	Novelty seeking (NS) Harm avoidance (HA) Reward dependence (RD)	TCI[a]	SPECT	Whole cortex (voxel-based analysis)	NS: left ACC, insula HA: several frontal, temporal, parietal, and paralimbic areas RD: several frontal, temporal, and paralimbic areas
Tankard et al. (2003)	30 men (*M* = 68 y)	Anxiety	STPI	SPECT	Prefrontal areas, hemispheres (mean relCBF)	No significant associations
Turner et al. (2003)	20 men (range 20-33)	Novelty seeking (NS) Harm avoidance (HA) Reward dependence (RD) Persistence (PS) Self directedness (SD) Cooperativeness (CO) Self transcendence (ST)	TCI	SPECT	Whole brain (voxel-based analysis)	Several associations are reported for each of the analyzed traits.
Zald et al. (2002)[b]	Sample 1: 28 men, 23 women (range 18-50 y); Sample 2: 24 men, 14 women (range 19-55 y)	Negative affect	PANAS	PET	Whole brain (voxel-based analysis)	Sample 1: ventromedial prefrontal cortex, left parainsular region Sample 2: ventromedial prefrontal cortex

Note. Cerebral blood flow (CBF) was always recorded in a resting situation and was reported in absolute values or relative to a reference value (relCBF). CBF was either measured with the 133-xenon inhalation technique, single-photon emission computed tomography (SPECT), positron emission tomography (PET), or with continuous arterial spin labeling (CASL).

The personality traits were assessed with the Spielberger state-trait anxiety inventory (STAI, Spielberger, 1983), Creative Functioning Test (CFT, Smith & Carlsson, 1990), Eysenck Personality Questionnaire (EPQ, Eysenck & Eysenck, 1975), NEO Five-Factor Inventory (NEO-FFI, Costa & McCrae, 1992), Eysenck Personality Inventory (EPI, Eysenck, 1968), Revised Eysenck Personality Questionnaire (EPQ-R, Eysenck & Eysenck, 1991), Temperament and Character Inventory (TCI, Cloninger, Przybeck, Svrakic, & Wetzel, 1994), Karolinska Scales of Personality (KSP, Schalling, Edman, & Åsberg, 1983), State-Trait Personality Inventory (STPI, Spielberger, 1979), and Positive and Negative Affect Scales (PANAS, Watson, Clark, & Tellegen, 1988).

y = years, ACC = anterior cingulate cortex, MCC = medial cingulate cortex.

[a] A Japanese version of the TCI was used (Kijima et al., 1996).

[b] Forty-two of the subjects in the first sample, and 17 of the subjects in the second sample received two or more resting scans that were averaged together before analysis.

Methodological problems and the latent state-trait (LST) theory

In order to examine this issue, it is necessary to examine to what extent do baseline CBF measurements reflect a stable physiological trait, the effects of the situation, and measurement error. A common applied methodological framework in psychophysiological studies is classical test theory, which allows the distinction between measurement error and true score. However, a major problem in classical test theory is that the effects of a specific situation and the person-situation interaction are treated as part of the measurement error and are thus confounded. A consequence for CBF studies is that the error variance may comprise physiologically meaningful information that cannot be identified within this methodological framework. To overcome this problem, one established approach is the latent state-trait (LST) theory, which was developed by Steyer and colleagues (Steyer, Ferring, & Schmitt, 1992; Steyer, Schmitt, & Eid, 1999). The LST theory can be regarded as an extension of classical test theory and takes into account that no measurement takes place in a situational vacuum. Whereas in classical test theory the observed variables (e.g., CBF) are decomposed into a true score and measurement errors, in LST theory the decomposition is performed in two stages: in a first step, the observed variables are decomposed into a latent (i.e. not observed) state and into measurement errors. In a second step, the latent state is decomposed into a latent trait, and into occasion-specific residuals, which represent the effects of the situation and the person-situation interaction on the latent state. The two step decomposition of the observed variables thus allows the distinction between temporally stable differences, occasion-specific fluctuations, and measurement errors.

To estimate the variances of these latent variables, the observed variables have to be assessed with at least two indicators on at least two measurement occasions. Then the LST models can be analyzed with techniques of structural equation modeling. In addition to several psychological measures (Steyer et al., 1999), LST theory has also been successfully applied to biological measures such as EEG asymmetry (Hagemann, Hewig, Seifert, Naumann, & Bartussek, 2005;

Hagemann, Naumann, Thayer, & Bartussek, 2002) and saliva cortisol (Hellhammer et al., 2007; Kirschbaum et al., 1990).

Measurement of cerebral blood flow with arterial spin labeling (ASL)

One promising method for the measurement of CBF is arterial spin labeling (ASL), which is based on magnetic resonance imaging (MRI) and uses magnetically labeled arterial blood water as an endogenous tracer (Detre et al., 1992; Liu & Brown, 2007). There are several ASL techniques, which are commonly classified as continuous (CASL; Detre et al., 1992; Williams et al., 1992) and pulsed ASL (PASL; Edelman et al., 1994; Kim, 1995). In ASL, the perfusion contrast is given by the difference in magnetization between an image acquired with magnetic label and an image without the label (control image). This permits the non-invasive quantification of CBF in the physiological unit ml of blood/100g of tissue/min—both in a resting state as well as during activation. Furthermore, due to its non-invasive nature and the short decay rate of the endogenous tracer (the label relaxes with T_1 of arterial blood), ASL measurements may be repeated many times and in short intervals. Therefore, ASL is well suitable for longitudinal studies, and the examination of slowly developing processes (Aguirre et al., 2002; Wang et al., 2003a). Validation studies which have been performed with positron emission tomography (PET) and dynamic susceptibility contrast imaging (DSCI) show that ASL measurements are in good agreement with these standard methods (Wolf et al., 2003; Ye et al., 2000).

The present study

The aim of the present study is to analyze continuous ASL (CASL) baseline CBF measurements in terms of LST theory. This allows the evaluation to what extent the baseline CBF measurements reflect a physiological trait and to what extent situational variables influence the measurement.

4.2 METHODS

Subjects and MR acquisition

Thirty-eight right-handed subjects (19 females and 19 males, mean age = 24.5 years, *SD* = 2.3 years, range = 20-29 years) were scanned on two measurement occasions separated by seven weeks. Prior to the first CASL measurement, all subjects underwent a screening interview in order to assess if they were suitable for MR imaging. The study was approved by the local ethics committee and informed consent was provided by all subjects. Exclusion criteria included cerebrovascular diseases, psychiatric disorders, regular medication (besides contraceptives) as well as any chronic diseases.

A detailed description of the imaging protocol for the present sample is reported by Hermes et al. (2007). In short, imaging was performed on a clinical 1.5 T scanner (Intera, Philips Medical Systems, Best, The Netherlands) with a send/receive coil provided by the manufacturer. Interleaved label and control images were acquired using a single-shot spin echo EPI sequence. Thirteen slices covering the whole brain were acquired from inferior to superior (field of view [FOV] = 230 mm, matrix = 64 × 63, slice thickness = 8 mm with a 1 mm gap, flip angle = 90°, TR/TE = 4125 ms/42 ms) and reconstructed to an in-plane resolution of 1.8 × 1.8 mm. The labeling plane was placed 60 mm beneath the center of the imaging slices (labeling duration = 2.2 s). The postlabeling delay (Alsop & Detre, 1996) varied from 0.8 s to 1.8 s because each slice was acquired at a slightly different time. In order to control for magnetization transfer effects, an amplitude-modulated version of the CASL technique was used (Alsop & Detre, 1998).

In both measurement occasions resting CBF was measured in four consecutive baselines in a well-lit scanning room. Each baseline consisted of 40 CASL acquisitions (scan duration: 5 min 42 s) and was acquired while the subjects kept their eyes open or closed. All subjects were randomly assigned to one of two

counterbalanced orders of the eyes-open (O) and eyes-closed (C) condition (OCCO and COOC). After each baseline, there was a short break that lasted about 10 s. Before the first baseline and during the breaks, each subject was instructed via microphone to open or close his eyes, respectively.

In addition, there was a high-resolution T_1-weighted sequence, which lasted 13 min 22 s, and which was acquired before the CBF measurements in order to allow the participants to acclimatize to the MR environment (fast field echo, field of view [FOV] = 256 × 192 mm, matrix = 256 × 256, slice thickness = 1 mm, TR/TE = 11.9 ms/3.3 ms). After the CASL measurements a T_2-weighted image was acquired, which was used to control for neurological abnormalities. The same imaging protocol was performed at both measurement occasions except that the T_2-weighted sequence was not acquired at the second time.

Data processing

Offline data processing of CASL and T_1 images was performed with the Statistical Parametric Mapping Software (SPM2, Wellcome Department of Imaging Neuroscience, London UK, implemented in MATLAB 7, The Math-Works Inc., Natick, MA) as described in Hermes et al. (2007). In short, the lowest slice in the CASL images was excluded from the following data analysis since there were heavy low-intensity artifacts in all subjects. In a first step the label and control images were separately motion corrected using a two-step protocol that includes a first realignment to the label/control image of the first scan and a second realignment to a label/control image, which is averaged over all scans. Then the label and control images were reoriented, coregistered to the T_1 image, and normalized based on the T_1 image. After these image registration steps we separately averaged over the 40 label and control images of each baseline, which resulted in two pairs of label and control images for the eyes-open condition and two pairs for the eyes-closed condition for each measurement occasion. Next, the CASL images were quantified according to the method devised by Alsop and Detre (1996). After quantification, the T_1 images were

segmented according to Good et al. (2001) and the resulting tissue probability maps were converted into dichotomous masks. Figure 7 shows an example of a segmented T_1 image and a quantitative CBF image.

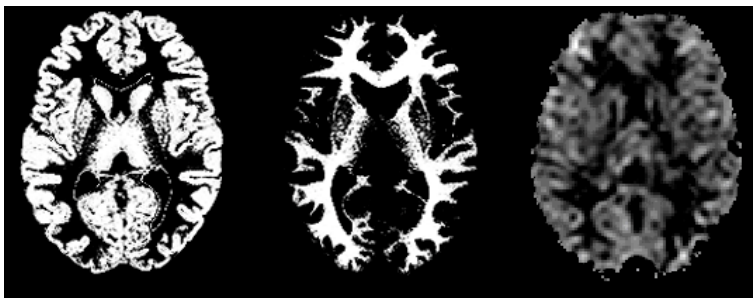

Figure 7. A segmented T_1 image (left: gray matter, middle: white matter) and a quantitative CBF image (right) of a healthy subject acquired at 1.5 T.

These masks were multiplied with the CBF images, which resulted in CBF maps for gray and white matter, respectively. Next, we defined several regions of interest (ROIs) based on published templates (Tatu et al., 1998; Tzourio-Mazoyer et al., 2002) and multiplied them with the segmented CASL images (see Table 7). We chose global ROIs such as whole gray and white matter as well as more specific ROIs, which may be target regions in the search for the biological basis of emotion and personality (Hamann & Canli, 2004; LeDoux, 2000; Rolls, 2005).

Table 7. Overview of Regions of Interest (ROIs)

Region of interest	
Whole gray matter	Dorsolateral prefrontal cortex (L, R)
Whole white matter	Medial prefrontal cortex (L, R)
Cerebral lobes	Orbital prefrontal cortex (L, R)
frontal (L, R)	Dorsolateral temporal cortex (L, R)
temporal (L, R)	Superior parietal cortex (L, R)
parietal (L, R)	Dorsolateral occipital cortex (L, R)
occipital (L, R)	Insula (L, R)
Arterial territories of	Anterior cingulum (L, R)
anterior cerebral artery (L, R)	Ventral striatum (L, R)
medial cerebral artery (L, R)	Amygdaloid area (L, R)
posterior cerebral artery (L, R)	Thalamus (L, R)

Note. Only the neocortical part of each arterial territory was defined as an ROI. L = left hemisphere; R = right hemisphere.

Statistical analysis

For each ROI two parallel CBF measures were defined by averaging across two baselines: the first parallel measure was the mean of the first eyes-open and the second eyes-closed baseline (i.e. for the OCCO condition it was the mean of the first and third baseline whereas for the COOC condition it was the mean of the second and fourth baseline). The second parallel measure was defined as the mean of the second eyes-open and the first eyes-closed baseline. This resulted in two CBF measures for the first measurement occasion and two CBF measures for the second.

Next we analyzed the baseline CBF data in terms of LST theory. Since there are several models that can be derived from this theory, we applied two competing models: a trait model and a latent state-trait model (see Figure 8).

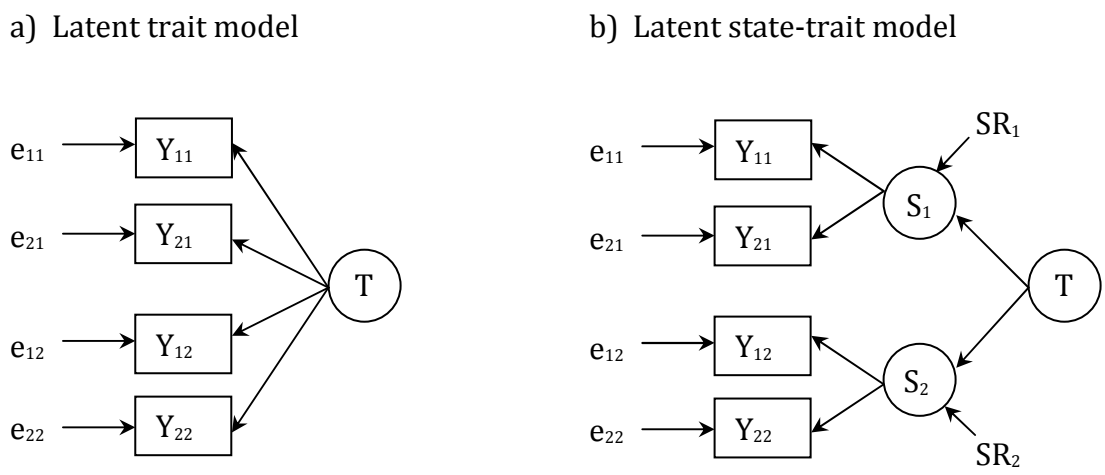

Figure 8. a) Latent trait model and b) latent state-trait model for two indicators *i* in two measurement occasions *k*. Y_{ik} are the manifest variables (corresponding to the parallel CBF measures), e_{ik} are the latent errors, *T* is the latent trait, S_k are the latent states, SR_k are the latent state residuals. Note that all exogenous variables (the latent errors, the state residuals, and the trait) are uncorrelated.

The first model is termed *latent trait model* (Figure 8 a) because it is presumed that the observed variables are only affected by effects of the person and measurement errors but not by situational factors or effects of the person-situation interaction. Therefore, the observed variables Y_{ik} are decomposed into a

common latent trait T and into measurement errors e_{ik} (where i denotes the parallel CBF measure of the measurement occasion k). In the second model, termed *latent state-trait model* (Figure 8 b), it is presumed that in addition to effects of the person and measurement errors the observed variables are also affected by situational factors and/or effects of the person-situation interaction. Here the decomposition is performed in two stages: in a first step, the observed variables Y_{ik} are decomposed into a latent state S_k and into measurement errors e_{ik}. In a second step, the latent state S_k is decomposed into a latent trait T, and into occasion-specific residuals SR_k, which represent the effects of the situation and the person-situation interaction on the latent state. In case of baseline CBF measurements the occasion-specific residuals SR_k represent influences on CBF such as the hormonal status, partial pressures of carbon dioxide (P_aCO_2), cardiac and respiratory rates, caffeine intake, or phasic neuronal activity.

These two competing models were separately tested for each ROI. In a first step, the two models were fitted to the particular covariance matrix by minimizing the generalized least squares (GLS) function. We analyzed different versions of each model and started with the most restrictive version of the model (i.e. for the latent state-trait model all variances of the measurement errors e_{ik} and all variances of the state residuals SR_k were equal, and all path coefficients were set to one). In case this version of the model could not be accepted, the restrictions were stepwise liberalized. In order to evaluate the general model fit, we used the χ^2 statistics ($\alpha = .05$) as well as the comparative fit index (Bentler, 1990) and the root mean square error of approximation (Browne & Cudeck, 1993). Note that a significant χ^2 model test indicates a substantial discrepancy between the data and the model (Hoyle, 1995). In this case, the model has to be rejected. The statistical significance of the single model parameters ($\alpha = .05$) was evaluated with the critical ratio (C.R.) of each parameter and the corresponding standard error (C.R. = Var/*SE*).

In addition, LST theory allows the definition of three coefficients: coefficient of trait specificity[4], occasion specificity, and reliability (Steyer et al., 1999). The coefficient of trait specificity is defined as the proportion of variance of the observed variable that is determined by transsituationally consistent and temporally stable individual differences. It thus represents the impact of a latent trait (i.e. the impact of effects of the person). In contrast the coefficient of occasion specificity is defined as the proportion of variance of the observed variable that is determined by effects of the situation and/or the person-situation interaction. Finally the coefficient of reliability is defined as the proportion of variance of the observed variable, which is attributable to all error-free latent components and represents the sum of the coefficients of trait specificity and occasion specificity. From this it follows that a high coefficient of trait specificity indicates that the observed variable may be interpreted as a proxy for a trait whereas a high coefficient of occasion specificity indicates that the observed variable mainly reflects occasion-specific fluctuations. These three coefficients were determined for each ROI. All LST analyses were performed with Amos (version 5.0.1; Amos Development Corporation, Spring House, PA).

4.3 RESULTS

Means and standard deviations

The arithmetic means and standard deviations of the parallel CBF measures in the whole gray matter were M = 71.9, SD = 13.0 ml/100g/min and M = 72.5, SD = 12.2 ml/100g/min for the first occasion, and M = 71.4, SD = 12.2 ml/100g/min and M = 71.8, SD = 11.7 ml/100g/min for the second.

[4] Previously, this coefficient had been termed *consistency* (e.g., Steyer et al., 1999). However, to specify the latent trait or LST model, the assumption has to be made that all manifest variables that were collected in different measurement situations that emerged on temporally distinct occasions k measure the same latent trait. Thus, this latent trait is transsituationally consistent and temporally stable across all occasions. Therefore, the coefficient that reflects the portion of variance of the manifest variable that is determined by the latent trait reflects both consistency and stability, and we prefer to term it *trait specificity* (Hagemann et al., 2002).

Thus, there were only small mean differences between the parallel measures within each occasion and between the two measurement occasions. Furthermore, the between-subject variability was high in all baselines.

Models of latent state-trait theory

Latent trait model. The restrictive latent trait model (equal variances of the measurement errors e_{ik} and equal effects of the trait on the measured variables) had to be rejected for most of the regions of interest. However, for the right orbitofrontal cortex, left and right insula, left and right ventral striatum, and left amygdaloid area the model showed an acceptable fit with all $\chi^2(8, N = 38) \leq 10.58$, all $p \geq .227$, all CFI $\geq .82$, and all RMSEA $\leq .09$ (see Table 8). For all of these six regions, there was a significant contribution of the latent trait variance and the latent error variances to the measured CBF variance (all C.R. ≥ 3.34).

A first liberalization of the model (no restrictions for the measurement errors e_{ik}) yielded an acceptable fit only for the right amygdaloid area, $\chi^2(5, N = 38) = 6.02$, $p = .305$, CFI = .90, RMSEA = .07 (see Table 9). There was a significant contribution of the latent trait variance and the latent error variances to the measured CBF variance (all C.R. ≥ 2.26). Further liberalizations of the latent trait model yielded no acceptable model fit.

Taken together, these results show that CBF cannot be adequately modeled by a latent trait model for all regions of interest except the right orbitofrontal cortex, bilateral insula, ventral striatum, and amygdaloid area. This suggests that there may be substantial situational influences on CBF, which are not considered by latent trait models. This hypothesis can be tested with a latent state-trait model.

Table 8. Chi-Square Statistics, Goodness-of-Fit Indices, and Estimated Model Parameters of the Restrictive Latent Trait Model

Region	χ^2 statistics		Goodness-of-fit		Estimated model parameters		
	χ^2 (8, N = 38)	p	CFI	RMSEA	Var (Y)	Var(T) *SE*	Var(e) *SE*
Orbital prefrontal cortex (R)	— / 10.58	— / .227	— / .86	— / .09	— / 116.18	— / 87.00 — / *23.05*	— /29.19 — / *4.36*
Insula (L/R)	10.19 / 9.80	.252 / .280	.88 / .90	.09 / .08	185.43 / 159.95	146.21 / 129.09 *37.49* / *33.59*	39.22 /30.86 *5.83* / *4.56*
Ventral striatum (L/R)	10.40 / 10.22	.238 / .250	.82 / .88	.09 / .09	144.80 / 133.25	105.62 / 104.22 *28.38* / *27.11*	39.18 /29.03 *5.83* / *4.31*
Amygdaloid area (L)	5.68 / —	.684 / —	1.00 / —	.00 / —	135.34 / —	69.39 / — *20.80* / —	65.95 / — *9.34* / —

Note. All reported statistics are based on parametric generalized least squares estimates. For all regions the same restrictive latent trait model was analyzed (equal variances of the measurement error e_{ik}, equal effects of the trait T). A significant χ^2 model test indicates a substantial discrepancy between the data and the model. CFI = comparative fit index; RMSEA = root mean square error of approximation; L = left hemisphere; R = right hemisphere.

Table 9. Chi-Square Statistics, Goodness-of-Fit Indices, and Estimated Model Parameters of the Liberalized Latent Trait Model

Region	χ^2 statistics		Goodness-of-fit		Estimated model parameters				
	χ^2 (5, N = 38)	p	CFI	RMSEA		Var (Y)	Var(T)	*SE*	Var(e) *SE*
Amygdaloid area (R)	6.02	.305	.90	.07	Y_{11} Y_{21} Y_{12} Y_{22}	135.05 112.75 150.34 154.16	88.61	*27.29*	46.44 *16.48* 24.14 *10.69* 61.72 *17.45* 65.55 *19.75*

Note. All reported statistics are based on parametric generalized least squares estimates. In the liberalized latent trait model there were no restrictions for the measurement error e_{ik} but the effects of the trait T had to be equal. A significant χ^2 model test indicates a substantial discrepancy between the data and the model. Y_{ik} are the parallel CBF measures i in the two measurement occasions k. CFI = comparative fit index; RMSEA = root mean square error of approximation; R = right hemisphere.

Latent state-trait model. The restrictive latent state-trait model (equal variances of the measurement errors e_{ik}, equal variances of the state residuals SR_k, and equal effects of the trait T and the states S_k) could be accepted for all of the regions of interest, all $\chi^2(7, N = 38) \leq 9.09$, all $p \geq .246$, all CFI $\geq .92$, and all RMSEA $\leq .09$ (see Table 10), except for the right anterior territory, left medial prefrontal cortex, right amygdaloid area, and left thalamus. For all regions with an acceptable model fit, there was a significant contribution of the variances of the latent variables to the measured CBF variance (all C.R. ≥ 2.27) except for the state residual variances SR_k of the left amygdaloid area and the latent error variance e_{11} of the left anterior territory. It should be noted that setting the state residual variances of the left amygdaloid area to zero is equivalent to the restrictive latent trait model that was analyzed and accepted above.

A first liberalization of the model (no restrictions for the state residuals SR_k) was introduced for the regions that yielded no acceptable fit to the restrictive LST model. This model was acceptable for the right anterior territory, the right amygdaloid area and the left thalamus, all $\chi^2(6, N = 38) \leq 9.35$, all $p \geq .228$, all CFI $\geq .89$, and all RMSEA $\leq .10$ (see Table 11). There was a significant contribution of the variances of the latent variables to the measured CBF variance (all C.R. ≥ 2.96) except for the state residual variance SR_2 of the anterior territory, both state residual variances SR_k of the right amygdaloid area, and the state residual variance SR_1 of the left thalamus. As in the case of the left amygdaloid area, setting the state residual variances of right amygdaloid area to zero is equivalent to the latent trait model that was analyzed and accepted above. Further liberalizations of the LST model yielded no acceptable model fit.

Taken together, the latent state-trait model could be accepted for all regions of interest except the left and right amygdaloid area and the left medial prefrontal cortex. This finding suggests that in most regions CBF is not only determined by trait-like factors and measurement errors but is also substantially influenced by situational factors.

Table 10. Chi-Square Statistics, Goodness-of-Fit Indices, and Estimated Model Parameters of the Restrictive Latent State-Trait Model

Region	χ^2 statistics		Goodness-of-fit		Estimated model parameters			
	χ^2 (7, N = 38)	p	CFI	RMSEA	Var (Y)	Var(T) *SE*	Var(SR) *SE*	Var(e) *SE*
Whole gray matter	3.67	.817	1.00	.00	128.69	99.08 *28.04*	21.10 *6.05*	8.52 *1.47*
Whole white matter	9.09	.246	.92	.09	41.96	31.72 *9.17*	7.36 *2.07*	2.88 *0.54*
Frontal lobe (L/R)	7.02 / 6.83	.427 / .447	1.00 / 1.00	.01 / .00	124.30 / 137.25	79.78 / 92.10 *25.65 / 27.43*	36.32 / 34.17 *9.55 / 9.42*	8.19 / 10.98 *1.49 / 1.99*
Temporal lobe (L/R)	4.18 / 3.90	.759 / .791	1.00 / 1.00	.00 / .00	154.83 / 160.00	118.83 / 128.52 *32.95 / 35.17*	22.84 / 18.04 *7.38 / 6.17*	13.16 / 13.45 *2.28 / 2.33*
Parietal lobe (L/R)	5.75 / 5.08	.569 / .650	1.00 / 1.00	.00 / .00	155.12 / 181.76	122.96 / 144.04 33.76 / *38.13*	22.87 / 26.99 *6.65 / 7.67*	9.30 / 10.74 *1.65 / 1.90*
Occipital lobe (L/R)	3.01 / 5.28	.884 / .626	1.00 / 1.00	.00 / .00	190.55 / 176.10	153.96 / 140.76 *41.49 / 38.53*	25.98 / 23.15 *7.59 / 7.56*	10.62 / 12.19 *1.82 / 2.16*
Anterior territory (L)	8.06 / —	.328 / —	.96 / —	.06 / —	116.82[a] / — 127.16[b] / —	87.14 / — *26.41 / —*	29.68 / — *7.87 / —*	10.34 / — *1.92 / —*
Medial territory (L/R)	5.21 / 2.98	.634 / .887	1.00 / 1.00	.00 / .00	159.79 / 173.35	117.85 / 136.55 *35.01 / 36.99*	31.73 / 23.76 *8.82 / 7.26*	10.22 / 13.04 *1.81 / 2.24*
Posterior territory (L/R)	5.61 / 5.63	.586 / .584	1.00 / 1.00	.00 / .00	159.71 / 164.22	129.51 / 127.84 *35.40 / 35.29*	19.11 / 23.45 *6.42 / 7.61*	11.09 / 12.93 *1.98 / 2.31*
Dorsolateral prefrontal cortex (L/R)	6.59 / 8.11	.473 / .323	1.00 / .96	.00 / .07	149.97 / 160.93	92.09 / 105.75 *29.67 / 31.42*	46.16 / 43.03 *12.17 / 11.77*	11.73 / 12.14 *2.13 / 2.26*
Medial prefrontal cortex (R)	— / 8.73	— / .273	— / .93	— / .08	— / 148.50	— / 71.43 *— / 27.43*	— / 54.42 *— / 15.74*	— / 22.66 *— / 4.26*
Orbital prefrontal cortex (L/R)	3.77 / 5.36	.805 / .616	1.00 / 1.00	.00 / .00	123.90 / 139.53	69.45 / 83.50 *24.01 / 27.19*	27.76 / 26.81 *10.64 / 10.69*	26.69 / 29.22 *4.46 / 5.05*
Dorsolateral temporal cortex (L/R)	3.74 / 4.30	.809 / .744	1.00 / 1.00	.00 / .00	185.34 / 174.73	143.77 / 140.65 *39.76 / 39.60*	27.78 / 19.99 *8.54 / 6.59*	13.80 / 14.10 *2.39 / 2.47*
Superior parietal cortex (L/R)	7.26 / 7.56	.402 / .373	.99 / .98	.03 / .05	137.11 / 178.96	89.21 / 133.81 *29.40 / 35.77*	22.19 / 26.11 *9.78 / 10.82*	25.71 / 19.04 *4.40 / 3.51*
Dorsolateral occipital cortex (L/R)	3.37 / 8.44	.849 / .296	1.00 / .94	.00 / .07	245.11 / 179.81	197.86 / 146.00 *53.14 / 40.94*	35.72 / 22.28 *10.02 / 7.94*	11.53 / 11.52 *1.99 / 2.14*
Insula (L/R)	3.75 / 3.31	.808 / .855	1.00 / 1.00	.00 / .00	198.45 / 169.32	131.78 / 117.42 *37.92 / 33.90*	31.68 / 24.24 *12.49 / 9.52*	34.98 / 27.66 *6.06 / 4.73*
Anterior cingulum (L/R)	0.97 / 7.40	.995 / .389	1.00 / .99	.00 / .04	193.34 / 201.48	110.17 / 117.59 *35.22 / 39.30*	56.04 / 60.15 *16.52 / 16.89*	27.13 / 23.74 *4.52 / 4.36*

Table 10. (continued)

Region	χ^2 statistics		Goodness-of-fit		Estimated model parameters			
	χ^2 (7, N = 38)	p	CFI	RMSEA	Var (Y)	Var(T) *SE*	Var(SR) *SE*	Var(e) *SE*
Ventral striatum (L/R)	4.94 / 2.82	.667 / .901	1.00 / 1.00	.00 / .00	153.78 / 144.44	95.70 / 92.50 *28.69* / *27.46*	23.33 / 25.91 *9.99* / *9.53*	34.75 / 26.03 *6.13* / *4.45*
Thalamus (R)	— / 5.81	— / .563	— / 1.00	— / .00	— / 178.81	—/ 101.12 —/ *32.09*	— / 44.74 — / *14.60*	— / 32.95 — / *5.89*

Note. All reported statistics are based on parametric generalized least squares estimates. For all regions the same restrictive latent state-trait model was analyzed (equal variances of the measurement error e_{ik}, equal variances of the state residuals SR_k, and equal effects of the states S_k and the trait T) except for the left anterior territory: because the error variance e_{11} was not significant, it was set to zero. A significant χ^2 model test indicates a substantial discrepancy between the data and the model. CFI = comparative fit index; RMSEA = root mean square error of approximation; L = left hemisphere; R = right hemisphere.

[a] Var (Y) for the first parallel CBF measure of the first measurement occasion (Y_{11}).

[b] Var (Y) for the parallel CBF measures Y_{21}, Y_{12}, and Y_{22}.

Table 11. Chi-Square Statistics, Goodness-of-Fit Indices, and Estimated Model Parameters of the Liberalized Latent State-Trait Model

Region	χ^2 statistics		Goodness-of-fit		Estimated model parameters						
	χ^2 (6, N = 38)	p	CFI	RMSEA		Var (Y)	Var(T)	*SE*	Var(SR)	*SE*	Var(e)	*SE*
Anterior territory (R) [a]	9.30	.232	.91	.09	Y_{11}, Y_{21} Y_{12}, Y_{22}	177.58 117.29	106.45	*28.77*	60.30	*16.82*	10.83	*2.01*
Thalamus (L) [b]	9.35	.228	.89	.10	Y_{11}, Y_{21} Y_{12}, Y_{22}	136.53 196.21	113.44	*29.76*	59.68	*20.15*	23.09	*4.36*

Note. All reported statistics are based on parametric generalized least squares estimates. In the liberalized latent state-trait model there were no restrictions for the variances of the state residuals SR_k but the variances of the measurement error e_{ik}, had to be equal as well as the effects of the states S_k and the trait T. A significant χ^2 model test indicates a substantial discrepancy between the data and the model. Y_{ik} are the parallel CBF measures i in the two measurement occasions k. CFI = comparative fit index; RMSEA = root mean square error of approximation; L = left hemisphere; R = right hemisphere.

[a] Because the variance of the state residual of the second occasion (SR_2) was not significant it was set to zero.

[b] Because the variance of the state residual of the first occasion (SR_1) was not significant it was set to zero.

Model Comparison. The previous analyses showed that five regions could be adequately modeled by the restrictive latent trait model as well as the restrictive latent state-trait model. These regions are the left orbital prefrontal cortex, the left and right insula, and the left and right ventral striatum. In order to directly compare the two competing models, we performed a χ^2 difference test for each of the five regions. Table 12 shows the results of these analyses. For all regions, the restrictive latent state-trait model revealed a significantly better model fit than the restrictive latent trait model, all $\chi^2(1, N = 38) \geq 9.80$, all $p \leq .020$.

Table 12. Comparison between the Restrictive Latent Trait Model and the Restrictive Latent State-Trait Model

		χ^2_{trait} (8, N = 38)	χ^2_{LST} (7, N = 38)	$\Delta\chi^2$ (1, N = 38)	p
Insula	L	10.19	3.75	6.44	.011
	R	9.80	3.31	6.48	.011
Ventral striatum	L	10.40	4.94	5.46	.020
	R	10.22	2.82	7.40	.007

Note. L = left hemisphere; R = right hemisphere.

In sum, the latent state-trait model could be accepted for 35 of 38 regions of interest. Therefore, the assumption that baseline CBF is determined by trait-like and situational factors as well as measurement errors was acceptable for most of the brain regions. While 33 regions could be modeled by a restrictive version of the LST model, two regions showed an acceptable fit to a liberalized LST model (right anterior territory and left thalamus). Furthermore, two regions could be adequately modeled by a latent trait model (left and right amygdaloid area), which suggests that these regions were not substantially influenced by situational factors. Finally, the left medial prefrontal cortex was the only region that could not be adequately modeled by a latent trait as well as an LST model.

Latent state-trait parameters of baseline CBF

As described in the Methods section, LST theory allows the definition of the coefficients of trait specificity, occasion specificity, and reliability. These parameter estimates are presented in Table 13 and 14 for the latent state-trait models. In addition, the coefficients of trait specificity for the latent trait models were .51 for the left amygdaloid area (restrictive model) and .66, .79, .59, and .57 for the four parallel measures (Y_{11}, Y_{21}, Y_{12}, Y_{22}) of the right amygdaloid area (liberalized model).

Table 13. Trait Specificity, Occasion Specificity, and Reliability for the Restrictive Latent State-Trait Model

	Latent state-trait parameters		
Region	TraSpe (*Y*)	OccSpe (*Y*)	Rel (*Y*)
Whole gray matter	.77	.16	.93
Whole white matter	.76	.18	.93
Frontal lobe (L/R)	.64 / .67	.29 / .25	.93 / .92
Temporal lobe (L/R)	.77 / .80	.15 / .11	.92 / .92
Parietal lobe (L/R)	.79 / .79	.15 / .15	.94 / .94
Occipital lobe (L/R)	.81 / .80	.14 / .13	.94 / .93
Anterior territory (L) [a]	.75 [b] / – .69 [c] / –	.25 [b] / – .23 [c] / –	1.00 [b] / – .92 [c] / –
Medial territory (L/R)	.74 / .79	.20 / .14	.94 / .92
Posterior territory (L/R)	.81 / .78	.12 / .14	.93 / .92
Dorsolateral prefrontal cortex (L/R)	.61 / .66	.31 / .27	.92 / .92
Medial prefrontal cortex (R)	— / .48	— / .37	— / .85
Orbital prefrontal cortex (L/R)	.56 / .60	.22 / .19	.78 / .79
Dorsolateral temporal cortex (L/R)	.78 / .80	.15 / .11	.93 / .92
Superior parietal cortex (L/R)	.65 / .75	.16 / .15	.81 / .89
Dorsolateral occipital cortex (L/R)	.81 / .81	.15 / .12	.95 / .94
Insula (L/R)	.66 / .69	.16 / .14	.82 / .84
Anterior cingulum (L/R)	.57 / .58	.29 / .30	.86 / .88
Ventral striatum (L/R)	.62 / .64	.15 / .18	.77 / .82
Thalamus (R)	— / .57	— / .25	— / .82

Note. TraSpe (*Y*) = coefficient of trait specificity; OccSpe = coefficient of occasion specificity; Rel (*Y*) = coefficient of reliability; L = left hemisphere; R = right hemisphere. $N = 38$.

[a] Because the error variance e_{11} was not significant, it was set to zero.

[b] Coefficients of trait specificity, occasion specificity, and reliability for the first parallel CBF measure of the first measurement occasion (Y_{11}).

[c] Coefficients of trait specificity, occasion specificity, and reliability for the parallel CBF measures Y_{21}, Y_{12}, and Y_{22}.

Table 14. Trait Specificity, Occasion Specificity, and Reliability for the Liberalized Latent State-Trait Model

		Latent state-trait parameters		
Region		TraSpe (*Y*)	OccSpe (*Y*)	Rel (*Y*)
Anterior territory (R) [a)]	Y_{11}, Y_{21}	.60	.34	.94
	Y_{12}, Y_{22}	.91	.00	.91
Thalamus (L) [b)]	Y_{11}, Y_{21}	.83	.00	.83
	Y_{12}, Y_{22}	.58	.30	.88

Note. Y_{ik} are the parallel CBF measures *i* in the two measurement occasions *k*. TraSpe (*Y*) = coefficient of trait specificity; OccSpe = coefficient of occasion specificity; Rel (*Y*) = coefficient of reliability; L = left hemisphere; R = right hemisphere. *N* = 38.

[a)] Because the variance of the state residual of the second occasion (SR_2) was not significant it was set to zero.

[b)] Because the variance of the state residual of the first occasion (SR_1) was not significant it was set to zero.

For all ROIs the coefficients of trait specificity were in the range of .48 to .91 (*M* = .70). Generally, greater values were present in posterior than in anterior regions. The coefficients of occasion specificity were in the range of 0 to .37 (*M* = .19) with the greatest values in anterior regions. Finally, the coefficients of reliability were in the range of .51 to 1.00 (*M* = .86). Generally, the reliability estimates were greater in neocortical than in subcortical ROIs.

4.4 DISCUSSION

The aim of the present study was to examine whether cerebral blood flow in a resting state may be a sound target for the investigation of the biological basis of personality traits. Baseline CBF data were analyzed within the methodological framework of the latent state-trait theory (LST) theory (Steyer et al., 1992; Steyer et al., 1999), which allows the decomposition of the measured variables into temporally stable differences, occasion-specific fluctuations, and measurement errors.

The influence of situational factors on baseline CBF

A latent trait model, which presumes that situational factors or person-situation interactions have no substantial effects on baseline CBF had to be rejected for most of the regions of interest. This suggests that baseline CBF is not only determined by trait-like factors and measurement errors in most of the ROIs. The left and right amygdaloid area were the only regions that were most appropriately modeled by a latent trait model. About 60 % of the variance in the amygdaloid area was due to temporally stable and transsituationally consistent individual differences and about 40 % was due to measurement error. The high measurement error may be explained by the small volume of this region and the insufficient image resolution of the CASL technique, respectively. This, in turn, increases the probability of partial volume errors und thus the impact of influences that are not related to baseline CBF in the amygdaloid area.

In contrast, a latent state-trait model, which explicitly includes the effects of a specific situation, could be accepted for all regions except the left and right amygdaloid area and the left medial prefrontal cortex. Thus, the present results suggest that baseline CBF is not only determined by trait-like factors and measurement errors but is also substantially influenced by effects of the situation and/or the person-situation interaction. Whereas about 70 % of the observed variance was determined by temporally stable and transsituationally consistent individual differences, about 20 % of the variance was due to situational influences. This is consistent with previous studies that demonstrated that baseline CBF may be influenced by several factors such as hormonal status, partial pressure of carbon dioxide (P_aCO_2), cardiac and respiratory rates, caffeine intake, or phasic neuronal activity (Ito et al., 2005; Krause et al., 2006; Mathew & Wilson, 1985). Furthermore it should be noted that the imaging setting under resting conditions is a highly standardized situation. Therefore, the variety of situational influences on CBF may be reduced in such a laboratory setting. Consequently, the estimated occasion specificity in our study might represent a lower bound of situational influences on CBF, which will be expected to be greater in more natural settings.

Finally, the reliability estimates were high in most regions (M = .86), which suggests that the contribution of measurement errors on baseline CBF was rather small. Generally, the reliability estimates were greater in neocortical than in subcortical ROIs. This may be due to the greater size of the neocortical ROIs, which yields an increased data sample and may decrease the impact of partial volume errors. The comparable values for the coefficients of occasion specificity (M = .19) and unreliability (M = .14) suggest that the variability between repeated scans of the same subjects is due to systematic effects of the situation and the person-situation interaction as well as due to unsystematic measurement errors. This suggests that the within-subjects variability in baseline CBF represents true physiological changes as well as measurement error.

Consequences for studies of baseline CBF and personality traits

The present finding of substantial situational influences on baseline CBF has several implications for psychophysiological studies of personality. A related issue was already addressed by Eysenck (1994) who discussed the problematic influence of situational factors in the measurement of arousal. In particular, Eysenck (1994) pointed to the substantial impact of a multitude of external factors—such as hours of sleep, drinking alcohol, smoking, and eating before the measurement, or the affective state and nervousness during the measurement, or the time of day—which may all increase the occasion specificity of the arousal measurements and hence decrease the correlations between personality traits and arousal. This line of reasoning and the present finding of substantial situational influences on baseline CBF measurements suggest that the relation between baseline CBF and personality traits may have been underestimated in previous research.

The missing findings on the relation between baseline CBF and neuroticism (Ebmeier et al., 1994; Mathew et al., 1984; O'Gorman et al., 2006; Stenberg et al., 1990) may be—at least in part—explained by the underestimation of this relation due to significant situational influences and due to measurement errors.

In addition, the situational influences may in part explain the inconsistent findings in studies of baseline CBF and introversion/extraversion (Ebmeier et al., 1994; Johnson et al., 1999; Mathew et al., 1984; O'Gorman et al., 2006; Stenberg et al., 1990; Stenberg et al., 1993). Since the situational influences introduce noise to the baseline CBF measurements, inconsistent findings are more likely to appear.

For future studies, it would be advantageous to minimize the impact of these situational variables. Common used approaches in order to control for situational effects are the standardization of the imaging setting, the careful selection of subjects, and the instructions not to smoke or to drink coffee before the measurement. Another approach is to measure the hypothesized effects and to employ them as covariates in the statistical analysis. However, many situational variables cannot be absolutely controlled even in a standardized imaging setting and can also not be reliably measured. To minimize the effects of these situational variables, an appropriate strategy is the repeated measurement of baseline CBF data in different occasions and the subsequent aggregation over these occasions (Hagemann et al., 2002; Steyer & Schmitt, 1990). This strategy will—provided that the occasion-specific residuals are not positively correlated between occasions (Steyer & Schmitt, 1990)—decrease the occasion specificity and increase the trait specificity of the baseline CBF measurements. Hence, the use of multiple measurement occasions in future studies may help to overcome the inconsistencies in the relation between baseline CBF and personality traits such as extraversion/introversion, neuroticism, or intelligence.

Conclusion

Taken together, the present findings suggest that baseline CBF measurements predominately reflect a stable latent trait that is superimposed by occasion-specific fluctuations and—to a lower part—by measurement errors. This suggests that the measurements of baseline CBF may be a sound target to investigate the biological basis of personality traits. However, especially if small

anatomical structures are considered, an aggregation over at least two measurement occasions may be necessary.

EXTRAVERSION AND ITS POSITIVE EMOTIONAL CORE: FURTHER EVIDENCE FROM NEUROSCIENCE

CHAPTER V

ABSTRACT

There is converging evidence from self-report data that extraversion and positive affect are systematically related. In the present study, we investigated whether this personality-affect relationship can also be observed on the physiological level. Baseline cerebral blood flow was measured in 38 participants and regressed to the respective questionnaire data. Positive affect and extraversion were both associated with the left ventral striatum and the left anterior cingulate cortex. These areas may be part of an approach system, which links the different facts of positive affect and extraversion. In addition, the correlations between extraversion and cerebral blood flow were almost completely mediated by positive affect, which supports the view that positive affect forms the central core of extraversion and not vice versa. Thus, the present study broadens the perspective on the positive affect-extraversion association by exploring its physiological basis.

5.1 INTRODUCTION

In the last decades, several theories of the structure of personality were developed (e.g., Eysenck, 1981; McCrae & Costa, 1987). These theories proposed different conceptualizations of "basic" personality traits, i.e. traits that explain the greatest amount of variance between individuals with the fewest number of (broad) dimensions and that are consistently observed in different samples and conditions. There is, however, substantial convergence among these theories, particularly for the traits of extraversion and neuroticism (Zuckerman, Kuhlman, Joireman, Teta, & Kraft, 1993). These two traits are included in most personality models and were accordingly termed the "Big Two" traits of personality by Watson, Wiese, Vaidya, and Tellegen (1999). Furthermore, extraversion and neuroticism have been identified across cultures (Eysenck & Eysenck, 1982) and seem to be substantially influenced by genetic factors (for a review, see Ebstein, 2006).

Extraverts are usually described as sociable, fun-loving, affectionate, friendly, and talkative (McCrae & Costa, 1987), whereas introverts are characterized by a lack of confidence and energy and tend to be reserved and socially aloof. Neuroticism, on the other hand, is commonly described by terms such as worrying, insecure, self-conscious, and temperamental (McCrae & Costa, 1987).

The structure of self-rated affect

Similar to the research on the structure of personality, the structure of self-rated affect was investigated in another fruitful line of research (Terracciano, McCrae, Hagemann, & Costa, 2003; Watson et al., 1999). Converging evidence suggests a hierarchical organization of self-rated affect (Tellegen, Watson, & Clark, 1999) with two higher-order factors, which were consistently identified in several studies (e.g., Diener & Emmons, 1984; Watson & Tellegen, 1985) and termed *positive affect* and *negative affect* (Watson & Tellegen, 1985) or *positive*

activation and *negative activation* (Watson et al., 1999), the latter to emphasize the activated nature of these dimensions. These two broad dimensions can be regarded as dispositions for the experience of discrete affects such as anger, fear, or happiness, which in turn constitute the lower level of the affect hierarchy.

According to Watson, Clark, and Tellegen (1988) high positive affect is "a state of high energy, full concentration, and pleasurable engagement" (p. 1063), whereas low positive affect is characterized by sadness and lethargy. In contrast, high negative affect includes a variety of aversive mood states such as anger, contempt, disgust, guilt, fear, and nervousness, whereas low negative affect is a "state of calmness and serenity" (Watson et al., 1988, p. 1063). These two basic dimensions of affect explain about two thirds of the variance among affect-related terms (Watson et al., 1988), they have been found both in state as well as in trait affect variables (Terracciano et al., 2003; Watson, 1988b), and they have been shown to be largely independent dimensions, particularly when longer time frames are considered (Watson et al., 1988; Watson & Tellegen, 1985). As such, several studies found specific—and not simply reverse—relations between positive and negative affect, and several daily activities and health complaints (Watson & Tellegen, 1985).

Personality and affect—evidence from self-report measures

In the last three decades a large body of evidence has suggested that the "Big Two" of personality, extraversion and neuroticism, are systematically associated with the "Big Two" of affect (Watson et al., 1999), positive affect and negative affect (e.g., Clark & Watson, 1999; Costa & McCrae, 1980; Meyer & Shack, 1989; Watson & Clark, 1992, 1997; Watson et al., 1999). In particular, it was found that self-report measures of positive affect are strongly related to extraversion but only weakly associated with neuroticism whereas self-report measures of negative affect are strongly related to neuroticism but only weakly associated with extraversion. Watson et al. (1999), for example, investigated these relationships in 12 samples with an overall sample size of 4.457 and found a mean correlation of .51 between measures of positive affect and extraversion,

and a mean correlation of .58 between negative affect and neuroticism. Furthermore, these associations were found when self-reported affect was assessed as a state as well as a trait variable (Meyer & Shack, 1989), although the correlations were greater when trait affect measures were used. Finally, this association was observed when trait affect was assessed with questionnaires as well as with aggregated daily affect ratings (Clark & Watson, 1999).

Thus, these findings demonstrate that there are strong and systematic associations between personality and affective traits. It is important to note, however, that this line of evidence is mainly based on correlations between data from trait questionnaires. Because such correlation analyses do not allow a testing of directional hypotheses, different interpretations may be compatible with the results of these analyses. For example, Watson and Clark (1997) suggested that positive affect forms the core of extraversion. An alternative model may suggest that extraversion forms the core of positive affect. Similar models may be proposed for neuroticism and negative affect. Importantly, both models are compatible with the evidence from questionnaire data. A comparative evaluation of the two models may be difficult unless Eysenck's claim on biologically-based personality conceptions is taken into account (Eysenck, 1967).

The present study

To investigate whether positive affect forms the core of extraversion or whether extraversion forms the core of positive affect, we examined the physiological basis of extraversion and positive affect, and tested specific hypotheses that allow an evaluation of the two models. In particular, if positive affect forms the core of extraversion (Watson & Clark, 1997), then first of all, positive affect and extraversion should at least partially be associated with the same brain areas. Second and more specifically, extraversion should no longer be associated with these common brain areas when positive affect is partialed out of extraversion. In contrast, positive affect should still be associated with these common brain areas when extraversion is partialed out of positive affect. Similar

hypotheses can be derived for neuroticism and negative affect. Thus, the investigation of the physiological basis of personality and affective traits allows a comparison of different models describing the relation between personality and affective traits.

In the present study baseline cerebral blood flow (CBF) was used to examine the physiological basis of personality and affective traits. This parameter was measured with continuous arterial spin labeling (CASL; Alsop & Detre, 1996), a non-invasive imaging technique that is based on magnetic resonance imaging (MRI). To increase the trait specificity of the CBF measures (Hermes et al., subm.), baseline CBF was measured on two measurement occasions and aggregated across these occasions.

5.2 METHODS

Participants

The sample of the present study was drawn from the student population of the University of Trier (Germany). Thirty-eight right-handed subjects participated in the study, which consisted of 19 men (mean age = 24.5 years, *SD* = 2.6 years) and 19 women (mean age = 24.5 years, *SD* = 2.1 years). All participants underwent a screening interview to assess if they were suitable for MR imaging. Additional exclusion criteria were left-handedness as assessed by a German version of the Edinburgh Handedness Inventory (Oldfield, 1971), cerebrovascular diseases, psychiatric disorders, regular medication (besides contraceptives) as well as any chronic disease. The study was approved by the local ethics committee and informed consent was provided by each individual. All participants were compensated with €100 (approximately US$125).

Measurement of affective and personality traits

Positive and negative affect were measured with a German version (Krohne, Egloff, Kohlmann, & Tausch, 1996) of the Positive and Negative Affect Schedule

(PANAS; Watson et al., 1988), and extraversion and neuroticism were measured with a German short version (Ruch, 1999) of the Eysenck Personality Questionnaire (EPQ; Eysenck & Eysenck, 1975). These questionnaires were administered on a separate occasion between the two occasions for CBF measurement. The reliability coefficients as estimated with Cronbach's alpha varied between .80 and .82 for all trait measures (see Table 15).

Imaging procedure

A detailed description of the imaging procedure, image acquisition, and image processing of the present sample can be found in Hermes et al. (2007). In short, all participants were scanned on two measurement occasions separated by seven weeks. The scanning protocol of the first occasion consisted of seven sequences: after a triplanar planning sequence (scan duration: 2 min 22 s), there was an anatomical T_1-weighted sequence (scan duration: 13 min 22 s), which was acquired before the CBF measurements in order to allow the participants to accustom to the MR environment.

Then four baseline CBF measurements (each lasting 5 min 42 s) were acquired while participants kept their eyes open or closed. All participants were randomly assigned to one of two counterbalanced orders of the eyes-open (O) and eyes-closed (C) condition (OCCO and COOC). Each of the four baseline CBF measurements consisted of 40 CASL acquisitions, which in sum results in 160 pairs of label and control images (Alsop & Detre, 1996).

Finally, a T_2-weighted sequence was acquired in order to control for neurological abnormalities. The scanning protocol of the second occasion was identical to the first occasion except that the T_2-weighted sequence was omitted at the second time.

All scans were performed on a clinical 1.5 T scanner (Intera, Philips Medical Systems, Best, The Netherlands) with a send/receive coil provided by the manufacturer. Interleaved label and control images were acquired using a single-shot spin echo EPI sequence. Thirteen slices covering the whole brain were

acquired from inferior to superior with a 64 × 63 matrix within a field of view of 230 mm (slice thickness = 8 mm with a 1 mm gap, flip angle = 90°, repetition time = 4125 ms, echo time = 42 ms) and reconstructed to an in-plane resolution of 1.8 × 1.8 mm. Labeling was turned on for 2.2 s and the postlabeling delay (Alsop & Detre, 1996) varied from 0.8 s to 1.8 s because each slice was acquired at a slightly different time.

MRI data processing

Offline data processing of CASL and T_1 images was performed with the Statistical Parametric Mapping Software (SPM2, Wellcome Department of Imaging Neuroscience, London UK, implemented in MATLAB 7, The Math-Works Inc., Natick, MA). The lowest slice in the CASL images was excluded from the following data analysis because of heavy low-intensity artifacts in all participants. In a first step the label and control images were separately motion corrected using a two-step protocol that includes a first realignment to the label/control image of the first scan and a second realignment to a label/control image, which is averaged over all scans. In a next step, the T_1 images were segmented and normalized to the gray matter Montréal Neurological Institute (MNI) template. Then the label and control images were reoriented, coregistered to the T_1 image, and normalized based on the T_1 image. After these image registration steps we separately averaged over the 320 label and control images of both occasions, which resulted in one pair of label and control images for each participant. Next, the CASL images were quantified according to the method devised by Alsop and Detre (1996) and the resulting CBF images were spatially smoothed with a 6 × 6 × 12 mm full width at half maximum (FWHM) kernel.

Statistical analyses

In SPM2 voxel-based analyses were performed within the framework of the general linear model (Friston et al., 1995b). The averaged (unsegmented and smoothed) CBF images were employed in random effects models by regressing

CBF to the respective trait scores. The mean gray matter CBF and sex were used as covariates in order to explain the variance in CBF due to individual differences in global brain activation and differences in CBF between men and women (Hermes et al., 2007).

In a first step we analyzed four regression models (one for each trait) in order to assess brain regions that are associated with each trait. To minimize the contribution of extracerebral voxels, we employed an absolute CBF threshold of 5 ml/100g/min in all analyses. The significance threshold was set to $p < .01$ (uncorrected) at the voxel level and the cluster size threshold was set to $k > 25$ voxels. To further reduce the probability of false positive activation clusters, only those significant clusters were accepted that exceeded a Pearson correlation coefficient of $r = .30$ (Cohen, 1992) between trait score and mean CBF in the cluster. The resulting activation clusters thus represent those brain regions that show a significant association between baseline CBF and trait scores.

To determine the brain areas that are both related to an affective trait as well as to a personality trait, we formed the intersection of significant voxels associated with positive affect with those related to extraversion and the intersection of significant voxels associated with negative affect with those related to neuroticism in a next step.

In addition, we examined whether these overlapping activation clusters are still observed if the common variance of the corresponding traits is partialed out. If so, this would suggest that baseline activation of these brain areas does not reflect individual differences of both affective and personality traits but would reflect *different* aspects of the affective and personality traits, which are associated with the same brain areas. If not, this would suggest that the overlapping activation clusters may reflect the *common* biological basis of individual differences in affective and personality traits. Therefore, we partialed out the common variance of positive affect and extraversion as well as of negative affect and neuroticism using SPSS for Windows (Version 12.0, SPSS Inc.) and repeated the regression analyses for those traits that showed overlapping activation clusters.

5.3 RESULTS

Intercorrelations of trait scales and reliability estimates

The intercorrelations of positive affect, negative affect, extraversion, and neuroticism are presented in Table 15. There were positive correlations between negative affect and neuroticism (r = .50), and between positive affect and extraversion (r = .29). In addition, negative affect was not correlated with extraversion (r = -.02) and positive affect was negatively correlated with neuroticism (r = -.23).

Table 15. Intercorrelations between Trait Measures, Correlations between Trait Measures and Mean Gray Matter Blood Flow, and Means, Standard Deviations, and Reliabilities of Trait Measures

	Negative affect	Extra-version	Neuro-ticism	Mean gray matter CBF	*M*	*SD*	Cronbach's alpha
Positive affect	-.32**	.29**	-.23	-.11	3.46	.51	.80
Negative affect	—	-.02	.50***	.01	1.61	.48	.80
Extraversion		—	-.33**	-.16	.69	.24	.80
Neuroticism			—	.12	.35	.26	.82

Note. All significance tests are one-tailed because the direction of the associations was predicted from previous research. N = 38.
** = p < .05. *** = p < .001.

Correlations with baseline CBF: Personality and affective traits

The correlation coefficients of baseline CBF averaged over the whole gray matter and trait scores are also shown in Table 15. There were only small correlations (-.16 ≤ r ≤ .12), which were positive for negative affect and neuroticism and negative for positive affect and extraversion.

The voxel-based analyses were separately performed for each trait by regressing baseline CBF to the respective traits scores. As presented in Table 16, positive affect significantly correlated with a larger cluster that mainly included the left and right caudate nucleus and extended to the left olfactory cortex. In addition, there were six other significant activation clusters, which included the

bilateral putamen and left pallidum, the left rolandic operculum, left insula, and bilateral anterior cingulate cortex as well as left frontal and temporal areas. In all clusters, there was a negative correlation between positive affect and baseline CBF (-.58 ≤ *r* ≤ -.33) with the greatest correlation in the caudate nucleus and olfactory cortex (*r* = -.58).

Table 16. Brain Areas Demonstrating Significant Associations between Blood Flow and Trait Scores

Anatomical region	Cluster size	MNI coordinates			*T* score	Cluster correlation
		x	*y*	*z*		
Positive affect						
Caudate nucleus (L,R), olfactory cortex (L)	176	-2	20	0	4.30	-.58
Rolandic operculum (L), temporal pole (L)	53	-54	-5	9	3.44	-.41
Putamen (L), pallidum (L)	97	-22	4	0	3.53	-.40
Rolandic operculum (L), Heschl gyrus (L)	36	-40	-20	18	3.73	-.37
Inferior frontal gyrus (L), insula (L)	27	-38	25	18	3.50	-.37
Putamen (R)	27	31	-7	9	2.89	-.35
Anterior cingulate cortex (L,R)	33	0	47	9	3.32	-.33
Extraversion						
Caudate nucleus (L)	31	-9	-2	9	3.52	-.51
Inferior frontal gyrus (L)	30	-50	36	-9	4.16	-.49
Anterior cingulate cortex (L), superior frontal gyrus (L)	98	-11	32	9	4.35	-.48
Putamen (R)	37	32	11	0	3.73	-.46
Temporal pole (R), insula (R)	32	31	13	-27	4.28	.31
Negative affect						
	no significant clusters					
Neuroticism						
Middle and superior temporal gyrus (R)	33	70	20	0	4.47	.57
Inferior frontal gyrus (L)	42	-34	23	27	4.15	.50
Inferior and middle frontal gyrus (R)	51	47	31	27	4.19	.47

Note. For each cluster the anatomical labels according to Tzourio-Mazoyer et al. (2002), cluster size *k* in number of voxels, and Pearson correlation coefficients *r* of the mean CBF in the respective cluster with the trait scores are reported (*r* >.30, *k* >25). For the voxel with greatest *t* score in each cluster the mm coordinates in Montréal Neurological Institute (MNI) space and the *t* score are reported ($p < .01$, uncorrected). 1 voxel = 29,2 mm^3. *N* = 38. L = left; R = right.

Extraversion also showed significantly negative correlations with baseline CBF. Similar to positive affect, the greatest correlation was observed in the left caudate nucleus (*r* = -.51). In addition, extraversion was negatively correlated

with CBF in the left anterior cingulate cortex, right putamen, and left inferior frontal gyrus (-.49 ≤ *r* ≤ -.46). A positive correlation was present in a cluster that included the right temporal pole and the right insula (*r* = .31).

In contrast to positive affect and extraversion, negative affect did not correlate with baseline CBF in any brain region. Finally, neuroticism was positively correlated with CBF in frontal areas of both hemispheres (.47 ≤ *r* ≤ .50) and with right temporal areas (*r* = .57).

Intersection of activation clusters

The intersection of voxels that were significantly associated with positive affect as well as with extraversion formed two clusters (see Table 17). The first was located in the ventromedial part of the left caudate nucleus and extended to the nucleus accumbens. Baseline CBF in this ventral striatal area showed a correlation of *r* = -.50 with positive affect and *r* = -.45 with extraversion. Figure 9 shows the location of this cluster overlaid on an anatomical image, which resulted from averaging over the normalized T_1 images of all participants. In addition, Figure 10 presents the scatter plots of positive affect and extraversion with mean baseline CBF in the intersection cluster.

Table 17. Brain Areas Associated with Positive Affect and Extraversion

Anatomical region	Cluster size	MNI coordinates			Cluster correlation (positive affect)	Cluster correlation (extraversion)
		x	*y*	*z*		
Caudate nucleus (L)	9	-6	8	0	-.50	-.45
Anterior cingulate cortex (L)	4	-2	38	11	-.31	-.38

Note. Areas resulted from forming the intersection of significant clusters of the affective trait–CBF association with significant clusters of the personality trait–CBF association ($p < .01$, $k > 25$, $r > .30$). For each intersection cluster the anatomical label according to Tzourio-Mazoyer et al. (2002), cluster size *k* in number of voxels, and Pearson correlation coefficients *r* of the mean CBF in the cluster with positive affect and extraversion are reported. Since there were no significant associations between baseline CBF and negative affect, no intersection cluster could emerge for negative affect and neuroticism. 1 voxel = 29,2 mm^3. *N* = 38. L = left.

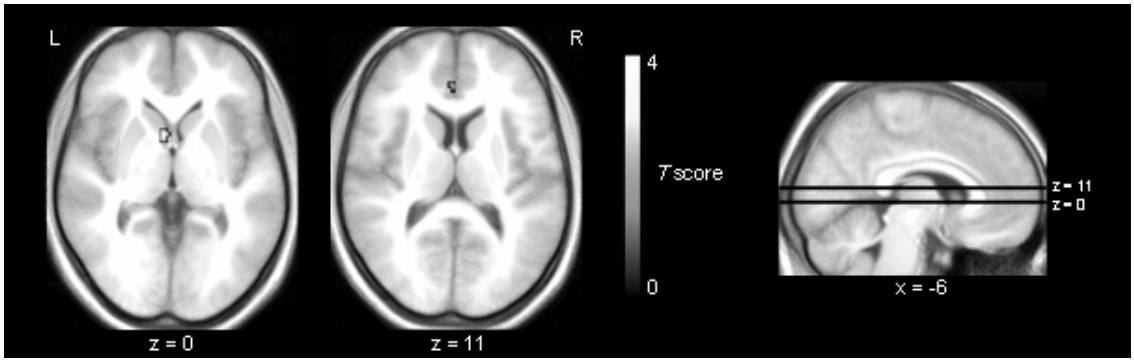

Figure 9. Areas showing associations with both affective and personality traits. The intersection clusters (see Table 17) represent areas that show a significant negative correlation between baseline CBF and positive affect as well as between baseline CBF and extraversion (left: ventral striatum, middle: anterior cingulate cortex). These clusters are overlaid on an averaged anatomical image of all participants in this study (N = 38). The axial position of the two slices is shown on the sagittal view (right). L = left; R = right; x = sagittal position in MNI space; z = axial position in MNI space.

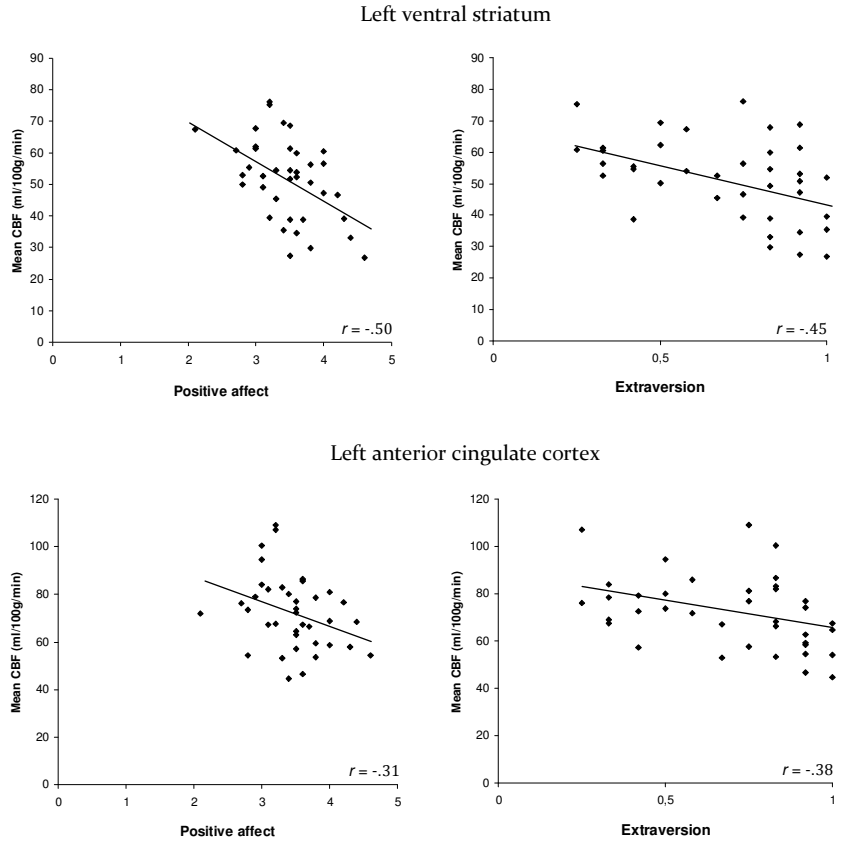

Figure 10. Correlations between mean baseline CBF in the two intersection clusters (left ventral striatum, left anterior cingulate cortex; see Table 17) and extraversion and positive affect, respectively.

The second cluster was located in the left anterior cingulate cortex (rostral part) and showed a correlation of r = -.31 with positive affect and r = -.38 with extraversion.

After partialing out the common variance of positive affect and extraversion, there was no overlap in the activation clusters between residualized positive affect and residualized extraversion. In particular, residualized positive affect was negatively correlated with baseline CBF in the basal ganglia, olfactory cortex, rolandic operculum, insula, and superior temporal gyrus ($-.54 \leq r \leq -.41$). These clusters included six of the nine voxels of the intersection cluster in the ventral striatum. Residualized extraversion was only correlated with the anterior cingulate cortex (r = -.51), which included only one of the four voxels of the intersection cluster. Hence, although there was no overlap in activation between positive affect and extraversion after partialing out their common variance, residualized positive affect was still associated with the ventral striatum, which constitutes the intersection cluster that was most strongly associated with positive affect as well as extraversion.

5.4 DISCUSSION

A large amount of literature suggests that there are systematic associations between positive affect and extraversion, and negative affect and neuroticism. These findings are mainly based on questionnaire data and daily affect ratings, and were most pronounced when self-rated affect was assessed on the trait level. The first aim of the present study was to examine whether these findings can be confirmed on the physiological level. The second aim was to analyze specific hypotheses that allow an evaluation of two competing models: whether positive affect forms the core of extraversion or whether extraversion forms the core of positive affect (and respective hypotheses for neuroticism and negative affect). On two measurement occasions, baseline CBF was measured with continuous arterial spin labeling and regressed to self-reported affect based on trait questionnaires.

The main finding of this study was that trait positive affect and extraversion were both associated with baseline CBF in the left ventral striatum and a circumscribed area in the left anterior cingulate cortex. In addition, when the common variance of both traits was partialed out, the overlap in activations disappeared and only residualized positive affect was still associated with CBF in the ventral striatum. These findings support previous findings on the relation between positive affect and extraversion and suggest that there is a biological basis for this association, which is located in the left ventral striatum and anterior cingulate cortex.

There is a good deal of evidence that the ventral striatum is related to individual differences in extraversion. Previous studies showed that extraversion is associated with baseline CBF in the caudate nucleus (O'Gorman et al., 2006) and CBF reactivity to passively perceiving visual stimuli (Canli et al., 2001; Fischer, Wik, & Fredrikson, 1997). Interestingly, Fischer et al. (1997) found that baseline CBF in the left caudate nucleus was lower in extraverts than in introverts, which is consistent with the negative correlation observed in our study. Because dopamine has an inhibitory effect on striatal neurons and the striatal neurons in turn exert a strong inhibitory effect on brain areas such as the pallidum and the substantia nigra (Gurney, Prescott, & Redgrave, 2001), low baseline CBF in the ventral striatum may be associated with reduced inhibition of these projection areas. This reduced inhibition may be relevant in the context of action selection because one main function of the basal ganglia is to select appropriate responses to environmental cues with respect to cognitive and motivational states (Gurney et al., 2001; Haber, 2003).

Several authors related extraversion to the activation of an approach system, i.e. a broad motivational system that is sensitive to positively valenced and rewarding stimuli (for an overview, see Elliot & Thrash, 2002). Extraversion is thus interpreted as an individual difference variable in the tendency to approach incentives, which are—in case of human beings—often social in nature. This model is consistent with our findings because the ventral striatal system has been related to the approach system, appetitive behaviors, and to the anticipa-

tion of rewards (Depue & Collins, 1999; Rolls, 2005). In addition, the approach system has also been associated with left prefrontal areas (Hewig, Hagemann, Seifert, Naumann, & Bartussek, 2004) and these areas have extensive projections to the ventral striatum (Haber, 2003). In particular, most connections are located within the same hemisphere and terminate in the ventromedial part of the caudate nucleus and the dorsal nucleus accumbens (Haber, Kunishio, Mizobuchi, & Lynd-Balta, 1995), which exactly corresponds to the striatal intersection cluster in our study. The observation that extraversion is associated with baseline CBF in the left ventral striatum may thus suggest that baseline CBF in this area reflects individual differences of an approach system, i.e. differential sensitivities towards appetitive cues.

Interestingly, the approach system has also been related to positive affect (Watson et al., 1999). On the one hand, positive affective states can serve as the major motivating factor and constitute the primary goal for approach-related behaviors. On the other hand, positive affective states also serve as a reinforcer after a goal is achieved. Therefore, it is not surprising that the ventral striatum has been associated with positive affect (Whittle, Allen, Lubman, & Yucel, 2006), which is consistent with our findings. Taken together, baseline CBF in the ventral striatum may reflect individual differences in positive affect and extraversion, which in turn are both associated with individual differences in the approach system. According to this view, extraverts experience more positive affect than introverts due to their greater sensitivity towards rewarding and approach-related incentives (Lucas et al., 2000).

In addition, our analyses suggest that a small area in the left rostral part of the anterior cingulate cortex is associated with positive affect as well as extraversion. This area is part of the "affective" division of the anterior cingulate cortex (Bush, Luu, & Posner, 2000) and projects to the medial part of the ventral striatum (Kunishio & Haber, 1994), which again corresponds to the striatal intersection cluster found in this study. Furthermore, the ventral-rostral anterior cingulate cortex has been associated with the processing of pleasant and rewarding stimuli and may receive inputs about expected and received rewards

(Rolls, 2005). Hence, there is preliminary evidence that the rostral anterior cingulate cortex may also be associated with the activation of the approach system. Taken together, the finding that positive affect and extraversion are partially associated with the same brain areas support the first hypothesis derived from Watson and Clark's (1997) theory, i.e. positive affect forms the core of extraversion.

The second and more specific hypothesis was examined in the follow-up analyses. When the common variance of positive affect and extraversion was partialed out, there was no intersection between activation clusters associated with residualized positive affect and residualized extraversion. This finding renders further supporting evidence for the ventral striatum and anterior cingulate cortex as a common biological basis of positive affect and extraversion. In addition, these analyses also suggest that baseline CBF in the ventral striatum more directly reflects individual differences in positive affect: positive affect was still associated with the ventral striatum when extraversion was partialed out but extraversion was no longer associated with the ventral striatum when positive affect was partialed out. This suggests that the association between baseline CBF in the ventral striatum and extraversion is mediated by the association between extraversion and positive affect. Thus, these findings strongly support and add psychophysiological evidence to Watson and Clark's (1997) theory that positive affect forms the core of extraversion and not vice versa.

No overlapping activation clusters were found for negative affect and neuroticism in this study. A crucial factor for this missing relation is the lack of significant correlations between negative affect and baseline CBF. Possibly, a relation between negative affect and CBF is only present when subjects engage in trait-related tasks such as procedures to induce a negative mood (Keightley et al., 2003) but not under resting conditions. Therefore, it may be promising to combine baseline CBF measurements with CBF measurements in response to appropriate, trait-related tasks in future studies.

Conclusion

The finding of systematic associations between positive affect and extraversion, and negative affect and neuroticism, which were mainly based on self-report data, is partially supported on the physiological level. Whereas no associations were found between negative affect and neuroticism, positive affect and extraversion were both correlated with baseline CBF in the left ventral striatum and the left anterior cingulate cortex. These areas may be part of the biological basis of an approach system, which is related to positive affect as well as extraversion. This conclusion is in line with the view that positive affect represents the subjective component of a more general biobehavioral system (Watson et al., 1999).

In addition, the associations between baseline CBF and extraversion were mainly mediated by positive affect, which suggests that that positive affect forms the core of extraversion and not vice versa. Thus, the present study supports the conception of Watson and Clark (1997) and moreover, it adds evidence that is beyond the scope of behavioral data.

GENERAL DISCUSSION

CHAPTER VI

The aim of the present work was to investigate the biological basis of the relationship between personality and affective traits. Chapter II provided an overview of studies based on self-report and behavioural measures that demonstrated strong and consistent associations between extraversion and positive affect.

Processes underlying the relationship between extraversion and positive affect

Chapter II also described two models offering different explanations for this relation. Indirect-effects models suggest that personality has an indirect influence on affect through its association to social engagement. According to temperament models, "personality traits [...] represent endogenous differences in sensitivity or response magnitude to positive- or negative-emotion stimuli, resulting in differences in long-term positive or negative affect" (Larsen & Ketelaar, 1991, p. 133). Temperament models thus suggest that extraverts show more pleasant affect than introverts due to their greater sensitivity to rewards. As reviewed in Chapter II, there is considerable evidence in support for temperament models.

However, the psychological processes that underlie the greater reward sensitivity of extraverts have yet to be specified. Possibly, extraverts are more sensitive to rewards because they attend more to reward cues. Some evidence suggests that positive affect is associated with a selective attention bias towards rewarding information (Tamir & Robinson, 2007) and if positive affect forms the core of extraversion (Watson & Clark, 1997), extraverts may be more prone to this bias than introverts. An alternative explanation may be that extraverts are slower in shifting their attention away from rewarding cues (Derryberry & Reed, 1994). Consequently, extraverts may be slower in shifting their attention to other relevant cues, such as signals that could predict failure. In addition, memory effects may also contribute to the greater reward sensitivity (Goetz, Goetz, & Robinson, 2007). In a happy mood state, a person may be more

sensitive to rewards because the reward value of a (complex) cue may be more easily retrieved from memory (Cunningham, 1988).

It is important to note that these mechanisms are not mutually exclusive, but may instead compound and interact. For example, the selective attention bias towards rewarding cues may not only increase the likelihood of achieving rewards but may also create a stronger memory trace for such cues and may help to maintain or even intensify current positive mood states (Lischetzke & Eid, 2006; Tamir & Robinson, 2007). These processes may facilitate the anticipation of desired, reward-associated states and inhibit the anticipation of undesired states. As a result, the initiation of approach-related behaviors may be supported, which in turn may increase the probability of achieving goals that are associated with positive affect. Thus, extraverts may have developed a motivational system that is characterized by a strong orientation towards reward-related goals (Elliot & Thrash, 2002), which predisposes them to approach-related behaviors (Gable, 2006). On the one hand, positive affect may facilitate the activation of this motivational system. On the other hand it may also reinforce the initiated approach-related behavior as a result of obtaining rewards. Hence, positive affect may not only be an outcome variable of obtaining rewards but may also be an antecedent for achieving further rewards.

These short-term cognitive and motivational processes may in turn support other mechanisms that help to consolidate the relation between extraversion and positive affect (Fredrickson, 1998; Mroczek & Spiro, 2005). For example, if extraverts are sensitive to rewarding information and are characterized by a motive to achieve these rewards, they may create life circumstances and develop behaviors that increase the probability to receive continuing rewards in the future (e.g., expanding social contacts or creating specific work environments). As a result, extraverts may obtain more rewards than introverts and experience more positive affect, which in turn supports their approach motivation towards rewarding situations. Thus, the relation between extraversion and positive affect seems to be determined by many factors and may be the result of a reciprocal person-situation interaction, in which a personality trait shapes the environment

a person inhabits and which in turn reinforces the original personality trait (Caspi & Bem, 1990).

Extraversion and affective reactivity

Whether extraverts are not only more strongly motivated to approach rewarding situations but furthermore experience greater positive affect than introverts when exposed to a positive situation, i.e. show increased affective reactivity, is still a matter of debate. The empirical evidence for this relationship is mixed (Gable, Reis, & Elliot, 2000; Gross et al., 1998; Larsen & Ketelaar, 1989; Lucas & Baird, 2004; Rusting & Larsen, 1997), which suggests that there may be some mediating factors. For example, it may be important to carefully consider the extent to which the same situation is identically rewarding for extraverts as well as for introverts. Most social situations may be more rewarding for extraverts than for introverts. Therefore, extraverts may be not only more motivated to approach these situations but also experience more positive affect. Other situations may be similarly rewarding for extraverts as well as for introverts and no differences in the experienced affect level occurs.

Implications for indirect-effects and temperament models

These suggestions also imply that it may be beneficial to integrate some assumptions of indirect-effects models into temperament models. In particular, extraverts may not only be characterized by a greater sensitivity to rewarding situations, as suggested by temperament models but may as well be preferentially sensitive to social (rewarding) situations as indicated by indirect-effect models. This hypothesis is in line with a study of Lucas and Diener (2001) who asked their participants how happy they would feel if they engaged in each of 247 situations. These situations were categorized as social or nonsocial and as pleasant, moderately pleasant, moderately unpleasant, or unpleasant. Consistent with temperament models, Lucas and Diener (2001) found that extraverts rated social as well as nonsocial situations more positively than introverts and this

difference was only present in pleasant (i.e. reward-associated) situations. In addition, however, extraversion was *more strongly* correlated with pleasant social situations than with pleasant nonsocial situations, which is in accordance with indirect-effects models. This finding suggests that although extraverts may be generally more sensitive to rewards than introverts, extraverts may be characterized by a specific sensitivity to social rewarding situations *as well*.

Furthermore, it may be helpful to ask which intraindividual processes underlie this specific sensitivity. Some evidence suggests that it may be the tendency to engage and enjoy social attention (Ashton, Lee, & Paunonen, 2002). If social attention is especially rewarding (at least in most situations), then extraverts will be even more strongly motivated to engage in social than in non-social situations in order to obtain these rewards. Similarly, greater pleasant affect displayed by extraverts (e.g., enthusiasm, energy, and excitement) may serve to attract and to maintain the attention of other persons (Ashton et al., 2002). This rewarding feedback of others may encourage extraverts to further engage in behaviors that attract social attention.

An alternative explanation for extraverts' pronounced sensitivity to social rewards is based on extraverts' general preference for more stimulating environments (Campbell & Hawley, 1982; Farthofer & Brandstätter, 2001; Geen, 1984)—a hypothesis derived from Eysenck's arousal theory of extraversion (Eysenck, 1967) and consistent with congruence models of personality (Diener et al., 1984; Emmons et al., 1986). Many types of social interaction may be particularly associated with stimulating environments (as is the case in the most prototypical situational setting when describing the defining characteristics of extraversion, i.e. going to parties) and extraverts may specifically select more stimulating social situations because of their greater enjoyment of these settings. Thus, many social situations may be specifically rewarding for extraverts because the high levels of sensory stimulation result in greater levels of positive affect. Again the need for a stronger differentiation of the social versus non-social categorization of settings is necessary. If extraverts prefer more stimulating situations than introverts, they may also enjoy stimulating non-social settings

more than introverts (such as watching a horror film when being alone). Accordingly, they may also show lower levels of pleasant affect in less stimulating social settings than introverts.

Taken together, despite conclusive evidence in favor of temperament models, further research is needed to clarify the exact mechanisms underlying the relation between extraversion and positive affect. It may be helpful, for example, to investigate the basic features of situations in which extraverts and introverts preferentially choose to participate.

The suitability of baseline CBF for investigating the biological basis of personality and affect

The main goal of the present work was to investigate the biological basis of the relationship between personality and affective traits. As outlined in Chapter I, there were two methodological issues that had to be addressed before continuous arterial spin labeling (CASL) measurements could be used for these examinations.

The first empirical study (Chapter III) investigated the reproducibility and validity of CASL baseline CBF measurements. This study demonstrated a good reproducibility of CASL measurements even after seven weeks. In addition, the validity of CASL measurements was underlined by showing that baseline CBF only differed in the visual areas when participants were compared between an eyes-closed and an eyes-open condition.

The second empirical study (Chapter IV) investigated the latent state-trait structure of baseline CBF measurements. The results suggested that baseline CBF predominately reflects a stable latent trait that is superimposed by occasion-specific fluctuations and by measurement errors. However, if smaller areas are analyzed, an aggregation over at least two measurement occasions may be necessary for a sufficient trait specificity. Hence, when aggregated over two measurement occasions, baseline CBF may be an adequate proxy for a biological trait. As described in Chapter II and IV, this characteristic was necessary in order to use baseline CBF as a sound target for the investigation of the biological

correlates of personality. Taken together, the two empirical studies suggest that CASL baseline CBF measurements are appropriate for examining the physiological basis of personality and affective traits because these measurements are reproducible over weeks, reflect known pattern of neural activation, and demonstrate a sufficient trait specificity.

Extraversion and positive affect—benefits from a psychophysiological approach

The third empirical study (Chapter V) investigated the physiological basis of the relation between personality and affective traits. Baseline CBF in specific areas was systematically associated with participants' scores on extraversion, neuroticism, and positive affect scales. The reported activation pattern was largely consistent with previous studies, which further supports the notion that personality and affective traits may be reflected by individual differences in brain function (Cloninger, 1986; Davidson, 1992; Eysenck, 1967; Gray, 1970; Zuckerman, 1983).

This finding has some implications for the design of functional magnetic resonance imaging (fMRI) studies, which are also used for the investigation of personality and affective processes (Canli, 2004; Phan, Wager, Taylor, & Liberzon, 2002). These studies assess the phasic changes in cerebral hemodynamics while participants are engaged in affective or cognitive tasks. Furthermore, fMRI studies usually rely on group analyses and attempt to describe common activations across participants while most of the variability among individuals is treated as statistical noise (Hamann & Canli, 2004). The present work suggests that these studies may benefit from integrating baseline CBF measurements in their study design because individual differences in baseline CBF are associated with personality and affective traits and may thus explain some of the variability between subjects that is observed in group analyses. As a result, an increase in statistical power may be accomplished. In addition, the combination of baseline and reactivity measurements may provide important information regarding the influence of the "default mode of brain

function" (Raichle et al., 2001) on the cerebral response to affective stimuli. This may help to understand the variability present in overt behavior.

A second result of the study presented in Chapter V was the finding of a biological basis of the relationship between extraversion and positive affect. Although there is extensive evidence from self-report measures in support for the strength of this relationship (see Chapter II and V), some researchers have argued that it may at least be partially due to artifacts (Matthews, Deary, & Whiteman, 2003; Yik & Russell, 2001). For example, it was hypothesized that the strong and consistent correlations between personality and affect variables are partially due to significantly overlapping operationalisations of the constructs or due to mood-congruent memory effects that bias the retrospective ratings in trait questionnaires. The present findings suggesting a biological basis of the extraversion-positive affect relation strongly support the view that the association between personality and affect is not due to artifacts but may rather reflect the existence of a more general biobehavioral system (Watson et al., 1999).

This conclusion is consistent with the theory of Elliot and Thrash (2002), who suggest that the constructs extraversion, positive emotionality, and behavioral activation system all share a common conceptual core, which is labeled “approach temperament” and reflects a “general neurobiological sensitivity to positive/ desirable (i.e. reward) stimuli (present or imagined) that is accompanied by perceptual vigilance for, affective reactivity to, and a behavioral predisposition toward such stimuli” (p. 805). Both conceptualizations, either as a “general biobehavioral system” or as a “general neurobiological sensitivity“, suggest the existence and relevance of a biological basis of this core construct and may suggest the need for biological indicators for its assessment. The present work offered such an approach by using baseline cerebral blood flow as an indicator of resting brain activation. The findings that the biological bases of extraversion and positive affect only overlap in brain areas that have previously been associated with approach motivation and reward processing, and that positive affect forms the core of extraversion and not vice versa not only provide valuable information about the association of personality with specific brain

areas. They also demonstrate how a psychophysiological approach may help to address conceptual problems and how to provide evidence that is beyond the scope of behavioral and self-report data.

Implications for biological theories of personality

The investigation of brain functions in a resting state will certainly not provide information about the proximal mechanisms that link personality traits and individual differences in specific behaviors outlined above. Activation studies may be more suitable for such examinations. In addition, cognitive and social-cognitive theories may offer more potent models for linking traits and specific behaviors by providing more precise specifications of moderating and mediating factors (Matthews & Gilliland, 1999). These factors may partially be too complex to be accessible with current psychophysiological measurement techniques.

In contrast, the examination of brain functions in a resting state may reveal or confirm associations that correspond to a more distal or abstract level of explanation, similar to factor analytic approaches of personality. These latter approaches aim to identify broad latent traits that emerge from analyzing consistent relations among more specific traits. Although some researchers contend that personality traits are simply descriptive statements about consistent relations without explanatory value (Block, 1995; Westen, 1996), others have argued that "these consistent relations reflect common processes that influence (but do not define) the more specific traits. According to this view, the broad traits that emerge from factor analyses are not simply arbitrary statements about consistent relations, they are hypothetical constructs that can explain the shared variance among specific facets" (Lucas & Diener, 2001, p. 353). The present work suggested that positive affect forms the core of extraversion on the biological level and thus confirmed a (partially) explanatory model of extraversion (Watson & Clark, 1997), in which positive affect and reward sensitivity reflect the common variance that link the different facets of extraversion. This model provides a valuable explanation of how behavior is energized or instigated but due to its dispositional conceptualization, it is less able to explain concrete

behaviors in specific situations. However, the integration of dispositional and social-cognitive approaches may yield models of extraversion that offer promising links between broad personality traits and specific behaviors (Elliot & Thrash, 2002).

Taken together, the psychophysiological approach of personality as presented in this manuscript provides supporting evidence for the view that personality traits are not "simply arbitrary statements about consistent relations", but are meaningful constructs beyond mere description. Baseline activation in specific brain areas may reflect the shared variance among specific trait facets. Particularly, baseline CBF in the left ventral striatum and the left anterior cingulate cortex may reflect the common variance that links the different facets of extraversion. These areas may thus represent common processes that influence the more specific traits, i.e. processes associated with positive affect and reward sensitivity. The extent, to which not only the shared variance of different trait facets but the specific variance is reflected by physiological processes as well, will be a matter of future research.

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LIST OF ABBREVIATIONS

ASL	Arterial spin labeling
BA	Brodmann area
C.R.	Critical ratio
CASL	Continuous arterial spin labeling
CBF	Cerebral blood flow
CFI	Comparative fit index
DSCI	Dynamic susceptibility contrast imaging
EPI	Echoplanar imaging
FOV	Field of view
LST	Latent state-trait
MNI	Montréal Neurological Institute
MRI	Magnetic resonance imaging
PASL	Pulsed arterial spin labeling
PET	Positron emission tomography
RMSEA	Root mean square error of approximation
ROI	Region of interest
SNR	Signal-to-noise ratio
SPECT	Single photon emission computed tomography
T	Tesla
T_1	Longitudinal relaxation time
T_2	Transversal relaxation time
TE	Echo time
TR	Repetition time

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ERKLÄRUNG

Hiermit erkläre ich, dass ich die vorliegende Dissertation selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe. Zudem wurde die Arbeit an keiner anderen Universität zur Erlangung eines akademischen Grades eingereicht.

Trier, den 28. September 2007

Michael Hermes

ERKLÄRUNG ZU KAPITEL III

Bei der in Kapitel III beschriebenen und in Hermes et al. (2007) veröffentlichten Studie war ich verantwortlich für die Ideengenerierung, Hypothesenbildung, Datenerhebung, Datenauswertung, Dateninterpretation sowie die schriftliche Ausarbeitung des Manuskripts.

Die Ko-Autoren der Studie waren verantwortlich für die medizinische Betreuung während der MRT-Datenerhebung (C. Walter, S. Lieser und J. Rock) und lieferten Anregungen bei der Diskussion der Befunde (D. Hagemann, E. Naumann, P. Britz und C. Walter).

Trier, den 28. September 2007

Michael Hermes